THE GLYCAEMIC INDEX OF INDIGENOUS SOUTH AFRICAN FOODS

Xikombiso G Mbhenyane, Christine S Venter, Hester H Vorster, H S Steyn

Objectives. The objective of this study was to determine the glycaemic index (GI) and insulin index (II) of indigenous foods consumed in the Northern Province of South Africa.

Design. The GI and II of 10 dishes were determined in 37 healthy student volunteers (18 males, 19 females) within the same range for age and body mass index (BMI). Subjects were divided into four groups of 10. Each group was allocated white bread as the standard and three other dishes. Venous blood samples were used to determine serum glucose and insulin concentrations.

Results. The GI of sorghum porridge with added tartaric acid was the lowest (64), while that of samp (130) was the highest. Adding beans to samp lowered the GI to 98. Mabella porridge without sugar had a GI of 124 and with sugar 106, while soft mealiemeal porridge without sugar produced a GI of 117 and with sugar 123. Stiff mealiemeal porridge with *nkaka* (Cucurbitaceae, *Mormordica balsamina L.*) had a GI of 105, while adding dried green bean leaf stew to the porridge lowered the GI to 87. Dried bean stew had a low GI (68).

Conclusion. The legume-based dishes and acid-added sorghum porridge produced GIs lower than that of bread, while stiff mealiemeal with *nkaka* or dried bean leaf stew, as well as samp and beans, and mabella with sugar produced insulin indices lower than that of bread. The addition of sugar to soft porridge made from sorghum or mealiemeal did not significantly influence the glycaemic and insulinaemic responses to these foods.

Department of Nutrition, University of Venda for Science and Technology, Thohoyandou, Northern Province

Xikombiso G Mbhenyane, BSc Hons (Diet), MSc Nutr, PhD, RD

Department of Nutrition and Consumer Sciences, Potchefstroom University for Christian Higher Education

Christine S Venter, DSc, RD

Hester H Vorster, DSc

Department of Statistics, Potchefstroom University for Christian Higher Education

H Stefanus Steyn, DSc

Much has been learned about carbohydrate digestion and absorption over the past 20 years, and this new knowledge has, in many ways, completely changed the way scientists think about dietary carbohydrates.[1] It is now known that starches are not completely digested; indeed, some are quite poorly digested. It has been learned that the indigestible carbohydrates are not just neutral bulking agents, but have important physiological effects, and even contribute energy to the diet. Starches are not all equal in their effects on blood glucose and lipids. Furthermore, carbohydrate foods often contain vitamins and minerals plus other compounds, such as phytochemicals and antioxidants, which may have health implications.

Black populations of South Africa are in a transition process.[2] This process is characterised by an increasing prevalence of chronic diseases of lifestyle. According to Walker,[2] the prevalence of obesity, hypertension and diabetes has risen in urban dwellers. Zimmet *et al.*[3] suggest that non-insulin-dependent diabetes mellitus (NIDDM) has reached epidemic proportions in developing nations as well as among disadvantaged groups in developing countries.

Several researchers are of the opinion that a diet containing low glycaemic index (GI) foods may be the answer in the prevention and treatment of a large number of nutrition-related diseases.[4] The GI of foods can be referred to as the acute or short-term effect of a food or a meal on postprandial blood glucose fluctuations.[5] Little is known about the GI of indigenous South African foods and dishes although it has recently been suggested that urbanised blacks suffering from NIDDM should revert to their typical diet, which is believed to be composed largely of starchy low-GI foods, and is low in fat content.[2] The GI of foods and dishes can be influenced in many ways, such as the combination in which the different foods are consumed,[6] type of starch,[7] and methods used in food preparation.[8] Physiological factors related to digestion and absorption as well as psychological stress-related factors are responsible for inter- and intra-individual variability in GI for a particular food.[6] Proper knowledge of the GI of foods and dishes in all circumstances can be crucial for proper planning of diets and education regarding food consumption to direct the nutrition transition in a more healthy direction.[4]

From the above discussion the necessity for more knowledge regarding the GI of foods regularly eaten by the black population is clear. It is also of great importance that low GI foods and meals should be tested in follow-up studies in healthy, diabetic and hyperlipidaemic subjects as well as subjects suffering from syndrome X, since these are subjects likely to benefit from the physiological effects of low-GI foods. In this study, the GI and insulin indices (II) of indigenous South African foods were determined.

METHODS

The sample consisted of 37 (19 female, 18 male) healthy student volunteers aged 23.3 ± 2.38 years, with a mean (± standard deviation (SD)) body mass index (BMI) of 22.7 ± 2.32 kg/m^2, systolic blood pressure (SBP) of 113 ± 9.96 mmHg, diastolic blood pressure (DBP) of 73 ± 7.15 mmHg, and a fasting blood glucose of 3.9 ± 0.77 mmol/l. The subjects were screened before inclusion in the study according to the following exclusion criteria: BMI greater than 27; existing metabolic disease and cardiovascular diseases; existing disease or condition that could have influenced digestion and absorption of food; present or past psychotherapy; a medically prescribed diet, slimming diet or diet with no breakfast, lunch or supper; more than 6 hours of exercise per day; more than 30 alcoholic beverages/week; more than 10 cigarettes per day; or a fasting capillary finger-prick blood glucose level > 6.7 mmol/l (using Glucostix reagent strips and the Glucometer II reflectance photometer, Ames Division, Miles Laboratories, Elkart, Indiana, USA). The subjects were homogenous with regard to age, height, weight, BMI, fasting glucose and blood pressure. Weight changes at the end of the study were minimal (0.5 ± 1.28 kg). Subjects gave written consent to participate in the study and the protocol was approved by the Ethics Committee of Potchefstroom University.

The subjects were randomly divided into four homogeneous groups of 10 (3 subjects participated in more than 1 group — groups A and D); there were 5 females and 5 males in groups A, C and D, while group B included 6 females and 4 males. During the test phase 40 subjects were divided into four groups and given three meals, with bread being constant for all groups. The meals were tested over a 5-week period for each group, with 1 week in-between tests. The methodology used in the study was standardised by Jenkins *et al.*[5]

A Latin square design was used to test randomly the effect of 50 g carbohydrate contained in white bread (all groups), mabella porridge with sugar (group A), mabella porridge without sugar (group A), stiff mealiemeal porridge and dried bean leaf stew (group A), fermented sorghum porridge *(ting)* (group B), sorghum porridge with added tartaric acid (group B), stiff mealiemeal porridge and *nkaka*, a bitter green vegetable (Cucurbitaceae, *Mormodica balsamina L.)* (group B and D), samp (group C), samp and beans (group C), dried bean stew (group C), soft mealiemeal porridge with sugar (group D), and soft mealiemeal porridge without sugar (group D). Standardised traditional South African recipes were used to prepare these dishes.

Ingredients such as cowpea, jugo beans, dried bean leaf vegetable and *nkaka* were collected raw from the Mhinga/Shikundu estates by the researcher (XGM), and all others were bought from Shoprite/Checkers. All ingredients were collected raw and in bulk to avoid differences in quality and quantity. Each individual portion was prepared (cooked) separately from the same batches of raw ingredients to ensure that 50 g of carbohydrate was contained in the final cooked product. The dishes were prepared within 12 hours of the test and reheated in a microwave at 600 W to 70°C (measured using a thermometer). All temperatures were recorded and similar dishes were eaten at the same temperature. The pH of the fermented *ting* and sorghum porridge with tartaric acid were measured (Hanna Instruments 8520, Singapore).

A standard pre-evening meal consisting of stiff mealiemeal porridge and sour milk containing 60% carbohydrate, 15% protein, 25% fat and low in fibre was given the night before the test to obviate variability and to control for second meal effect.[9] Subjects were asked to eat the standard meal at 19h00, followed by a 12-hour fast.

Blood was collected at the end of the 12-hour fast; within 10 minutes subjects then took their meals with 250 ml water. Thereafter, blood was collected at 15, 30, 45, 60, 90 and 120 minutes. About 1 ml of blood was drawn from each subject and discarded before drawing the actual sample. A 10 ml venous blood sample was then drawn from each subject. Venous blood was divided into 5 ml amounts in red-stopper vacutainers (Hemograd Closure, Europe) for insulin determinations, and into 5 ml amounts in potassium oxalate/sodium fluoride-containing Vac-u-Test tubes with grey stoppers for glucose determinations. Blood was allowed to stand for at least 15 minutes, after which it was centrifuged at 1 500 revolutions per minute (rpm) using a centrifuge (Hettich, Universal) for 15 minutes. Serum samples were aliquoted into 2 ml tubes which were kept on ice, then stored at -20°C until further analysis.

The serum glucose concentration was determined by the enzymatic colormetric method of Boehringer Mannheim (catalogue numbers 676543 for 10 × 1 100 ml reagent and 676551 for 6 × 500 ml reagent, Boehringer Mannheim Peridochrom, Mannheim, Germany). Serum insulin concentration was determined using a radioimmunoassay kit for human insulin supplied by Medgenix Diagnostics in Brussels, Belgium (INS-RIA-100, Code 3012500, Lot. CH.B. 64312).

The areas under the glucose curves using the lowest value observed during the GTT as baseline[9] were calculated using a computerised program (Department of Statistics, Potchefstroom University). The GI was then calculated according to the formula of Jenkins *et al.*[5] namely:

GI = incremental area under the glucose curve for 50 g carbohydrate from test meal ÷ incremental area under the glucose curve for 50 g carbohydrate from white bread × 100.

Insulin areas under the curve were calculated using a computerised program (Department of Statistics, Potchefstroom University) and the same formula for GI was used to calculate II, with 'glucose curve' in the formula replaced by 'insulin curve'. The insulin-glucose sensitivity index (IGSI) was also calculated, using the formula of Orchard *et al.*,[10] namely

$$IGSI = \frac{1}{(PI \times PG)} \times 10\,000,$$

where PI is peak incremental insulin and PG peak incremental glucose.

Statistical analyses of variance and covariance were used to calculate differences in GI and II. Significant differences between interventions were calculated using the Newman-Keuls method of multiple comparisons.[11] Spearman and Pearson's correlations were performed to explain the differences in glycaemic and insulin responses.

RESULTS

All dishes consisted of 50 g carbohydrate and the energy, protein and fat were variable (Table I).

Glucose responses

Table II shows the mean (± standard deviation (SD)) incremental glucose response area, maximum incremental glucose and GIs of the 37 subjects to the test meals.

Significant differences in the mean areas under the glucose response curves were found between the log transformed data for dried bean stew and the following: bread ($P < 0.05$), mabella porridge without sugar ($P < 0.05$), mabella porridge with sugar ($P < 0.05$), fermented sorghum porridge ($P < 0.05$), samp ($P < 0.005$), samp and beans ($P < 0.05$), and mealiemeal with sugar ($P < 0.05$). When absolute values were used, significant differences were seen between acid-added sorghum and the following: bread ($P < 0.05$), mabella porridge without sugar ($P < 0.05$), mabella porridge with sugar ($P < 0.05$), samp ($P = < 0.005$), soft mealiemeal porridge without sugar ($P <$ 0.05), and soft mealiemeal porridge with sugar ($P < 0.05$). These differences disappeared when log transformations were used.

The means of maximum incremental glucose values are shown in Table II. Whean all interventions were compared, statistical significance of difference was reached between dried bean stew and the following: samp ($P < 0.05$), soft mealiemeal porridge without sugar ($P < 0.05$), and soft mealiemeal porridge with sugar ($P < 0.05$). Maximum glucose increment significantly correlated with GI ($r = 0.48$, $P < 0.005$) and the areas under the curves ($r = 0.54$, $P < 0.005$).

The GIs are also shown in Table II. When the GIs were compared, significant differences were noted between the following interventions: acid added to mabella porridge without sugar ($P < 0.005$), mabella porridge with sugar, soft mealiemeal porridge without sugar, and soft mealiemeal with sugar (all at $P < 0.05$). The GI of dried bean stew was significantly lower than that of samp, soft mealiemeal porridge without sugar, and soft mealiemeal porridge with sugar (all at $P < 0.05$). The GI of acid-added sorghum porridge was the lowest, while that of samp was the highest.

There were large variations of glucose areas under the curves between individuals. Variations of 30% above or below the mean are common.[12] Large variations are avoided if the standard food is consumed by the same subject more than

Table I. Nutrient analysis of individual dish/meal portions using computerised food composition data

Dish/food	CHO (g)	Protein (g)	Fat (g)	Fibre (g)	Energy (kJ)	% CHO	% Protein	% Fat
White bread	49.99	8.6	1.8	3.1	1 014	80	14	7
Soft mealiemeal with sugar	49.93	4.1	1.7	2.8	961	87	7	7
Soft mealiemeal porridge without sugar	49.96	5.8	2.4	4	1 026	82	10	9
Mabella porridge with sugar	49.92	4.6	1.2	0.7	960	87	8	5
Mabella porridge without sugar	49.97	6.6	1.7	1.0	1 026	82	11	6
Stiff mealiemeal with *nkaka*	49.98	8.1	2.4	5.2	1 069	79	13	8
Stiff mealiemeal and dried bean leaf stew*	49.95	19.8	27.0	8.6	2 170	39	15	47
Samp	49.99	5.1	0.4	1.9	941	89	9	2
Samp and beans	50.02	12.6	0.8	11.4	1 082	78	20	3
Dried bean stew*	50.01	26.3	29.3	8.1	2 368	36	19	47
Sorghum porridge †	50.30	6.4	0.3	6.7	1 128	75	10	1

*These dishes had ground peanuts added.
Sorghum porridge: both fermented and acid-added sorghum porridge had the same amount of meal.
CHO = carbohydrate.

Table II. Mean glucose responses to different meals, (means ± standard deviations)*

Intervention	*N*	Incremental glucose (mmol/l/min)	MIG (mmol/l)	GI
White bread	120	9.4 ± 4.1^{i}	2.2 ± 0.9	100
Mabella porridge (no sugar)	10	10.1 ± 4.1^{h}	1.7 ± 1.0	123 ± 70.8^{aJ}
Mabella porridge and sugar	10	9.2 ± 2.4^{J}	2.2 ± 1.3	106.4 ± 25.1^{d}
Stiff mealiemeal porridge and *nkaka*†	20	9.1 ± 3.8	1.9 ± 1.4	105.3 ± 52.3
Fermented sorghum porridge	10	10.3 ± 4.8^{e}	2.3 ± 1.3	113.2 ± 61.3
Acid-added sorghum porridge	10	6.2 ± 2.3^{ab}	1.6 ± 1.2	64.3 ± 20.0^{abcdf}
Stiff mealiemeal porridge and dried green bean leaf stew	10	8.3 ± 4.1	13 ± 1.0	87.3 ± 33.8
Samp	10	12.8 ± 6.0^{ac}	2.9 ± 1.6^{b}	130.0 ± 68.7^{fg}
Samp and beans	10	10.2 ± 4.3^{g}	2.5 ± 1.5	98.4 ± 29.1
Dried bean stew	10	6.2 ± 2.8^{edefghi}	1.1 ± 1.0^{ab}	68.5 ± 42.1^{eghi}
Soft mealiemeal porridge (no sugar)	10	10.2 ± 3.0^{bf}	2.7 ± 1.3	117.6 ± 51.8^{ch}
Soft mealiemeal porridge and sugar	10	11.1 ± 3.9^{d}	3.0 ± 1.9^{a}	123.3 ± 47.5^{be}

*Means in the same column with the same letter are significantly different ($P < 0.05$). Log transformations were used to determine significance.
†*Nkaka* - an African medicinal plant, *Cucurbitaceae, Momordica balsamina L.*
MIG = maximum incremental glucose; GI = glycaemic index.

once. In this study the subjects consumed bread twice and the mean glucose area under the curve was 6.1 mmol/l/min and the within-subject variation 26%. Wolever[12] reported a within-subject variation of 22% in normal subject eating white bread.

Insulin responses

The incremental insulin areas under the curve, maximum incremental insulin (MMI), II, and IGSIs are shown in Table III. Significant differences in insulin areas under the curves were observed between fermented sorghum porridge and the following: mabella porridge without sugar ($P < 0.05$), mabella porridge with sugar ($P < 0.05$), stiff mealiemeal porridge with *nkaka* ($P < 0.005$), samp ($P < 0.05$), samp and beans ($P < 0.001$), and dried bean stew ($P < 0.005$). The samp and bean dish was significantly different from acid-added sorghum ($P < 0.05$), and stiff mealiemeal porridge with dried bean leaf stew ($P < 0.05$).

Insulin areas under the curves were highest for fermented sorghum porridge, while they were low for stiff mealiemeal porridge with *nkaka*, samp and beans, and dried bean stew. The incremental areas under the insulin curve were significantly correlated with II ($r = 0.71$, $P < 0.005$).

The mean maximum incremental insulin values are shown in Table III. A significant difference was reached between fermented sorghum porridge and the following: samp and beans ($P < 0.05$), stiff mealiemeal porridge with *nkaka* ($P < 0.05$), bread ($P < 0.05$), dried bean stew ($P < 0.05$), and mabella porridge with sugar ($P < 0.05$). The maximum insulin increments significantly correlated with the IIs (r = 0.69, $P < 0.005$).

Table III. Mean glucose responses to different meals, (means ± standard deviations)*

Intervention	*N*	I-AUC (µU/ml)	MII (µU/ml)	II	IGSI
White bread	120	328.4 ± 322.2	66.8 ± 69.2^{c}	100	19.1 ± 13.1
Mabella porridge (no sugar)	10	317.9 ± 322.4^{a}	119.8 ± 140.3	137.0 ± 142.3	23.4 ± 24.9
Mabella porridge with sugar	10	252.7 ± 224.1^{b}	78.2 ± 66.7^{ee}	87.8 ± 65.3	26.8 ± 17.5^{c}
Stiff mealiemeal porridge with *nkaka*	20	172.5 ± 108.9^{c}	60.8 ± 45.2^{b}	76.4 ± 62.7	26.0 ± 21.7^{d}
Fermented sorghum porridge	10	691.3 ± 427.3^{abcdef}	213.8 ± 148.3^{abcde}	179.4 ± 156.7	7.1 ± 4.8^{abcd}
Acid-added sorghum porridge	10	474.7 ± 340.8^{g}	163.0 ± 122.6	118.2 ± 89.2	15.7 ± 13.8
Stiff mealiemeal porridge with dried bean leaf stew	10	517.1 ± 415.8^{h}	170.3 ± 181.4	98.2 ± 44.2	14.5 ± 9.8
Samp	10	405.9 ± 446.5^{d}	121.5 ± 125.0	153.0 ± 141.0	32.6 ± 39.9
Samp and beans	10	181.7 ± 297.7^{egh}	44.1 ± 74.0^{a}	83.8 ± 97.21	28.3 ± 16.6^{b}
Dried bean stew	10	193.5 ± 165.7^{f}	66.9 ± 62.6^{d}	133.7 ± 153.3	29.4 ± 24.5^{a}
Soft mealiemeal porridge (no sugar)	10	285.4 ± 222.8	108.8 ± 104.9	117.7 ± 107.7	17.4 ± 12.7
Soft mealiemeal porridge with sugar	10	275.4 ± 168.6	100.8 ± 78.4	135.3 ± 127.2	13.6 ± 11.7

*Means in the same column with the same letter are significantly different ($P < 0.05$).
I-AUC = incremental insulin areas under the curve; MII = maximum insulin increments;
II = insulin index; IGSI = insulin-glucose sensitivity index.

The IIs of the meals are shown in Table III. No significant differences were noted between the meals/dishes. However, fermented sorghum porridge had the highest II, while stiff mealiemeal porridge had the lowest II. The IGSI was determined using the formula given in the methods section. IGSI is a positive score that indicates the activity of insulin. A high score indicates high sensitivity, while a low score is indicative of low sensitivity and increased peripheral resistance. In the context of this paper, IGSI and insulin resistance reflect insulin action and therefore acute effects. High IGSI were seen after eating samp and beans, dried bean stew, mabella porridge with sugar and stiff mealiemeal porridge with *nkaka.* These indices were significantly higher when compared with that of fermented sorghum porridge ($P < 0.05$), which gave the lowest value.

Discussion

Glycaemic and insulinaemic responses

These results clearly demonstrate that traditionally eaten carbohydrate-containing foods elicit varying glucose and insulin responses. Increased blood glucose is the major stimulant for insulin secretion. Therefore, as glucose rises, insulin rises accordingly.[13-15] The correlation between GI and II in this study was 0.33 ($P < 0.005$). This supports the secretory effect of a carbohydrate load on insulin. However, it also shows that insulin level is not the only determinant of blood concentration (and vice versa). A low GI should be accompanied by a high IGSI since it indicates greater insulin activity and low peripheral insulin resistance.[10] The correlations were –0.18 ($P = 0.05$) between GI and IGSI, and 0.5 ($P = 0.0001$) between II and IGSI. The meals with a low GI had correspondingly higher IGSIs. GI and II were not influenced by gender and this confirms the finding of Rasmussen *et al.*[6] who observed similar GI and II in NIDDM patients of both sexes.

Legume-based dishes

Beans and samp

The bean-based dishes produced GIs that were lower than those for bread. Samp alone produced a high GI of 130, but when beans were added the GI was reduced to 98 for samp and beans, and 68 for dried bean stew (two types of beans and peanuts). The difference between dried bean stew and samp was significant ($P < 0.005$). Samp and beans is a traditional African dish. For many years it, as well as other cereal-legume mixtures, has been recommended as an ideal combination to ensure intake of all essential amino acids, especially in vegetarian diets.[2] The present study provides evidence that this traditional dish would, because of its low GI, also be an ideal food for diabetic diets. The samp used in this study was commercial and not traditionally processed from maize. Industrial processing (cooking, leaching and heat) could have had an influence on the samp particle size as well as antinutrients, thereby affecting the GI. According to the Maize Board,[19] South African samp does not contain the germ of the kernel, and very little fibre (0.05%) and fat (0.8%). It can therefore be expected that home-produced samp, containing more fibre, may have a lower GI.

Beans and peanuts

Brown beans have been reported to have a low GI of 40,[20] while butter beans have a GI of 28.[20,21] Legumes are known to contain antinutrients, among them phytate and lectins, which have been shown to reduce the rate of the starch digestion and to flatten postprandial glycaemia.[12] The GIs of kidney beans, jugo beans and cowpeas used in this study were not determined as individual foods but rather in mixed dishes as this is the manner in which they are consumed in the Northern Province. When raw peanuts were added to the dried bean stew the GI was markedly reduced (from 98 to 68). Peanuts have been reported by Walker and Walker[20] to have a GI of 10, and will lower GI of carbohydrate-containing meals, probably because of the increase in protein and fat intake. Dried bean leaf stew with peanuts with stiff mealiemeal porridge gave a GI of 87. This meal had a composition similar to that of mixed bean stew: protein (20 g v. 26 g), fat (27 g v. 29 g), and fibre (8.6 g v. 8.1 g) for mealiemeal porridge with dried bean leaf stew and mixed bean stew respectively. Clearly, adding peanuts to other carbohydrate-containing meals will lower the GI, probably, as mentioned, because of the increase in protein and fat intake.

The IIs for samp and beans, mealiemeal porridge with dried bean leaf stew and dried bean stew were 83, 98, and 133, respectively. These did not differ significantly, and were accompanied by IGSIs of 14, 28 and 29 for mealiemeal porridge with dried bean leaf stew, samp and beans, and dried bean stew, respectively. Both bean-based dishes had a significantly higher IGSI when compared with fermented *ting,* illustrating the potentially beneficial effects of bean dishes in glycaemic control.

Porridge-based meals

Addition of sugar (sucrose)

The addition of sugar resulted in a GI of 106 v. 124 for mabella, with and without sugar respectively; and 123 v. 117 for mealiemeal porridge with and without sugar respectively. The differences in both types of porridge did not reach significance, but it is important to note that the addition of sucrose to porridge, replacing an equal weight of carbohydrate, did not increase the GI of the porridge and even lowered the GI in mabella. Other researchers have reported that addition of sucrose to certain breakfast cereals or porridge lowers the GI.[22-24] Van Tonder[21] demonstrated that addition of sucrose to butter beans (GI = 28) did not raise GI at 5 g (GI = 30) and 10 g (GI = 30) replacements but a 15 g replacement raised the GI to 54, illustrating that partial replacement of the 'complex' carbohydrate in beans with sucrose does not necessarily have detrimental effects on its GI. There is general agreement that this effect of sucrose is related to its fructose moiety, which is not measured as blood glucose.[25] Improved taste of traditional high-fibre foods or meals with the addition of sugar may increase palatability and compliance to high-fibre, low-fat diets.

Mabella versus maize

Both mabella and mealiemeal are refined products, and it appears that their GIs are not significantly different. This is very important since there are misconceptions that sorghum porridge is better than mealiemeal porridge in glycaemic control, as evidenced by information given to some diabetics by general practitioners (unpublished observations — XGM). Venter[26] reported a GI of 86 (converted by multiplying using a factor of 1.42)[27] for mabella porridge. The mabella porridge in this study was consumed alone or with sugar, while in the study by Venter[26] it was consumed with skimmed milk. Milk has been reported by Walker and Walker[20] to have a low GI and could have contributed to lowering the GI of mabella porridge.

Previously reported South African GI values for mealiemeal porridge are: refined mealiemeal 106,[20] unrefined mealiemeal 101,[20] refined mealiemeal 80,[28] hot mealiemeal 94,[26] reheated mealiemeal 79,[26] and cooled mealiemeal 71.[26] The GI of mealiemeal porridge in the present study (117) is higher than levels previously reported. The mealiemeal was refined, prepared soft, and reheated before eating. Venter[26] prepared stiff mealiemeal porridge which was fed immediately, or cooled, or cooled and then reheated afterwards. The main reason for the above difference is probably that soft and stiff porridge cannot be compared with regard to their GIs because of differences in viscosity and volume, which may affect the gastric emptying rate. Other reasons may be the amount of resistant starch formed by cooling and reheating cycles, and actual amounts of starch and other carbohydrates present in test meals. The GI of reheated porridge reported by Venter[26] is lower than currently seen in this study (79 v. 117). The temperature of the porridge before eating in this study was on average 70ºC. It is possible that the temperatures in the two studies were not the same (temperature of the porridge was not reported by Venter[26]). There are different brands of mealiemeal and it is possible that the processing methods are different. Also, the moisture content and therefore carbohydrate content of raw mealiemeals may differ, affecting the amount of carbohydrate in a calculated 50 g portion based on food composition tables. The differences seen in GIs of local mealiemeal porridges are not unusual since large variations in individual responses have been reported.[27] It should also be noted that the carbohydrate content of maize used to determine the portion size that will give 50 g of carbohydrate, was taken from South African Food Tables (Program Manager). It could be that these values, obtained by calculating the difference in total energy and that provided by fat and protein, may not be a true reflection of the carbohydrate content of a particular maizemeal product.

Addition of *nkaka*

The GI of soft mealiemeal porridge alone was 117, reduced to 105 when eaten with *nkaka* and 87 when eaten with dried bean leaf stew. The differences in these indices did not reach significance, but it is clear from this lowering trend that some combinations may be beneficial in reducing the GI of mealiemeal porridge. Gresse[29] reported a GI of 101 for mealiemeal porridge eaten with soya mince, spinach and milk in NIDDM subjects.

The IIs for mealiemeal porridge eaten with *nkaka* (76) and dried bean leaf stew (98) were lower than for mealiemeal porridge alone (135), while the IGSIs were 22 for mealiemeal porridge eaten with *nkaka*, 10 for mealiemeal porridge eaten with dried bean leaf stew, and 13 for mealiemeal porridge alone (not significantly different). This suggests that *nkaka* may contain some compounds that may be beneficial to glucose homeostasis by increasing insulin sensitivity or by stimulating glucose uptake. The observation in this study confirms what has been reported previously. In an observational study, Mabogo[30] reported that *nkaka* is used by the Venda people as a medicinal plant for a range of illnesses. Other researchers have also suggested that wild plants have potential antidiabetic effects.[31-33] Winkelmann[31] identified a number of plants used in the treatment of diabetes by herbalists in Baja California Norte, USA. There is a need in South Africa to study other edible wild plants so that recommendations for inclusion in the diet can be made based on scientific evidence.

Fermentation in porridge preparation

Fermented porridge is preferred by many Africans for its sourness. The sourness of the porridge is brought about nowadays by the addition of acids, such as vinegar and tartaric acid, to save time. In this study the traditionally fermented porridge was compared with the acid-added porridge. Sorghum porridge with added tartaric acid produced the lowest GI compared with all the other meals. The GIs were 113 for *ting* fermented in the sun before cooking, and 64 for *ting* cooked with tartaric acid (not statistically significantly different). It has been reported, but not confirmed by Mosala *et al.*[34] that the *in vitro* digestibility of the starch of *ting* is higher than that of non-fermented sorghum porridge. The mean pH was 6.1 for *ting* fermented in the sun, and 2.0 for *ting* with tartaric acid. Acid addition seems to lower the GI. Brighetti *et al.*[35] studied the effect of neutralised and native vinegar on blood glucose and acetate responses to a mixed meal in healthy subjects. They gave healthy subjects acetic acid in the form of vinegar with bread, and sodium acetate with sodium bicarbonate in bread. They observed that the blood acetate response was reduced markedly after ingestion of acetic acid and bread compared with sodium acetate and bread. The glucose response was depressed by 31.4% with acetic acid and bread compared with sodium acetate and bread. They concluded that a limited amount of vinegar, in the form of salad dressing, is sufficient to influence significantly the glycaemic response to a mixed meal in normal subjects. They speculated that the mechanism was related to acidity and not to an effect on gastric emptying.

A similar conclusion could be drawn for the low GI of *ting* with tartaric acid. Tartaric acid is a strong dicarboxylic acid obtained from tartar. The possible mechanisms by which tartaric acid lowers the GI could be through reduced gastric emptying,[35] slower digestion by inhibiting the amylase activity which is more active in an alkaline environment[25] or by slowing absorption of glucose on the brush border. The difference in GI for fermented *ting* and that of *ting* with tartaric acid did not reach significance, despite the 43% reduction in the tartaric acid-added *ting*. This could have been due to the high coefficient of variation (CV) in individual responses (43% fermented *ting* in the sun and 37% for *ting* with tartaric acid).

The average peak time for glucose was at the 32nd minute (CV 62%) for *ting* with tartaric acid and at the 20th minute (CV 28%) for fermented *ting*. The maximum increments were 2.3 mmol/l glucose for fermented *ting*, and 1.6 mmol/l glucose for *ting* with tartaric acid. It can be concluded based on the above observations that acid-added *ting* peaked later than fermented *ting*, had a lower maximum increment for glucose, and therefore a lower glycaemic response.

The II for *ting* with tartaric acid was 118 and lower than that of fermented *ting* (II = 179), but not significantly so. The maximum increment was 163 µU/ml insulin and peak time at the 51st minute for acid-added *ting*, while the maximum increment was 213.8 µU/ml insulin and peak time at the 38th minute for fermented *ting*. The maximum increments were not significantly different. The lower II and maximum insulin increment of *ting* with tartaric acid were accompanied by a significantly higher IGSI of 16 compared with 7 for fermented *ting*. This suggests that there may be a higher insulin activity and less peripheral resistance after eating *ting* with tartaric acid when compared with fermented *ting*. The high insulin response to the fermented product could have been a result of an early peak in glucose response (20th minute) or stimulation of insulin secretion by other fermented products such as amino acids, gases and other products. The high insulin response may be undesirable, especially in individuals who consume fermented porridge daily. This may increase the risk of developing insulin resistance over time, which may in turn increase the risk of glucose intolerance and eventually lead to diabetes mellitus.

In order to understand the mechanism of action of fermented starches, fermentation products and the nature of starch have to be determined. These include the amylose/amylopectin ratio and the amount of resistant starch in fermented porridge. Discouraging the use of fermented porridge would seem premature at this stage, while encouraging the use of tartaric acid should be done cautiously since not enough is known about its safety in large quantities. Further research on the subject of fermentation and the benefits of tartaric acid is essential.

Protein, fat and fibre content of the dishes

The protein and fat content of the dishes would seem to influence the GI in a systematic manner because the two dishes that had a high content of protein (20 g and 26 g) and fat (27 g and 29 g) for mealiemeal porridge eaten with dried bean leaf stew and dried bean stew, respectively, gave similar responses (GIs of 87 and 68 respectively). The influence of fat and protein on lowering the GI has been reported to occur at high doses of fat (25 g) and 50 g protein/50 g carbohydrate load.[36-38] Three dishes with a similar fibre content per 50 g carbohydrate: mealiemeal porridge eaten with dried bean leaf stew (8.6 g fibre), samp and beans (11.4 g fibre), and dried bean stew (8.1 g fibre) had similar low GI responses of 87, 98 and 68, respectively. The low GI of these dishes cannot be attributed to total dietary fibre, protein and fat content alone, since legumes contain antinutrients such as phytates and lectins, known to lower GI by reducing the rate of digestion of starch.[12] The protein and fat contents and total fibre content were estimated using South African food composition tables. This may not be a true reflection of the actual nutrient content since the green leafy vegetables used in this study have not been analysed to determine their chemical components. *Mfino* (a type of green leafy vegetable unspecified in the table) was used in the nutrient analysis, and this may not belong to the same botanical family as the vegetables used in this study. Foods without available chemical composition should be analysed for use in future studies.

It is concluded that traditional eating patterns, such as adding legumes to maize products and acid to sorghum, seem to lower the GI of staple foods. However, the long-term physiological effects of the African diet should be determined, especially in individuals with conditions such as diabetes mellitus, hypertension and obesity, as these individuals are likely to benefit from the physiological effects of low-GI foods. The chemical composition, especially the antinutrients and phytochemicals, of these indigenous foods should also be determined as these may help to explain some of the effects observed. Physiological responses to fermented products should be studied further in order to rule out undesirable effects on insulin sensitivity. The GI of other indigenous/traditional South African foods should be determined as these will assist dietitians/nutritionists when planning diets for African patients.

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