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The glycaemic index of foods containing sugars: comparison of foods with naturally-occurring *v.* added sugars*

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The primary aim of the present study was to expand the glycaemic index (GI) database by determining the GI and insulin index values of thirty-nine foods containing sugars in healthy adults. The second aim was to examine the hypothesis that glycaemic and insulin responses to foods which contain added sugar(s) are higher than responses to foods containing naturally-occurring sugars. Eight healthy subjects drawn from a pool of eighteen consumed 50 g carbohydrate portions (except 25 g carbohydrate portions for fruits) of the test foods. The GI and insulin index were determined according to standardized methodology and expressed on a scale on which glucose = 100. The median GI and insulin index values of all foods tested were 56 (range 14 to 80) and 56 (range 24 to 124) respectively. The median GI of the foods containing added sugars was similar to that of foods containing naturally-occurring sugars (58 *v.* 53 respectively, *P* = 0·08). Likewise, the median insulin index of the foods containing added sugars was not significantly different from that of foods containing naturally-occurring sugars (61 *v.* 56 respectively, *P* = 0·16). There was no evidence of 'rebound hypoglycaemia' or excessive insulin secretion relative to the glucose response. We conclude that most foods containing sugars do not have a high GI. In addition, there is often no difference in responses between foods containing added sugars and those containing naturally-occurring sugars.

Glycaemic index: Plasma glucose: Insulin: Sugars: Carbohydrate

A decade ago Jenkins, Wolever and co-workers introduced the concept of glycaemic index (GI) to rank foods according to their postprandial impact on plasma glucose levels (Jenkins *et al.* 1981). Since then the GI values of over 200 foods have been determined (Brand *et al.* 1985; Jenkins *et al.* 1988). Many diabetes associations have accepted the principle of the GI, but they recommend that more research is needed for general application (Brand Miller, 1994). Apart from some fruits, most of the foods tested have been high in starch rather than sugars.

Sugars are an important component of diets in developed countries, providing about 20% of the total energy consumed and nearly half the total carbohydrate (Glinsmann *et al.* 1986; Baghurst *et al.* 1989; Department of Health, 1989). Approximately half the sugar is derived from added sugars and the other half from naturally-occurring sources, such as fruit and milk.

The glycaemic and insulin responses to sugars are also relevant to sports performance (Thomas *et al.* 1991), satiety (Holt *et al.* 1992) and serotonin-related phenomena, such as sleepiness (Lyons & Truswell, 1988). The GI of foods containing sugars should also be considered in the emergency treatment of hypoglycaemia. The common assumption that foods containing sugars will produce a more rapid glycaemic response than starchy foods has little scientific basis.

* No reprints will be available.

The primary aim of the present study was therefore to expand the GI database by determining the GI for a wide range of common foods containing simple sugars, including sources of both refined and naturally-occurring sugars. The selection of foods was based on those that had not been tested in previous GI studies. Insulin indices were also measured to examine the hypothesis that insulin responses to foods containing sugars are inappropriately high relative to the degree of glycaemia. Lastly the data were also used to examine the hypothesis that glycaemic and insulin responses to foods which contain added sugar(s) are higher than those to foods containing naturally-occurring sugars.

MATERIALS AND METHODS

Foods

Forty-two products were studied, thirty-nine of which were significant sources of simple sugars. The majority had not been previously tested for their GI. White bread (Tip Top; George Weston Foods, Chatswood, NSW, Australia) and two unsweetened cracker-type products (Sao™ and Jatz™; Arnott's Biscuits, Homebush, NSW, Australia), which are manufactured without added sugar, were also studied for comparison. The chemical composition of the foods was supplied by the manufacturers or determined from food tables (English & Lewis, 1991). The foods were studied in food groups (e.g. breakfast cereals, fruit, confectionery) and the order of testing within each group was randomized. White bread was used as the reference food and tested at least once for each group of foods.

Study design

Each food was tested in eight subjects drawn from a pool of eighteen healthy volunteers with normal glucose tolerance. The same group of individuals tested foods within the one food group and some subjects volunteered for several food groups. Their ages ranged from 19 to 59 years (mean 28, SD 10 years) and their body mass index (BMI) from 18 to 27 kg/m^2 (mean 22, SD 3 kg/m^2). The subjects consumed portions of each food containing 50 g available carbohydrate except the tropical fruits (with high water content), for which 25 g carbohydrate portions were consumed. The foods were tested in random order at approximately the same time of the morning after a 10 h overnight fast. Foods were consumed evenly over 12 min. The breakfast cereals were consumed with 150 ml full-cream milk (37 g fat/l) which contributed an additional 7 g lactose. The meals were consumed with additional water so that the total meal volume was 600 ml in all cases except fruit, where the final volume was 700 ml. The tests were given about 1 week apart.

Finger-prick capillary blood samples were taken at 0 min (fasting), 15, 30, 60, 90 and 120 min after the meal was commenced. Hands were placed in a 45° water bath for at least 2 min before puncturing with an Autolet device (Owen Mumford Ltd, Woodstock, Oxon) using Autoclix lancets (Boehringer Mannheim, Mannheim, Germany). Blood (800 μl) was collected into 1 ml tubes with heparin, centrifuged and the plasma stored at −20° before analysis. Glucose was assayed using the glucose hexokinase (*EC* 2.7.1.1) method on a Cobas Fara centrifugal analyser (Roche Diagnostica, Basle, Switzerland) and insulin by radioimmunoassay with the Bio-RIA ^{125}I-Insulin Chromacode Radioimmunoassay kit (Bio-Mega Diagnostica Inc., Hamon, Montreal, Canada).

The GI and insulin index of each food were calculated as described previously (Brand *et al.* 1985) using a 50 g carbohydrate portion of white bread as the reference food. Because the tropical fruits were consumed in 25 g carbohydrate portions, the incremental area under the curve was doubled. This was justified on the basis of the proven linear dose–response relationship between the area under the curve and the amount of carbohydrate consumed in the range 25 to 50 g (Jenkins *et al.* 1981). The GI of every food was multiplied by the factor 70/100 in order to express the final result on a scale on which glucose = 100 (when glucose is the reference food, the GI of white bread is 70). Jenkins *et al.* (1988) have made this adjustment in the opposite direction to express their early results with a white-bread standard. We believe that an index where glucose is 100 is more logical and easier to explain to patients.

The Dixon test for extreme values (Dixon, 1953) was applied in a few instances to exclude very high values from calculation of the mean. For these foods the number of subjects in the group was seven. Linear regression analysis was used to test for association between glycaemic and insulin responses and between the nutrient content of the foods and their GI or insulin index. Comparisons between natural and refined sources of sugars were made using the Mann Whitney U test because the data were not normally distributed. The protocol was approved by the Medical Ethical Review Committee of the University of Sydney and subjects gave written, informed consent.

RESULTS

The GI and insulin index of each food were calculated as described previously (Brand *et al.* 1985). In practice the reference food was white bread but the final result was multiplied by 70/100 in order to use a scale where glucose = 100. The final GI and insulin index values for the foods tested are shown in Table 1. The GI values ranged from 14 (SE 4) for low-fat, artificially sweetened yoghurt to 102 (SE 9) for the glucose tablets (Glucodin®). The median GI of all foods tested was 56. The insulin index values ranged from 24 (SE 8) for dried apricots to 124 (SE 21) for Coco Pops® (a sweetened, puffed rice cereal), the median insulin index being 56. There was a good correlation between GI and insulin index (r 0·69, $P <$ 0·001).

The median GI of the seventeen foods containing only naturally-occurring sugars was similar to that of the twenty-one foods containing added sugars (53 *v.* 58 respectively, $P = 0{\cdot}08$, Fig. 1). Similarly, the median insulin index of the foods containing naturally-occurring sugars was not significantly different from that of the foods containing added sugars (56 *v.* 61, $P = 0{\cdot}16$). (Glucose tablets and the cracker biscuits made without sugar were excluded from this analysis because they contained neither naturally-occurring sugars nor significant amounts of added sucrose.) When foods were compared within categories (bakery products, dairy products, canned fruit, beverages), there were no significant differences for cakes, muffins and most cookies made with or without added sugars (Fig. 2). However, there were significant differences among dairy products, canned peaches and beverages according to the presence or absence of added sugars (Fig. 3).

There was no evidence of 'rebound hypoglycaemia' (undershoot of the baseline plasma glucose value) within 2 h of consumption of any of the foods. Fig. 4 shows that sugar in some forms of confectionery produces a response similar to that to bread with no evidence of rebound hypoglycaemia. Plasma glucose and insulin levels had returned to fasting levels within the 2 h except in the case of bread.

Correlations were calculated between GI and the fat, protein, sugar and fibre contents of the foods in order to determine whether macronutrient content of the foods influenced the GI value. A significant negative relationship was found between the protein content of the food (per 50 g carbohydrate portion) and the GI (r 0·63, $P < 0{\cdot}05$, n 36, Fig. 5), but this did not hold for the insulin index. There was no significant relationship between GI and fat, GI and sugar or GI and fibre in the foods per 50 g carbohydrate portion (Fig. 5). Similarly there was no relationship between nutrient content and insulin index (results not shown).

Table 1. *The glycaemic index, insulin index and composition of the foods (g/kg edible portion)*

Food	*n*	Glycaemic index (glucose = 100)		Insulin index (glucose = 100)		Protein (g/kg)	Fat (g/kg)	Carbohydrate (g/kg)	Sugars (g/kg)	Dietary fibre (g/kg)
		Mean	SE	Mean	SE					
Breakfast cereals										
Coco Pops® (puffed rice with cocoa, Kellogg)	8	77	8	124	21	47	25	863	390 (r)	17
Nutrigrain® (extruded cereal, Kellogg)	8	66	12	73	17	21	27	715	350 (r)	15
Natural muesli (oats, fruit, nuts, Uncle Toby's)	8	56	8	53	10	113	70	650	213 (r)	107
Toasted muesli (oats, fruit, nuts, Purina)	8	43	4	35	4	80	165	578	200 (r)	124
Sultana Bran® (wheat bran flakes, Kellogg)	8	52	7	45	11	102	16	772	230 (r)	165
Canned fruit										
Peaches in natural juice (Goulburn Valley)	8	30	4	30	8	5	1	105	96 (n)	14
Peaches in heavy syrup (Letona)	8	58	11	50	7	13	2	150	136 (r)	10
Dairy products										
Chocolate milk (Lite White® with sugar)	8	34	4	69	12	42	14	103	103 (r)	0
Chocolate milk (Lite White® + Aspartame)	8	24	6	34	7	42	15	58	58 (n)	0
Yoghurt, low fat, with fruit and sugar (Ski®)	8	33	7	28	5	50	2	154	154 (r)	0
Yoghurt, low fat, with fruit + Aspartame (Ski®)	7	14	4	63	9	52	2	64	64 (n)	0
Vitari® (frozen fruit confection)	8	28	6	27	5	2	1	230	229 (n)	11
Ice-cream, low fat (Light®, Peters)	7	50	8	42	7	23	15	120	91 (r)	0
Bakery products										
Banana cake made without sugar	7	55	10	53	9	ND	ND	360	89 (n)	ND
Banana cake made with sugar	8	47	8	55	9	ND	ND	480	298 (r)	ND
Apple muffins made without sugar	8	48	10	61	18	ND	ND	313	86 (n)	ND
Apple muffins made with sugar	8	44	6	65	10	ND	ND	476	176 (r)	ND
Continental fruit loaf (bread with dried fruit)	8	47	6	62	14	ND	ND	520	ND (n)	ND
Fruit										
Mango	7	51	3	61	12	10	2	126	121 (n)	16
Pawpaw	7	56	6	49	7	4	1	69	69 (n)	23
Rockmelon/cantaloupe	8	65	9	79	10	5	1	47	47 (n)	10
Watermelon	8	72	13	73	15	3	2	50	50 (n)	6
Pineapple	8	66	7	56	7	10	1	80	80 (n)	21
Kiwi fruit	7	58	7	62	2	14	2	98	98 (n)	33

Dried fruit										
Dried apricots	8	30	7	24	8	45	4	683	683 (n)	240
Sultanas	8	56	11	32	8	18	0	763	763 (n)	70
Biscuits (cookies) and crackers										
Milk Arrowroot® (sweet biscuits, Arnotts)	8	69	7	69	8	66	104	801	217 (r)	29
Shredded Wheatmeal® (sweet biscuits, Arnotts)	7	62	4	55	6	85	152	711	201 (r)	48
Highland Oatmeal® (sweet biscuits, Westons)	7	55	8	36	5	62	156	730	240 (r)	50
Morning Coffee® (sweet biscuits, Arnotts)	8	79	6	80	10	60	137	762	212 (r)	30
Sao® (savoury cracker biscuits, Arnotts)	8	70	9	51	6	111	153	670	32	35
Jatz® (savoury cracker biscuits, Arnotts)	8	55	5	41	5	81	200	699	50	34
Confectionery										
Muesli bars (Uncle Toby's)	7	61	7	47	9	58	112	688	246 (r)	51
Life Savers® (peppermint candy)	8	70	6	73	11	5	7	980	980 (r)	0
Jelly beans (Allen's)	8	80	8	98	10	1	6	900	900 (r)	0
Chocolate (milk, Cadbury's)	8	49	6	61	8	84	303	591	567 (r)	8
Concentrated sources of sugar										
Honey (pure, Capilano)	8	58	6	58	7	5	0	830	830 (n)	0
Glucodin® (glucose tablets)	7	102	9	97	24	0	0	900	900	0
Beverages										
Orange juice (unsweetened, Quelch)	8	53	6	56	8	6	0	85	80 (n)	3
Orange cordial (Berri)	8	66	8	69	12	0	0	80	80 (r)	3
Orange soft drink (Fanta®)	7	68	6	84	18	0	0	134	134 (r)	0

ND, not determined; (r), the main source of sugars is refined sugar (sucrose), but some foods will also contain naturally-occurring sugars; (n), only naturally-occurring sugars are present.

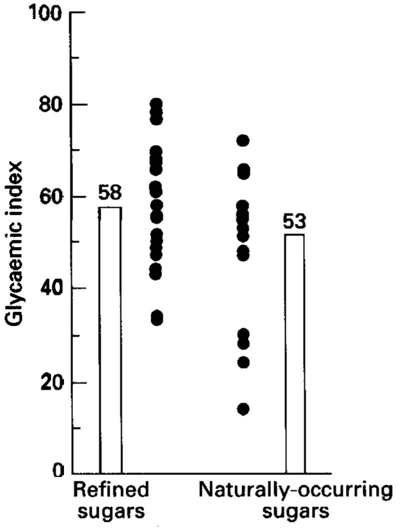

Fig. 1. The glycaemic index (median and range) of foods containing added sugars (n 21) v. foods containing only naturally-occurring sugars (n 17).

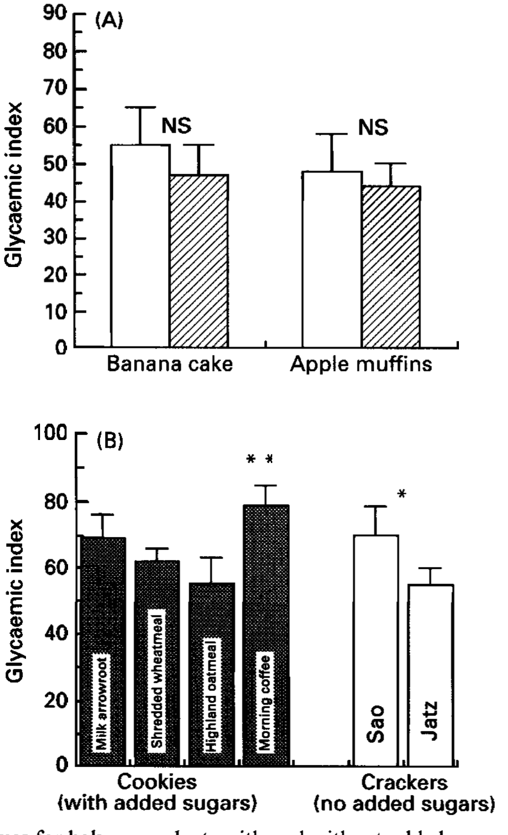

Fig. 2. Glycaemic index values for bakery products with and without added sugars. (A), comparison of banana cake and apple muffins made with (▨) or without (□) added sugars; (B), comparison of cookies containing added sugars and savoury crackers made without added sugars. NS, not significant. Mean value was significantly higher than that for Jatz® savoury crackers, * $P < 0.05$, ** $P < 0.01$.

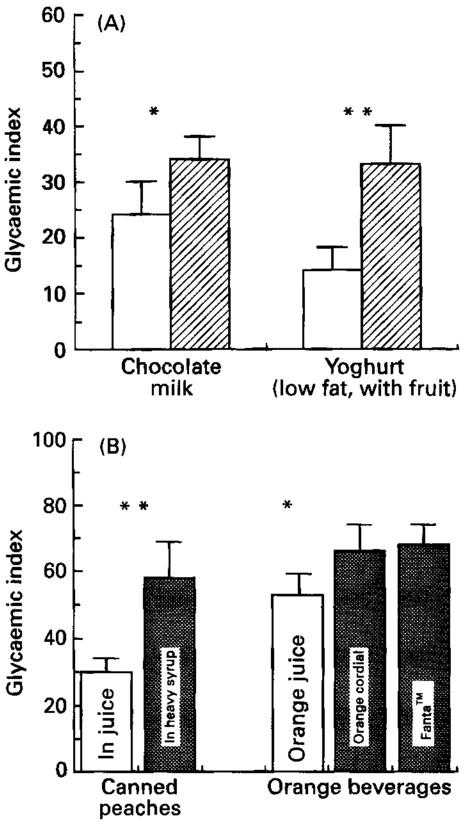

Fig. 3. Glycaemic index values for dairy products and fruits with and without added sugars. (A), comparison of chocolate milk and yoghurt made with (▨) or without (□) added sugars. Mean values were significantly different for the two products, * $P < 0.05$, ** $P < 0.01$. (B), comparison of canned peaches and orange beverages made with (▩) and without (□) added sugars. Peaches in juice were significantly different from those in syrup, ** $P < 0.01$; orange juice was significantly different from Fanta®, * $P < 0.05$.

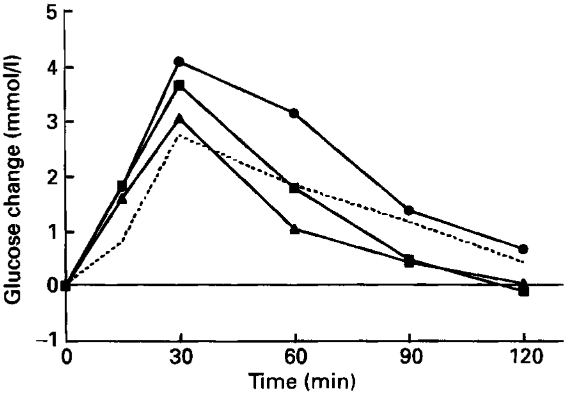

Fig. 4. Plasma glucose change after two confectionery items (Life Savers (▲) and jelly beans (■)) compared with equal carbohydrate portions of white bread (----) and glucose tablets (●, Glucodin® tablets). The figure shows that sugar in the form of confectionery produces a response similar to that of bread with no evidence of rebound hypoglycaemia within 2 h of consumption.

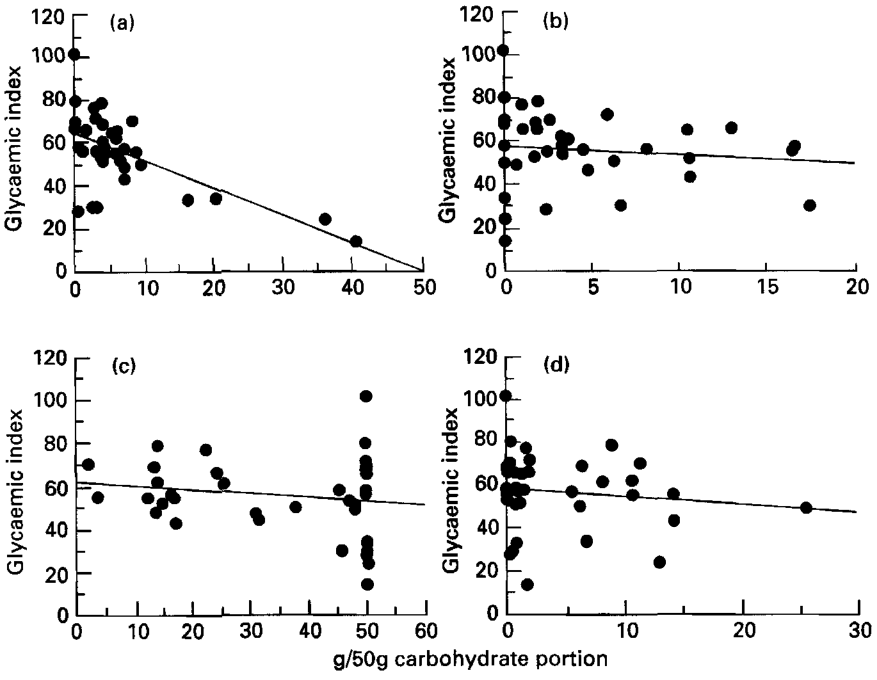

Fig. 5. Relationship of (a) protein (*n* 36, *r* −0·63, $P < 0.05$), (b) fibre (*n* 37, *r* −0·11, not significant), (c) sugars (*n* 40, *r* −0·18, not significant) and (d) fat (*n* 36, *r* −0·12, not significant) content per 50 g carbohydrate portion to the glycaemic index of the foods studied.

DISCUSSION

This study indicates that most foods containing sugars do not have a high GI. The majority fell within the intermediate range (50–70) on the GI scale where glucose = 100. The results belie the commonly held belief that foods containing added sugars produce higher glycaemic and insulin responses than starchy foods. The GI of bread is about 70 and potatoes have a GI of 70–90 depending on the method of preparation (Jenkins *et al.* 1981). The majority (over 80 %) of 'sugary' foods tested in the present study had a GI lower than 70. Recently, Wolever *et al.* (1994) showed that the strongest determinant of whole diet GI in 340 individuals with non-insulin-dependent diabetes mellitus (NIDDM) was the intake of simple sugars which correlated inversely with the diet GI. The present findings are further evidence that foods rich in simple sugars usually have lower GI values than most common starchy foods.

Simple sugars in their natural state in plant foods are thought to give rise to flatter metabolic responses than foods containing added sucrose (Department of Health, 1989). In the present study, however, the median GI of foods containing naturally-occurring sugars was not significantly different (in a statistical or biological sense) from that of foods containing added sugars. In addition, we could find no significant difference between responses to cakes, muffins and most cookies made with or without added sugars (Fig. 2). Foods where added sugars produced substantially higher values included canned peaches, milk, yoghurt and soft drinks. However, even in these instances the GI values of the foods containing added sugars were less than that of bread. These results support the predictability of GI in the context of mixed meals (Chew *et al.* 1988). It is clear that addition of sucrose (which has an intermediate GI) to a low GI food will increase the final GI, while addition of sucrose to a high GI food will result in a lower GI meal (Brand Miller & Lobbezoo, 1994).

The low mean GI of the foods studied is best explained by the composition of the individual sugars. Sucrose is a disaccharide composed of glucose and fructose so that only half the glucose-equivalents are available compared with an equal carbohydrate portion of bread or glucose. The sweetness of fruit is determined by a mixture of glucose, fructose, sucrose and other sugars, which do not affect plasma glucose levels equally. Fructose has a very small effect on the overall rate of glucose appearance (Delarue *et al.* 1993). None of the foods were manufactured using high-fructose maize syrup as is commonly used in North America.

Unlike many studies in this area, the findings also expand our knowledge of insulin responses after different foods. There was a good correlation between the GI of the foods and their insulin index (*r* 0·69). Hence the results do not support the hypothesis that foods containing sugars give an inappropriately high insulin response relative to the degree of glycaemia. There were some exceptions to this, for example Coco Pops gave a GI of 77 (SE 8), but a mean insulin index of 124 (SE 21). Individual variation in insulin index was very high for this food, with one or two subjects requiring much greater insulin secretion to restore euglycaemia. It is also noteworthy that the yoghurt which was sweetened with Aspartame™ (a dipeptide composed of aspartic acid and phenylalanine) gave a much higher insulin response than predicted. However, this extreme disparity between glucose and insulin response did not apply to the chocolate milk sweetened with Aspartame™.

We found no evidence that bread stimulates more insulin relative to oral glucose, as reported by Bornet *et al.* (1987) in individuals with NIDDM. The mean glycaemic response to the glucose tablets was 1·48 times that to white bread, while the mean insulin response to glucose was 1·41 times that to bread. The conflicting findings may be explained by the type of subjects studied (healthy *v.* diabetic) or by the mode of administration of glucose, solid in the present study and dissolved in water in the other study.

An insulin index of foods deserves further research because chronic hyperinsulinaemia is thought to play an important role in the development of NIDDM and hypertriacylglycerolaemia (DeFronzo *et al.* 1992). Unlike glycaemic responses, insulin responses to foods are affected by the degree of insulin resistance in the individual. Ageing, obesity and genetic inheritance all influence the degree of insulin resistance (DeFronzo *et al.* 1992). Furthermore, the insulin requirements of individuals with insulin-dependent diabetes are presently based on carbohydrate and energy intake rather than on precise quantitative measurements of insulin responses to foods in healthy individuals.

We found that the GI of tropical/exotic fruits ranged from 51 to 72, which is higher than that obtained previously for temperate zone fruits such as apples and oranges (34 to 44, where glucose = 100; Jenkins *et al.* 1981). There is no obvious reason why tropical fruits should have a higher GI than temperate fruits. The methodology was similar to that used by Jenkins *et al.* (1981), although they used 50 g rather than 25 g carbohydrate portions of fruit. Bananas, another tropical fruit, also gave a higher GI (62) than temperate fruits in the Jenkins study. One could speculate that the cell walls of tropical fruits are softer and more readily dispersed in the gastrointestinal tract than the cell walls of temperate fruits, thereby releasing sugars more quickly. The type of fibre in temperate fruit may be different to that of tropical fruit, with a higher proportion of pectins and other viscous soluble fibres.

Alternatively, the pattern of individual sugars may be different in tropical and temperate fruits. Using published data (Southgate *et al.* 1978), we calculated that the average fructose content was higher (39 *v.* 27 g/kg) and the average sucrose content was lower (20 *v.* 40 g/kg) in eight temperate fruits compared with the six tropical fruits studied. However, total glucose-equivalents were similar (41 *v.* 44 g/kg respectively), suggesting that the glycaemic response should also be similar. However, these figures may not represent the composition of the fruit actually tested by us. Further studies directly comparing temperate and tropical fruits of known sugar composition are obviously needed to resolve the issue.

Fat in foods is known to flatten the plasma glucose curve and thus high-fat foods may appear in a favourable light according to their GI. However, the fat content of the foods was not responsible for the low GI values because over three-quarters of the foods contained less than 30 g fat/kg. Moreover, there was no correlation between fat content and either GI or insulin index (Fig. 5). Protein was the only nutrient which correlated with the GI of the foods. The inverse correlation between protein content and GI could be explained by the fact that protein is an additional stimulus for insulin secretion thereby lowering plasma glucose and the GI (Nuttall *et al.* 1984).

We conclude that many foods containing sugar(s), whether naturally-occurring or refined, give glycaemic and insulin responses that are similar to or lower than those of many common starchy foods in the Western diet. Although the subjects studied were normal healthy individuals, the findings are likely to apply to individuals with diabetes (Wolever *et al.* 1991). Some of our comparisons, however, should be confirmed in diabetic subjects before applying the findings to clinical practice.

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