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Glycaemic index and glycaemic load values of cereal products and weight-management meals available in the UK

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There is currently an increased global interest in the published glycaemic index (GI) values of foods. The aim of the present work was to supplement a previous study on the glycaemic response of 140 foods available in the UK by studying a further forty-four foods. One hundred and twenty-two healthy subjects, with a mean age of 32·4 (SD 11·4) years and a mean BMI of 23·6 (SD 3·6) kg/m^2, were recruited to the study. Subjects were served equivalent available carbohydrate amounts (50 or 30 g) of test foods (cereal products and weight-management meals) and a standard food (glucose) on separate occasions. Capillary blood glucose was measured from finger-prick samples in fasted subjects (0 min) and at 15, 30, 45, 60, 90 and 120 min after starting to eat each test food. For each test food, the GI value was determined, and the glycaemic load was calculated as the product of the GI and the amount of available carbohydrate in a reference serving size. The GI values of the foods tested ranged from 23 to 83. Of the forty-four foods tested, thirty-three were classified as low-GI, eight as medium-GI and three as high-GI foods. Most GI values of the foods tested compared well with previously published values for similar foods. In summary, this study provides reliable GI and glycaemic load values for a range of foods, further advancing our understanding of the glycaemic response of different foods. The data reported here make an important addition to published GI values.

Glycaemic index: Glycaemic load: Cereal products: Weight-management meals

The glycaemic index (GI), first introduced by Jenkins and colleagues (1981), is a classification of the blood glucose-raising potential of carbohydrate foods. It is defined as the incremental area under the blood glucose curve of a 50 g carbohydrate portion of a test food expressed as a percentage of the response to 50 g carbohydrate of a reference food taken by the same subject, on a different day (FAO/WHO, 1998). The principle is that the slower the rate of carbohydrate absorption, the lower the rise in blood glucose level and the lower the GI value (Augustin *et al.* 2002). Indeed, high-GI foods are characterised by fast-release carbohydrate and higher blood glucose levels. A GI value of 70 or more is considered high, one of 56–69 is medium and one of 55 or less is low (where glucose = 100; Brand-Miller *et al.* 2003).

Since the concept of GI was first introduced, many studies have investigated the potential health benefits of low-GI foods. Recent data support the preventive potential of a low-GI diet against the development of type 2 diabetes and cardiovascular disease (Salmeron *et al.* 1997*a*,*b*; Frost *et al.* 1999). There is also an interest in the potential of low-GI diets for body-weight management. Several studies have shown that low-GI foods, or lowering the GI of a food, reduces hunger and results in a lower energy intake (Ludwig, 2000; Warren *et al.* 2003).

GI values represent the glycaemic response of equivalent available carbohydrate amounts of foods and are therefore not always representative of the glycaemic effect of a typical serving of that food. To quantify the overall glycaemic effect of a standard portion of food, the concept of glycaemic load (GL) was introduced (Salmeron *et al.* 1997*a*,*b*). This is the product of the amount of available carbohydrate in that serving and the GI of the food divided by 100. It is often necessary to consider the GL alongside GI values, especially when the carbohydrate content of the food is relatively small. A GL value of 10 or less is considered low, a GL value of 11–19 is medium and one of 20 or more is high (Brand-Miller *et al.* 2003).

Carbohydrate foods consumed in equivalent available carbohydrate amounts produce different glycaemic responses depending on many factors, such as particle size, cooking and food processing, other food components (e.g. fat, protein, dietary fibre), the proportion and type of sugars and starch, and the starch structure (Björck *et al.* 1994). Consequently, there is often considerable variation in the GI of the same food produced in different countries or by different manufacturers. The publication of reliably measured GI and GL values is needed to facilitate consumer application and to reduce unnecessary regional duplication. Until recently, the vast majority of published GI values have been Australasian or Canadian (Foster-Powell *et al.* 2002). Henry *et al.* (2005) published a paper detailing GI and GL values for 140 foods

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Abbreviations: GI, glycaemic index; GL, glycaemic load; IAUC, incremental area under the blood glucose response curve.

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commonly consumed in the UK. Thus, the aim of the current work was to provide additional GI and GL values for a wider range of foods available in the UK.

Methods

Subjects

One hundred and twenty-two healthy subjects, with a mean age of 32·4 (SD 11·4) years and a mean BMI of 23·6 (SD 3·6) kg/m^2, were recruited via posters distributed throughout Oxford Brookes University, in addition to announcements in lectures and through personal networks. Exclusion criteria were as follows: age less than 18 or over 60 years, a BMI of 27 kg/m^2 or more, and a fasting blood glucose value of over 6·1 mmol/l. Ethical approval for the study was obtained from the University's Research Ethics Committee. Subjects were given full details of the study protocol and had the opportunity to ask questions. All subjects gave written informed consent prior to participation.

Study protocol

The protocol used was adapted from that described by Wolever *et al.* (1991) and is in line with procedures recommended by the FAO/WHO (1998). The FAO/WHO state that, to determine the GI of a food, tests should be repeated on six or more subjects; thus in the current study, each product was tested on a minimum of ten subjects. Overall, subjects tested between one and twelve different foods during the study. On the day prior to a test, subjects were asked to restrict their intake of alcohol and caffeine-containing drinks and to restrict their participation in intense physical activity. Subjects were also told not to eat or drink after 21.00 hours on the night before a test, although water was allowed in moderation.

Test foods

Forty-four different foods were tested, including breads, breakfast cereals, mixed meals (breakfast cereals with milk), snack bars and weight-management meals, representing a diverse range of foods commonly consumed in the UK. All foods were tested in equivalent available carbohydrate amounts (50 or 30 g) and compared with a reference food (glucose). In the case of foods with a low to moderate carbohydrate density, it is justified to reduce the carbohydrate load to avoid an unrealistically large meal size; such reductions are shown to produce similar GI values (Brouns *et al.* 2005). For each food product, the experimental portion was determined using data for available carbohydrate provided by the relevant food manufacturer. In the case of the mixed meals, both the breakfast cereals and milk contributed to the 50 g available carbohydrate (Table 1).

Table 1. Amount of available carbohydrate from mixed meals

Food	Amount of available carbohydrate (g)	
	Test food	Milk
Cereal biscuit	40·6	9·4
Cereal biscuits – cocoa flavour	40·6	9·4
Cereal biscuits – honey flavour	40·7	9·3
Cereal biscuits – fruit flavour	40·4	9·6
Cereal flakes with fruit	41·9	8·1
Cocoa crunch cereal	39·6	10·4
Honey crunch cereal	40·3	9·7
Hot oat cereal I	37·7	12·3
Hot oat cereal II	35·6	14·4
Hot oat cereal – berry flavour	41·0	9·0
Hot oat cereal – cocoa flavour	37·3	12·7
Hot oat cereal – fruit flavour	38·2	11·8
Hot oat cereal – honey flavour	40·9	9·1
Hot oat cereal – orchard fruit	40·6	9·4

In accordance with FAO/WHO recommendations, subjects tested each test food once and the reference food three times randomly on separate days, with a gap of at least 1 d between measurements to minimise carry-over effects (FAO/WHO, 1998). Subjects were studied in the morning after a 12 h overnight fast. Subjects consumed the reference food/test product within 15 min. The test products and the reference food were served with 200 ml water, and a further 200 ml water were given during the subsequent 2 h. Subjects remained sedentary during each session.

Blood glucose measurements

A fasting blood sample was taken at 0 min, and the reference food/test product was consumed immediately after this. Further blood samples were taken at 15, 30, 45, 60, 90 and 120 min after starting to eat. Blood was obtained by finger-prick using the Unistik 2 single-use lancing device (Owen Mumford). Prior to a finger-prick, subjects were encouraged to warm their hand to increase blood flow. Fingers were not squeezed to extract blood from the fingertip, in order to minimise plasma dilution. Blood glucose was measured using Ascensia Contour automatic blood glucose meters (Bayer HealthCare). The blood glucose meters were calibrated daily using control solutions from the manufacturer, and were also regularly calibrated against a clinical dry chemistry analyser (Reflotron Plus; Roche) and the HemoCue Glucose 201 + analyser (HemoCue Ltd).

Figure 1 shows the Pearson regression and Bland–Altman analyses for a random selection of 1400 blood samples simultaneously measured using the Ascensia Contour and the HemoCue Glucose 201 + analyser. There was a very strong correlation ($r = 0{\cdot}960$, $P < 0{\cdot}001$) and good agreement (mean difference 0·10 mmol; 95 % CI 0·07, 0·12; limits of agreement 0·88 and 1·08) between blood glucose measurements using the automatic analyser and the HemoCue analyser.

Calculation of glycaemic index and glycaemic load

The incremental area under the blood glucose response curve (IAUC), ignoring the area beneath the baseline, was calculated geometrically for each food (FAO/WHO, 1998). The IAUC for each test product eaten by each subject was expressed as a percentage of the mean IAUC for the reference food eaten by the same subject:

$$\mathrm{GI} = (\mathrm{IAUC\ test\ product}/\mathrm{IAUC\ reference\ food}) \times 100.$$

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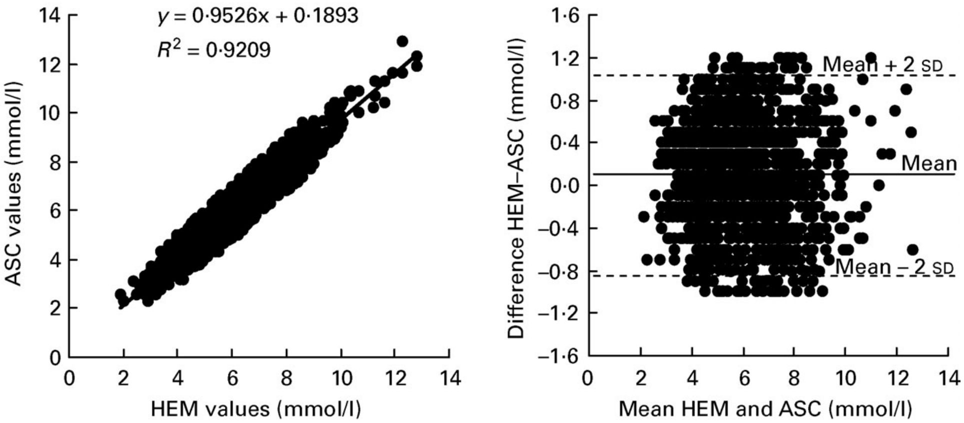

Fig. 1. Pearson regression and Bland–Altman analyses of 1400 random blood glucose measurements between the Ascensia Contour (ASC) and the HemoCue 201 + analyser (HEM).

The GI of each test product was taken as the mean for the whole group.

The GL of a specific serving of each food was calculated using the following equation:

$$\mathrm{GL} = (\mathrm{GItestfood} \times \mathrm{weight\,of\,available\,carbohydrate}_{\mathrm{in\,a\,serving\,of\,test\,food}}[\mathrm{g}])/100.$$

The serving size of each food was taken from manufacturers' information or, when this was not available, from standard food portion sizes (Food Standards Agency, 2004).

Statistical analysis

Statistical analysis was performed using the Statistical Product and Service Solutions software (SPSS version 11.0.1; SPSS Inc., Chicago, IL, USA). To examine the correlation and agreement between the automatic analyser and the HemoCue Glucose 201 + analyser, Pearson's correlation coefficient and the method of Bland & Altman (1986) were used. Pearson's correlation coefficient and Spearman's correlation coefficient (rho) were used, where appropriate, to assess the relationship between the GI values and macronutrient content of the test foods. Statistical significance was set at $P < 0{\cdot}05$.

Results

The GI and GL values for all forty-four tested foods are given in Table 2. Values are given as means with their standard errors. The GI values of the foods tested ranged from 23 (chocolate flavour drink) to 83 (hot oat cereal with water). Of the forty-four foods tested, thirty-three were classified as low-GI, eight as medium-GI and three as high-GI foods. The GL per serving ranged from 2·3 (choice grain crackers, rich tea biscuits) to 20·9 (chocolate soya drink).

Bread and crackers and breakfast cereals represented a wide range of GI values, most showing low (e.g. multiseed bread, choice grain crackers, high-fibre cereals), with some medium (e.g. rye crackers, cereal flakes with fruit) and two high (e.g. cereal biscuit, hot oat cereal I with water), values. All snack bars and sweet biscuits fell into the low-GI category. Most weight-management meal products fell into the low-GI category, with the exception of the chocolate soya drink (high), and vegetable and chicken, and mushroom soups (medium).

The addition of semi-skimmed milk to the breakfast cereals reduced the GI values from a high to a low classification. The GI values of cereal biscuits and hot oat cereal I were reduced from 72 to 47 ($P=0{\cdot}112$) and 83 to 47 ($P=0{\cdot}011$), respectively, when consumed with milk.

There was no relationship between the GI value and the amount of protein per 50 g available carbohydrate portion (Fig. 2; Pearson's $r = -0{\cdot}288$; $P=0{\cdot}061$). There was, however, a weak negative relationship between the GI value and amount of fat per experimental portion (Fig. 2; Spearman's rho $= -0{\cdot}373$; $P=0{\cdot}014$). When the weight-management meals (i.e. lower-fat products) were excluded, there was a strong negative relationship between GI value and amount of fat per experimental portion (Fig. 3; Spearman's rho $= -0{\cdot}727$; $P<0{\cdot}001$), but not between GI value and amount of protein per 50 g available carbohydrate portion (Fig. 3; Pearson's $r = -0{\cdot}295$; $P=0{\cdot}095$).

Discussion

This study provides the GI values of a number of foods not previously tested, further expanding our database of the glycaemic response of different foods available in the UK. The GI values of several foods and mixed meals reported in this study have not previously been published. Where, however, comparison with published values (Foster-Powell *et al.* 2002) was possible, foods tested in the current study compared favourably. For example, in healthy subjects, the GI values for wheat biscuits (61–75), rye crisp bread (69), meal-replacement bars (30–45) and meal-replacement chocolate drink powder (26) reported in international GI tables (Foster-Powell *et al.* 2002) are similar to those reported here.

Small differences of less than 10–15 units lie within the error associated with the measurement of GI (Wolever *et al.* 1991; Foster-Powell *et al.* 2002), but there were a few values that were notably different from those previously reported. In particular, the GI value of white bread reported in the current study was lower than that reported for most white breads. This may be due to differences in processing conditions and the use of new food ingredients in the baking

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Table 2. Glycaemic index (GI) and glycaemic load (GL) values for forty-four foods available in the UK

Food	Carbohydrate (g/100 g)	Experimental portion (g)	GI		Standard serving size (g)	Carbohydrate (g/serving)	GL (per serving)
			Mean	SE			
Bread and crackers							
Multiseed bread	41·8	119·6	54	4	36	15·0	8·1
Seeded bread	38·2	130·9	49	7	36	13·8	6·8
White bread	44·3	112·9	59	11	46	20·4	12·0
White bread with wheatgerm and fibre	41·6	120·2	49	12	33	13·7	6·7
Cheese-filled white rolls	39·6	126·3	50	6	62	24·6	12·3
Choice grain crackers	65·5	76·3	49	7	7	4·6	2·3
Rye crackers with oats	63·6	78·6	64	11	13	8·3	5·3
Rye crackers with sesame	64·9	77·0	57	12	13	8·4	4·8
Wholegrain crackers with sesame seeds and rosemary	62·3	80·3	53	8	13	8·1	4·3
Wholewheat crackers with pumpkin and thyme	61·3	81·6	36	3	13	8·0	2·9
Crunchy yeast-extract-flavoured wholewheat sticks	57·3	87·3	50	8	25	14·3	7·2
Breakfast cereals							
Cereal biscuit	67·1	74·5	72	10	38	25·5	18·4
High-fibre cereal	57·4	87·1	52	6	40	23·0	12·0
Hot oat cereal I (water)	57·4	87·1 (348)	83	10	30 (120)	17·2	14·3
Mixed meals – breakfast cereals							
Cereal biscuit (semi-skimmed milk)*	19·1†	60·4 (201]	47	8	38 (125)	31·1	14·6
Cereal biscuits – cocoa flavour (semi-skimmed milk)*	19·4†	57·7 (200)	46	7	36 (125)	31·2	14·4
Cereal biscuits – honey flavour (semi-skimmed milk)*	19·7†	56·8 (197)	52	7	36 (125)	31·7	16·5
Cereal biscuits – fruit flavour (semi-skimmed milk)*	19·0†	58·9 (204)	56	7	36 (125)	30·6	17·1
Cereal flakes with fruit (semi-skimmed milk)*	21·9†	55·2 (173)	57	8	40 (125)	36·1	20·6
Cocoa crunch cereal (semi-skimmed milk)*	18·2†	53·1 (221)	58	11	30 (125)	28·2	16·4
Honey crunch cereal (semi-skimmed milk)*	19·5†	49·6 (207)	54	6	30 (125)	30·2	16·3
Hot oat cereal I (semi-skimmed milk)*	15·3†	65·6 (262)	47	6	30 (120)	23·0	10·8
Hot oat cereal II (semi-skimmed milk)*	13·6†	61·2 (306)	40	9	30 (150)	24·5	9·8
Hot oat cereal – berry flavour (semi-skimmed milk)*	19·7†	62·0 (192)	43	6	40 (125)	32·5	14·0
Hot oat cereal – cocoa flavour (semi-skimmed milk)*	14·9†	65·0 (270)	40	5	30 (125)	23·1	9·2
Hot oat cereal – fruit flavour (semi-skimmed milk)*	16·0†	60·4 (252)	47	8	30 (125)	24·8	11·7
Hot oat cereal – honey flavour (semi-skimmed milk)*	19·5†	62·0 (194)	47	6	40 (125)	32·2	15·1
Hot oat cereal – orchard fruit flavour (semi-skimmed milk)*	18·9†	64·0 (200)	50	7	40 (125)	31·2	15·6
Snack bars							
Apricot and almond bar	51·4	97·3	34	6	35	18·0	6·1
Cereal bar – cranberry flavour	48·5	103·1	42	5	35	17·0	7·1
Cereal bar – hazelnut flavour	36·3	137·7	33	6	35	12·7	4·2
Cereal bar – orange flavour	47·4	105·5	33	3	35	16·6	5·5
Sweet biscuits							
Digestive	62·7	79·7	39	5	15	9·4	3·7
Rich Tea	71·2	70·2	40	5	8	5·7	2·3
Oat biscuits	60·8	82·2	45	7	14	8·5	3·8
Weight-management meals							
Chocolate drink‡	7·0	428·6	39	8	200	14·0	5·5
Chocolate flavour drink‡	35·3	85·0	23	5	40	14·1	3·2
Chocolate soya drink‡	54·0	55·6	73	17	53	28·6	20·9
Lactose-free chocolate drink‡	38·0	78·9	29	10	40	15·2	4·4
Chicken and mushroom soup‡	35·5	84·5	46	6	40	14·2	6·5
Chicken and mushroom soup‡	37·3	80·4	69	14	40	14·9	10·3

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Table 2. *Continued*

Food	Carbohydrate (g/100 g)	Experimental portion (g)	GI		Standard serving size (g)	Carbohydrate (g/serving)	GL (per serving)
			Mean	SE			
Vegetable soup‡	35·0	85·7	60	12	40	14·0	8·4
Lemon bar‡	41·5	72·3	32	8	50	20·8	6·7
Malt toffee bar‡	47·5	63·2	43	7	52	24·7	10·6

Serving size for breads, biscuits and crackers is one slice of bread or one cracker/biscuit.

* Semi-skimmed milk contained 3·4 g protein, 1·7 g fat and 4·7 g carbohydrate per 100 g.

† Available carbohydrate (g/100 g) of test food and semi-skimmed milk.

‡ Both the test food and the reference food contained 30 g available carbohydrate.

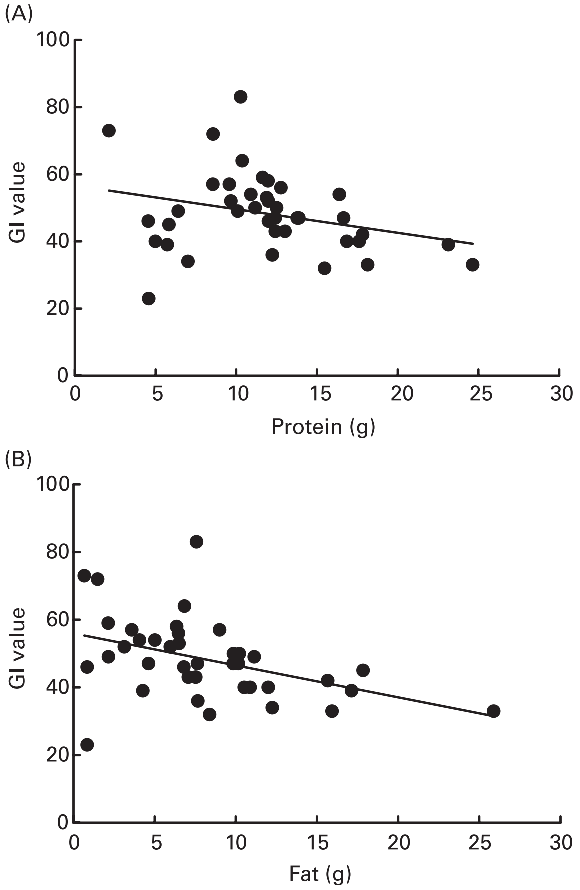

Fig. 2. Relationship between the glycaemic index (GI) value and the amount of protein (A) and fat (B) per 50 g available carbohydrate portion in all foods tested.

process. This therefore reconfirms the need to test food products in the country of consumption.

The weight-management meals were mostly low GI. There is considerable interest in the potential of low-GI foods for the management of obesity (Warren *et al.* 2003), and such products may play an important role in body-weight regulation. With the increasing consumption of weight-management meals in our society, the current GI table will enable consumers and researchers alike to select low-GI foods for their respective needs.

In the current study, ‘mixed meal’ testing of breakfast cereal with milk was conducted, in contrast to standard GI testing for breakfast cereals per se. Given the practical nature of GI, food companies, industry and individuals now want to know the GI values of food as eaten. The results from our study suggest that the addition of semi-skimmed milk to breakfast cereals may reduce the GI value. It is now well recognised that the low glycaemic response to milk does not solely depend on its lactose content. Milk protein has a strong insulinotropic effect (Nilsson *et al.* 2004). Consequently, when testing foods with the addition of milk, the role that milk proteins play may also need to be considered. Casein and whey proteins are rich sources of leucine and phenylalanine. Leucine in particular has been shown to promote insulin secretion by simulating β-cell function (van Loon *et al.* 2000). The results obtained from our study may be interpreted

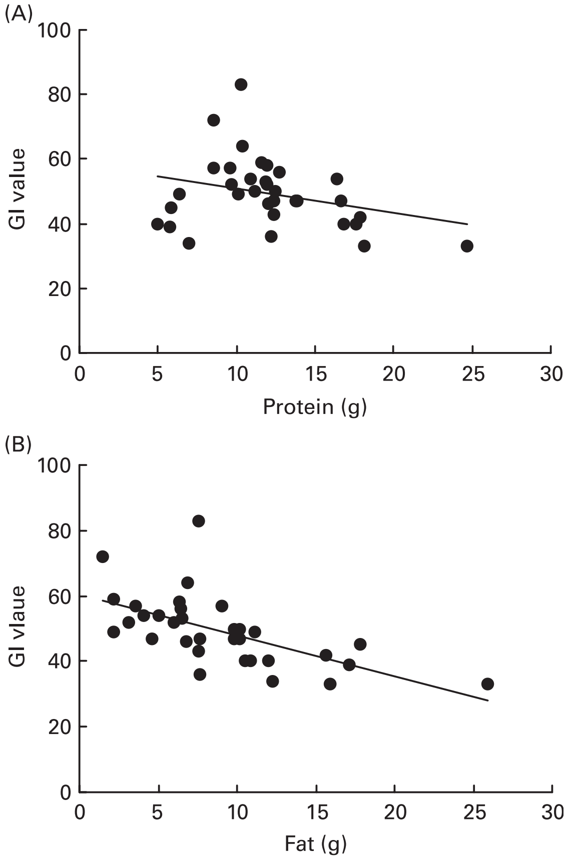

Fig. 3. Relationship between the glycaemic index (GI) value and the amount of protein (A) and fat (B) per 50 g available carbohydrate portion, excluding weight-management meals.

on the basis of the above observations. The co-ingested milk protein stimulated insulin production, which in turn facilitated glucose utilisation, leading to a lower GI value. Further investigations on the association between GI and lactose and fructose would be of interest.

The presence of large amounts of fat and protein may also reduce the GI of a food (Wolever *et al.* 1994). It is generally accepted that fat may lower the postprandial glucose response by delaying the rate of gastric emptying (Owen & Wolever, 2003). It has also been speculated that lipids may bind with the amylose fraction of starch, rendering it less susceptible to amylase (Siswoyo & Morita, 2001). Protein increases the amount of insulin secreted, causing blood glucose levels to be less affected, and may also form a protective network around the carbohydrate molecule, preventing the action of glycolytic enzymes (Bornet *et al.* 1987). In the present study, although an effect of protein and fat was not observed across the entire group of foods, there was a strong negative association with fat content when the weight-management meals (i.e. lower-fat foods) were excluded. Therefore, this does not rule out the fact that the GI value of individual products may be determined by their protein and fat content.

Many of the products presented in the current paper are a result of a simple reformulation and alteration of processing conditions by food manufacturers to reduce the glycaemic response of the food; for example, a reformulated white bread in our study had a GI value of 59 compared with a GI value of 70 for standard white wheat flour bread (Foster-Powell *et al.* 2002). This confirms the view that the demand for and interest in low-GI foods is an adequate stimulus for the food industry to develop such foods.

In conclusion, the present paper provides reliable GI and GL values for a range of different foods and mixed meals consumed in the UK, further advancing our understanding of the glycaemic response of different foods. The data reported here make an important addition to published GI values, enabling consumers to have a wider range and selection of low-GI foods to choose from.

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