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Contributors to dietary glycaemic index and glycaemic load in the Netherlands: the role of beer

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Abstract

Diets high in glycaemic index (GI) and glycaemic load (GL) have been associated with a higher diabetes risk. Beer explained a large proportion of variation in GI in a Finnish and an American study. However, few beers have been tested according to International Organization for Standardization (ISO) methodology. We tested the GI of beer and estimated its contribution to dietary GI and GL in the Netherlands. GI testing of pilsner beer (Pilsner Urquell) was conducted at The University of Sydney according to ISO international standards with glucose as the reference food. Subsequently, GI and GL values were assigned to 2556 food items in the 2011 Dutch food composition table using a six-step methodology and consulting four databases. This table was linked to dietary data from 2106 adults in the Dutch National Food Consumption Survey 2007–2010. Stepwise linear regression identified contribution to inter-individual variation in dietary GI and GL. The GI of pilsner beer was 89 (SD 5). Beer consumption contributed to 9·6 and 5·3 % inter-individual variation in GI and GL, respectively. Other foods that contributed to the inter-individual variation in GI and GL included potatoes, bread, soft drinks, sugar, candy, wine, coffee and tea. The results were more pronounced in men than in women. In conclusion, beer is a high-GI food. Despite its relatively low carbohydrate content (approximately 4–5 g/100 ml), it still made a contribution to dietary GL, especially in men. Next to potatoes, bread, sugar and sugar-sweetened beverages, beer captured a considerable proportion of between-person variability in GI and GL in the Dutch diet.

Key words: Glycaemic index: Glycaemic load: Beer: Diet: Dietary patterns: Inter-individual variation

The glycaemic index (GI) was introduced in 1981 as a means of classifying carbohydrate-rich foods according to their effect on glucose levels[1]. A food's glycaemic effect is derived from the body's glucose response to the food. As such, the GI is a property of foods that is measured in humans[2]. In the total diet, the importance of an individual food's GI is quantified by its overall contribution to carbohydrate intake. The glycaemic load (GL) expresses the amount of carbohydrates consumed multiplied by its GI[3]. In epidemiological studies, diets high in GI and/or GL have been associated with an increased risk of developing type 2 diabetes[2,4]. However, the association appears to be more pronounced in women than in men[5].

When studying GI and GL at a population level, it is important to know which food items contribute to the total GI and GL of the diet. Food items that contribute most to the absolute dietary GI are those that have a high GI and/or foods that contribute a greater proportion of the total amount of carbohydrates eaten – that is, are eaten most often and/or in larger amounts[6]. Furthermore, food items that capture most inter-individual variation are able to rank persons according to their dietary GI or GL. These foods do not necessarily have a high GI, but may also be markers of a high- or low-GI diet. Several studies have identified food items contributing to the absolute dietary GI and GL and inter-individual variation in GI and GL. Across several countries and populations, these foods mainly include carbohydrate-rich foods – for example, bread, potatoes, pasta, rice, cereals, dairy products, fruits, vegetables and sugar-containing foods and drinks[7–11].

Two studies have shown that beer consumption contributed to the inter-individual variation in dietary GI. Together with dairy products, potatoes, bread, cereals and fruits, beer contributed the most to the inter-individual variation in GI of 1071 US adults. Beer contributed to 30 % of the variation in men and to 5 % in women[6]. Beer and milk captured most between-individual variation of GI in 25 943 male participants from a large Finnish intervention study. In this study, beer contributed

Abbreviations: GI, glycaemic index; GL, glycaemic load.

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to 41 % of the inter-individual variation[12]. This may be due to the higher GI of beer, but it may also be that persons with a higher beer intake also have in general a higher consumption of high-GI foods. Thus, in the Netherlands, it has previously been observed that persons who preferred beer also consumed more high-GI foods such as potatoes and bread[13].

Despite the potential substantial contribution of beer to dietary GI and GL, a valid GI value for beer is still lacking in the scientific literature. Several GI values have been reported, ranging from 0 to 119. A GI of 119 is the only published value determined following the standard research methodology[14]. In this study, the GI of Nikolai Lager (4·5 % alcohol by volume) was determined. In the Netherlands, beer is a regularly consumed alcoholic beverage, of which pilsner is the most consumed type[15]. In 2015, 67 % of the Dutch adult men and 28 % of the Dutch adult women reported to consume beer at least once a month[16]. Therefore, the objective of this study was to provide a reliable estimate of the GI of pilsner beer. Moreover, our aim was to estimate the contribution of beer and all other foods to the absolute level of dietary GL and to the inter-individual variation of dietary GI and GL in the Dutch diet.

Methods

Glycaemic index testing of pilsner beer

The GI testing was performed by the Sydney University's Glycemic Index Research Service (SUGiRS) and conducted according to the internationally recognised GI methodology[17,18]. The experimental procedures were in accordance with international standards for conducting ethical research with humans and were approved by the Human Research Ethics Committee of Sydney University. The GI of Pilsner Urquell beer (4·4 % alcohol by volume; Plzeňský Prazdroj, A.S.) was determined using pure glucose sugar (Glucodin® powder; Boots Health Care Company) as the reference food. The brand of Pilsner Urquell was chosen because of its availability in Australia and the Netherlands. It was assumed that the nutritional composition between different brands of pilsner beers do not differ significantly.

A group of ten healthy, non-smoking persons, aged between 18 and 65 years, were recruited from the staff and student population of the University of Sydney. People volunteering to participate in the study were excluded if they were overweight or underweight, were dieting, had impaired glucose tolerance, were suffering from any illness or food allergy or were regularly taking prescription medication other than standard contraceptive medication.

A total of three men and seven women, Caucasian, with a mean age of 31·7 years and mean BMI of 23·7 kg/m^2 (range 21·4–25·0 kg/m^2) were included in the study. The reference food and the pilsner beer were served to the subjects in fixed test portions containing 25 g of digestible carbohydrate. A dose of 25·7 g pure glucose sugar dissolved in 250 g water was consumed by each subject on three separate occasions. Subjects consumed 554·3 g of the test beer on one occasion only. This amount was calculated according to the total carbohydrate content as displayed on the food label. During these occasions, two fasting finger-prick blood samples were obtained following an overnight fast. After the second fasting sample (0 min) was obtained, subjects were given the fixed portion of the test or reference food, which they consumed with 250 ml of water within 12 min. Additional blood samples were collected at 15, 30, 45, 60, 90 and 120 min after consumption. Glucose concentration of each subject's eight plasma samples was analysed in duplicate using a glucose hexokinase enzymatic assay (Roche Diagnostic Systems).

A 2-h plasma glucose response curve was constructed for each subject's test sessions using the average glucose concentrations for each of their plasma samples. The incremental area under the 2-h plasma glucose curve (iAUC) was calculated. A GI value for the Pilsner Urquell beer was then calculated for each subject by dividing their 2-h glucose iAUC value for the test product by their average 2-h plasma glucose iAUC value for the reference food and multiplying it by 100.

Glycaemic index and glycaemic load food composition table

On the basis of the six-step methodology for assigning GI values as suggested by Louie *et al.*[19], GI values were assigned to 2556 food items in the 2006 and 2011 Dutch food composition database[20]. All GI values were expressed on the glucose scale. In Step 1, foods with <2·5 g available carbohydrates/100 g were assigned a GI of 0. In Step 2, GI values were assigned for foods with a direct match in the databases consulted in the following order: (1) the 'International table of glycemic index and glycemic load values'[21], (2) the SUGiRS online database[22], (3) the Dutch GI table as prepared within the DiOGenes project[7,23] and (4) a study of Chinese foods by Chen *et al.*[24]. In this step, all beers were assigned a GI value of 89. When there was no direct match, GI values of closely related food items were assigned in Step 3. In Step 4, the weighted average GI values of the components of mixed meals were assigned regardless of the availability[2]. In Step 5, the median GI of the corresponding food group was assigned. Finally, in Step 6, foods that were not significant sources of carbohydrates in portions normally consumed in diets were assigned a GI of 0. In this study, all herbs and spices, miscellaneous and dietetic products were assigned a GI of 0. Moreover, unprocessed flours and powders were assigned a GI value of 0. The GI of these products – for instance, rice flour or custard flour – has not been tested. These food codes were not consumed as such, and the GI value would be largely determined by its processed form. These food items were not used in Step 4. The number of products assigned GI values according to this stepwise methodology as well as the median GI and GL of the food group are shown in Table 1.

Dutch National Food Consumption Survey 2007–2010

The Dutch National Food Consumption Survey 2007–2010 was conducted among children and adults aged 7–69 years in the Netherlands and aimed to gain insight into the Dutch diet[15]. Data were collected from March 2007 to April 2010 by means of age-specific general questionnaires and two non-consecutive

Table 1. Foods with glycaemic index (GI) and glycaemic load (GL) assigned at each step*
(Numbers, medians and 25th–75th percentiles (P25–P75))

	Step 1	Step 2	Step 3	Step 4	Step 5	Step 6	Total	GI		GL	
Food groups	*n*	*n*	*n*	*n*	*n*	*n*	*n*	Median	P25–P75	Median	P25–P75
Alcoholic beverages	10	5	3	2	17	0	37	0	0–0	0	0–0
Bread	0	35	39	21	6	0	101	67	53–73	30	22–43
Cake and cookies	0	66	61	57	26	0	210	59	54–63	33	24–39
Cereals	1	54	11	1	10	27	104	49	0–68	30	0–45·5
Cheese	57	4	3	0	0	0	64	0	0–0	0	0–0
Dairy products	1	119	22	17	37	3	199	34	31–36	4	2–6
Dietetic products	6	3	7	0	0	161	177	0	0–0	0	0–0
Eggs	6	0	0	0	0	1	7	0	0–0	0	0–0
Fats, oils savoury sauces	102	3	12	0	129	0	246	0	0–0	0	0–0
Fish	72	2	6	0	4	0	84	0	0–0	0	0–0
Fruit	2	55	24	0	9	5	95	45	42–61	7	4–10
Herbs and spices	4	0	0	0	0	48	52	0	0–0	0	0–0
Legumes	0	15	0	0	0	0	15	32	22–37	8	4–16
Meat	199	2	34	0	25	0	260	0	0–0	0	0–0
Miscellaneous	12	0	0	1	0	16	29	0	0–0	0	0–0
Mixed dishes	1	37	15	16	1	6	76	52	42–80	9	4–18
Non-alcoholic beverages	39	41	163	0	0	3	246	66	43–66	5	2–7
Nuts and seeds	0	12	11	0	2	0	25	24	21–24	3	2–6
Potatoes and tubers	0	32	22	0	0	2	56	71	64–87	14	10–18
Savoury sandwich toppings	0	2	5	0	0	0	7	23	23–45	6	3–7
Snacks	0	22	22	8	17	0	69	56	45–56	20	8–34
Soups	11	16	5	0	0	0	32	45	0–57	2	0–3
Soya and vegetarian products	5	1	10	0	25	6	47	15	15–15	1	0–2
Sugar and confectionery	2	26	56	18	11	0	113	51	41–65	33	23–52
Vegetables	71	57	47	7	22	1	205	0	0–45	0	0–2
Total	601	609	578	148	341	279	2556	31	0–56	2	0–13

* Step 1: foods with <2·5 g available carbohydrates/100 g were assigned a GI of 0; Step 2: direct match in one of the four consulted databases; Step 3: GI value of a closely related food item; Step 4: for mixed meals, the weighted average GI of the components were assigned; Step 5: the median GI of the corresponding food group was assigned; Step 6: foods that were not significant sources of carbohydrates were assigned a GI of 0.

24-h dietary recalls. The survey population was representative with respect to age and sex and within each age group, region, degree of urbanisation and educational level. All persons living in the Netherlands were eligible for inclusion, except for pregnant and lactating women, institutionalised persons or persons with insufficient knowledge of the Dutch language. In total, 5502 people were invited, of which 3819 agreed to participate. For the present study, 2106 adults aged 19 years and older were included.

The two 24-h recalls were obtained within an interval of 2–6 weeks; the recalls were spread equally over days of the week and seasons. Food consumption from Sunday to Friday was recalled the next day, and consumption on a Saturday was recalled on the following Monday. The recalls were conducted by telephone using the computer-directed programme EPIC-SOFT[25,26]. Consumption data were linked to the GI food composition table. Dietary GL was calculated by multiplying the carbohydrate content of the reported food by the consumed quantity per day and its GI. The GL was summed for all reported foods, after which dietary GI was calculated as the dietary GL divided by the total carbohydrate intake.

Statistical analysis

All statistical analyses were performed with SAS, version 9.3, software (SAS Institute Inc.). For GI testing, ANOVA and the Fisher's protected least significant differences *post hoc* test for multiple comparisons were used to determine whether there was a difference between the GI values of the test beverage and the reference food.

In contrast to nutrients, the GI of foods does not vary with the consumed quantity. Therefore, it was not possible to derive the absolute contribution of all food items to dietary GI. The GL does take into account the consumed amount of carbohydrates; therefore, the GL was used for calculating the percentage absolute contribution of all 2556 food items to dietary GL. Second, stepwise linear regression was used to estimate the contribution of the food items to the inter-individual variation in dietary GI and GL. Two regression models, one for GI and one for GL, were specified, where dietary GI or GL was the dependent variable and all food items were independent variables. These analyses were not adjusted for covariates.

Dietary GI and GL, including and excluding beer, were calculated across categories of alcoholic beverage preference. A person was classified as having a beer, wine or spirit preference when the average number of glasses of the respective drink comprised 70 % or more of the total number of glasses. When the average number of glasses of beer, wine or spirits did not add up to 70 %, the person was classified as having no preference[13]. Dietary GI and GL were adjusted for age, sex, BMI, smoking status (never, former, current), educational level (low, medium, high), physical activity, energy, total alcohol consumption (average number of glasses per day) and

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drinking frequency and weighted for demographic factors, seasons and day of the week.

Results

Glycaemic index and glycaemic load of pilsner beer

Fig. 1 displays the average plasma glucose response curves for the equal carbohydrate portions of both the reference food and the pilsner beer. There was normal variation in glucose response and resulting GI values among the subjects, with no outliers. The final mean GI value for Pilsner Urquell was 89 (SD 5). The reference food's GI value was significantly greater than the average GI value produced by Pilsner Urquell ($P < 0.05$).

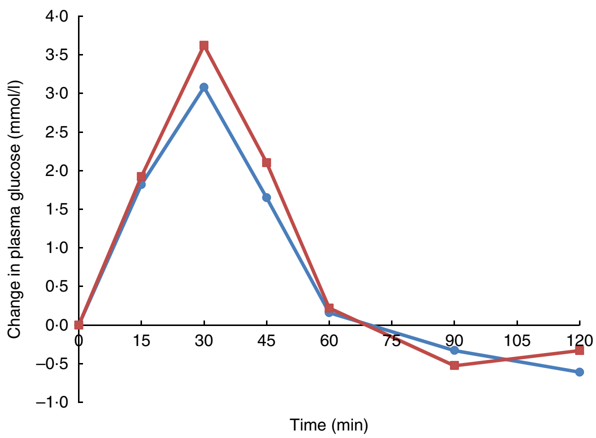

Fig. 1. Average plasma glucose response curves for the equal carbohydrate portions of the reference food and the pilsner beer, shown as change in plasma glucose from fasting baseline level. —●—, Pilsner Urquell; —■—, glucose.

According to the Dutch food composition table, 100 ml of pilsner beer contains 3·1 g of digestible carbohydrate, resulting in a GL of (3·1 × 89)/100 = 3 g/100 ml and 9 g/330 ml serving.

Absolute contribution of pilsner beer to dietary glycaemic load

Foods with the highest absolute contribution (%) to the dietary GL among 2106 adults from the Dutch National Food Consumption Survey 2007–2010 included the following: potatoes (8·5 %), wheat bread (7·9 %), white bread (5·4 %), whole-grain bread (4·2 %), table sugar (3·1 %), multigrain bread (2·8 %), white rice (2·5 %), cookies (2·5 %), beer (2·4 %) and white pasta (2·4 %). Results were similar for men and women, except that beer and cola contributed more to the dietary GL of men and bananas had a higher contribution among women.

Contribution to inter-individual variation in dietary glycaemic index and glycaemic load

Foods that contributed to ≥1 % of the total inter-individual variation in dietary GI and GL, as revealed from a stepwise linear regression, are listed in Tables 2 and 3, respectively. Foods that contributed most to the inter-individual variation in GI included potatoes, beer, wheat bread, white bread, wine, and coffee and tea (Table 2). In men, beer contributed more to the variation than in women (9·9 *v.* 3·2 %), whereas in women wine contributed more to the variation compared with men (8·0 *v.* 2·3 %). With respect to the contribution to GL, beer took the fourth place with an explained variance of 5·3 %, after sugar, cola and wheat bread (Table 3). Sex-specific stepwise linear regression showed that sugar, wheat bread and beer explained

Table 2. Foods that contributed to ≥1·0 % of the inter-individual variation in dietary glycaemic index (GI) in 2106 men and women from the Dutch National Food Consumption Survey 2007–2010

All (*n* 2106)			Men (*n* 1055)			Women (*n* 1051)		
Product name	GI	%	Product name	GI	%	Product name	GI	%
Potatoes, boiled	96	9·6	Potatoes, boiled	96	10·4	Potatoes, boiled	96	12·5
Beer, pilsner	89	9·6	Beer, pilsner	89	9·9	Wine	0	8·0
Wheat bread	74	6·0	Whole-grain bread	54	5·4	Wheat bread	74	4·9
White bread	75	5·8	Wheat bread	74	4·5	Dietetic products	0	3·6
Wine	0	4·2	White bread	75	4·2	White bread	75	3·6
Coffee/tea	0	3·4	Apple	39	3·1	Beer	89	3·2
Dietetic products	0	2·8	French fries, pre-fried	64	3·1	Coffee/tea	0	2·9
White pasta, boiled	46	2·4	Coffee/tea	0	2·8	White pasta, boiled	46	2·6
Milk, semi-skimmed	30	2·1	Dietetic products	0	2·7	Dough for pizza and savoury pie	72	2·2
Apple	39	1·9	Milk, semi-skimmed	30	2·3	Tomato	45	1·9
Candy, liquorice	78	1·6	Wine	0	2·3	Milk, semi-skimmed	30	1·7
Yogurt drink	34	1·6	Dough for pizza and savoury pie	72	1·6	Candy, liquorice	78	1·6
Potatoes, sliced, fried	98	1·5	Savoury sauces	0	1·5	Water	0	1·5
Dough for pizza and savoury pie	72	1·3	Liqueur	0	1·4	Japanese rice snacks	87	1·5
Liqueur	0	1·2	Chocolate sandwich spread	25	1·4	French fries, pre-fried	64	1·5
Whole-grain bread	54	1·2	Chocolate, dark	23	1·3	Chocolate, dark	23	1·3
Chocolate sandwich spread	25	1·1	White pasta, boiled	46	1·1	Pear	38	1·1
Yogurt	31	1·1	Yogurt drink	34	1·1	Meat (different types)	0	1·0
Savoury sauces	0	1·0	Dietetic shake and soup	35	1·1			
			Candy, liquorice	78	1·1			
			Nuts	14	1·1			
			Cider	0	1·0			

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Table 3. Foods that contributed to >1·0 % of the inter-individual variation in dietary glycaemic load (GL) in 2106 men and women from the Dutch National Food Consumption Survey 2007–2010

All (n 2106)			Men (n 1055)			Women (n 1051)		
Product name	GI	%	Product name	GI	%	Product name	GI	%
Table sugar (sucrose)	65	12·3	Table sugar (sucrose)	65	11·2	Fruit drink	66	9·7
Cola	58	9·2	Cola	58	8·3	Cola	58	9·0
Wheat bread	74	5·4	Soft drinks, fruit lemonade	59	6·7	Soft drinks, fruit lemonade	59	6·8
Beer, pilsner	89	5·3	Candy, liquorice	78	5·9	Table sugar (sucrose)	65	6·5
Soft drink, fruit lemonade	59	4·8	Wheat bread	74	4·9	Sport drink	70	5·1
Candy, liquorish	78	4·6	Beer, pilsner	89	4·2	Candy, liquorice	78	4·6
White bread	75	3·9	White bread	75	4·1	Ice cream	57	4·2
White rice, boiled	72	2·6	White rice, boiled	72	3·0	Crisps	56	4·1
Ice tea	49	2·2	Potatoes, boiled	96	2·8	Banana	60	3·6
Potato crisps	56	2·2	Mayonnaise	0	2·4	Wheat bread	74	3·6
French oven fries, pre-fried	64	2·2	Dough for pizza and savoury pie	72	2·1	Syrup	63	2·6
Potatoes, boiled	96	2·0	Crisps	56	2·0	Potatoes, boiled	96	2·2
White baguette, hard roll	57	1·9	Energy drink	70	2·0	White baguette, hard roll	57	2·1
Dough for pizza and savoury pie	72	1·8	Banana	60	1·7	White bread	75	2·1
Banana	60	1·7	White baguette	57	1·2	White rice, boiled	72	1·9
Energy drink	70	1·3	Ice tea	49	1·2	Japanese crackers	87	1·5
Potato, sliced, frozen	98	1·2	Multigrain bread	57	1·1	Dough for pizza and savoury pie	72	1·5
White pasta, boiled	46	1·2	Fruit drink	66	1·0	Dutch spiced cake ('ontbijtkoek')	63	1·3
Fruit drink	66	1·1	Fruit biscuit	77	1·0	Jam	51	1·1
Jam	51	1·0	Whole-grain bread	54	1·0	White bread (Turkish)	87	1·0
Pancake	80	1·0	French oven fries, pre-fried	64	1·0	Fruit biscuit	77	1·0
			Dutch spiced cake ('ontbijtkoek')	63	1·0	White bread	75	1·0

Table 4. Dietary glycaemic index (GI) and glycaemic load (GL) in 2106 adults from the Dutch National Food Consumption Survey 2007–2010 according to alcoholic beverage preference†
(Numbers and percentages; mean values with their standard errors)

	Beer preference		Wine preference		Spirit preference		No preference		Non-consumers	
	n	%	n	%	n	%	n	%	n	%
	387	18	384	18	109	5	575	27	651	31
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
GI	58·5	0·3	54·1	0·3*	56·7	0·6*	56·0	0·2*	56·3	0·2*
GI excluding beer	53·8	0·3	53·7	0·3	55·9	0·6*	54·7	0·2	55·2	0·3*
GL	151	3	132	3*	152	5	143	2	143	2
GL excluding beer	140	3	131	2	150	5	140	2	140	2

* $P < 0.05$ compared with beer preference.
† Intakes are adjusted for age, sex, BMI, smoking status, educational level, physical activity, energy, total alcohol consumption (average number of glasses per day) and drinking frequency and weighted for demographic factors, seasons and day of the week.

more inter-individual variation in men than in women. In women, fruit drinks and sport drinks contributed more to the variation in dietary GL than their counterparts.

Alcoholic beverage preference and dietary glycaemic index and glycaemic load

Table 4 shows the mean dietary GI and GL across categories of alcoholic beverage preference, including and excluding beer from the measurement. Persons with a beer preference had the highest dietary GI compared with the other preference categories, after adjustment for socio-demographic and lifestyle factors as well. When beer was excluded from the GI measurement, those with a beer or wine preference had the lowest dietary GI. Differences in dietary GL between the alcoholic beverage preference groups were smaller than that for dietary GI. Crude means and differences were similar to the adjusted values (data not shown).

Discussion

The GI value of pilsner beer, as determined according to the internationally recognised GI methodology, was 89 (SD 5). Although the GI has been commonly regarded as a property of high carbohydrate foods, beer can be categorised as a high-GI food despite its relatively low carbohydrate content/100 ml. Within the Dutch diet, beer had a considerable contribution both to the absolute GL and to the inter-individual variation in GI and GL, especially in men. The high dietary GI and GL of beer consumers was mostly driven by the GI of beer, indicating that it was not simply a marker of a high-GI diet.

Other important contributors to dietary GI and GL were potatoes, bread, sugar, soft drinks and candy.

Foods that contributed to the absolute dietary GI included carbohydrate-rich foods, but also products with a relatively low GI that are consumed in high amounts, such as semi-skimmed milk. Next to starchy foods, foods high in sugar such as sweets and sugar-sweetened beverages contributed to the inter-individual variation in dietary GI and GL. Furthermore, low-GI foods including wine, coffee and tea also contributed to the inter-individual variation in dietary GI. This confirms that foods that capture most inter-individual variation do not necessarily have a high GI, but may also be markers of a high- or low-GI diet. Therefore, we have additionally calculated dietary GI and GL, across categories of alcoholic beverage preference, including and excluding beer from the calculations. The results indicated that the dietary GI of persons with a beer preference is indeed mostly driven by the consumption of beer rather than other high-GI foods. The differences in dietary GL between the alcoholic beverage preference groups were smaller than that for dietary GI, which was probably due to the low carbohydrate content of beer.

As a reliable GI value for beer has been lacking in scientific literature, several studies have assigned different GI values to beer. In DiOGenes, a GI value of 61 was assigned to beer, liquors and cocktails, which is similar to that of sucrose, and a value of 0 to other alcoholic beverages[27]. In unpublished observations of SUGiRS, a GI value of 66 for Toohey New Draft (4·6 % alcohol by volume) was found, using a non-standard portion of 10 g carbohydrates[28]. In contrast, Schulz *et al.*[6] assigned a value of 95 to beer because of its starch content and a value of 61 to wine and other alcoholic beverages. Simila *et al.*[12] also assigned a high value to beer. The only reliable GI value that is published is a GI of 119 for Nikolai Lager (4·5 % alcohol by volume) as tested by Hätönen *et al.*[14]. Compared with this study, the present study tested three glucose solutions instead of two to minimise within-person variability. However, as the GI cannot easily be predicted and variations within food groups may exist[2], the difference in GI might be due to the nutritional composition of different types of beer. Nikolai Lager contained slightly more carbohydrates than pilsner beer – that is, 4·9 g/100 ml *v.* 4·5 g/100 ml. However, this should not necessarily explain the higher GI value, as the test portion takes into account differences in available carbohydrates. Nikolai Lager may contain different types of carbohydrates or small differences in alcohol percentage or pH that may influence the GI. Nevertheless, both Hätönen *et al.*[14] and the present study classify beer as a high-GI food.

Several experimental studies have shown that ethanol acutely impairs insulin sensitivity due to delayed gastric emptying[29]. Hätönen *et al.*[14] observed an 18 % increase in 2-h glucose after a glucose solution with alcohol; 2-h glucose was lower after non-alcoholic beer, but consumption of beer and alcohol in the glucose solution gave similar responses[14]. It appears that alcohol may catalyse the breakdown of the complex carbohydrates, causing the high GI of beer. Brand-Miller *et al.*[28] confirmed these results and showed that beer produced higher glucose scores than wine and gin compared with white bread.

The high GI of beer might be caused by its complex carbohydrate content, rather than due to monosaccharides or disaccharides. In the brewing process, a mixture of amylases breaks down starch to glucose, maltose, maltotriose and higher saccharides including maltodextrins. Yeast ferments glucose and maltose to ethanol, but cannot break down all maltodextrins. Thus, beer does not contain any significant amounts of maltose or other sugars, but it can contain maltodextrins[30]. Hätönen *et al.*[14] also tested the nutritional composition of their beer: a portion of 25 g contained 16 g starch, 0·03 g maltose and 9 g maltooligosaccharides[14]. According to the Dutch food composition table, pilsner beer does not contain any maltose or other monosaccharides and disaccharides, but it does contain polysaccharides including starch[20]. In contrast, different types of beer including stout, ale and lager were assigned maltose values ranging from 0 to 6·10 g/100 g in the food composition tables of McCance and Widdowson's (UK) and the food composition table from Finland[31,32]. In addition, these beers contained only small amounts of glucose, fructose and sucrose and did not contain any starch. It remains unclear whether the soluble starch molecules or maltodextrins are responsible for the high GI of beer. Moreover, it is not known whether other types of beer with different carbohydrate composition will have the same GI, even though all might be classified as high-GI foods.

Although diets high in GI and GL have been associated with increased type 2 diabetes risk[5,33], moderate alcohol consumption is related to a lower risk of diabetes[34]. Some studies have found differential effects for the type of alcoholic beverage, leaning towards a more favourable association for wine consumption on diabetes risk[35–37]. In contrast, several other large observational studies have observed no beneficial effect of wine over beer or spirit consumption[38–40]. It has been argued that the largest part of the beneficial effect of moderate alcohol consumption on diabetes risk is most likely due to ethanol itself and that any beverage-specific effects are due to (residual) confounding[35]. Furthermore, Brand-Miller *et al.*[28] observed that when consumed with or before a carbohydrate meal, beer tended to reduce postprandial glycaemia. Therefore, the difference between GI and glycaemic response of beer may also play a role[2]. As alcoholic beverages are often consumed together with a meal, the glycaemic response of beer consumed together with a meal might be more important to consider for diabetes risk than the GI itself.

Next to beer, other products that contributed to the absolute dietary GL and the inter-individual variation in dietary GI and GL included carbohydrate-rich foods such as potatoes, breads, rice, pasta, sweets and sugar-sweetened beverages. These findings are in line with other epidemiological studies assessing the contribution of foods to GI and GL. Several investigations from different countries in Europe, USA, Australia and Asia identified cereals, breads, pasta, rice, potatoes, dairy products, fruits, juices, vegetables, sugar and sugar-containing foods as main contributors to the dietary GI and GL[8,10,11,41–43]. Most of these observational studies have calculated dietary GI and GL with a general FFQ, which might not be able to specify between all low- and high-GI food items within the same food group. To estimate the absolute contribution as well as the contribution to inter-individual variation is a common method to select informative foods for a FFQ[44]. Indeed, the food items that have been identified in the present study will be used to develop a dedicated FFQ to assess dietary GI and GL. This FFQ will be developed and validated within the framework of the PREVention of diabetes through lifestyle intervention and population studies in Europe and around the World (PREVIEW) project.

In conclusion, the present study provides a reliable GI value for pilsner beer and describes the development of a GI table for the Netherlands according to a standardised methodology. Next to potatoes, bread, sugar-sweetened beverages, candy, wine, and coffee and tea, beer captured a large proportion of between-person variability in GI and GL in the Dutch diet. Thus, beer consumption should be considered when studying dietary GI and GL.

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