TYPES OF CARBOHYDRATES AND THEIR ROLE IN MAINTAINING THE GLYCEMIC CONTROL

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Abstract

Diet has an extremely important role in the postprandial glycemic response, which is determined both by the quantity as well as the quality of the ingested carbohydrates (HC). The effect of food ingestion on glycemia is assessed using the glycemic index (GI) and the glycemic load (GL). GI determines the quality of HC, while GL determines both the quality and quantity of HC. GI is influenced both by factors that are related to food as well as by factors related to consumers. The diet with low GI and low GL reduces the risk of cardiovascular disease and DZ type 2, improving the glycemic control, the sensibility to insulin, the lipid profile and the weight control. It is also a protective factor against colon and breast cancer.

Key words: *glycemic response, glycemic index (GI), glycemic load (GL).*

Food contains simple glucids (mono- and oligosaccharides), as well as complex glucids (polysaccharides) (1).

Types of carbohydrates (HC) found in food, as they are used by USA producers to label food (Table 1):

Table 1. Classification of HC and terminology (OMS and *Food and Agriculture Organization of the United Nations*-Rome, 1998) (2)

Classification major HC of the diet, based on polimerisation degree and subgroups	Components	Signalling of HC on labels in USA
Saccharides(1–2 molecules)		
Monosaccharides	Glucoses, fructose, galactose	Sweeteners
Disaccharides	Sucrose, Lactose	Sweeteners
Polyols (alcoholic sweets)	Sorbitol, mannitol, xylitol, isomalt, maltitol, lactitol, hydrolyzed by hydrogen amidone	Sugar alcohol
Oligosaccharides (3–9 molecules)		
Malt oligosaccharides	Maltodextrin	Other HC
Other oligosaccharides	Raffinose, Stachiose, Fructoligosaccharides	Other HC
Polysaccharides (>9 molecules)		
Starch	Amylose, amylopectin, modified amidones	Other HC
Fibers (non-starch polysaccharides)	Cellulose, hemicelluloses, pectins, hydrocolloids	Food fibers

Most glucids used in human food are found under the shape of starch.

Starch sources: potatoes, cereals and derivates (3). Saccharose is found in sugar and its derivates, while lactose in milk and dairy products (3). Fructose and glucose are monosaccharides present in fruits and honey (3).

The glycemic response is determined both by the quantity, as well as the quality of ingested HC (4). In the case of natural food consumption, there are no major differences of postprandial glycemia related to the content in simple glucids (fruits, milk) and complex glucids (pasta, rice) (1). Although some aliments have the same quantity of HC, the glycemic level after the ingestion of each food is very different (10). In the alimentation of diabetes patients, for example, it is not recommended the consumption of simple glucids, such as glucose, since they produce high glycemic increases, recommending the predominant consumption of complex glucids, which are more slowly digested and absorbed, thus avoiding brutal increases of glycemia (1, 2). The quality of HC in food is given by the glycemic index (GI), while the glycemic load (GL) assesses both the quality and quantity of HC. GI and GL show the effect of food ingestion on glycemia (4, 5).

In order to explain the postprandial glycemic response determined by equiglucid quantities (50 g) from various foods, GI was elaborated, an indicator of HC capacity from the tested food to increase the glycemic level compared to the reference food (3, 6, 7, 8).

As reference foods there have been used glucose or white bread (in quantities equivalent to 50 g HC) and curves have been traced as result of glycemia determination, up to 2 hours obligatorily and up to 3 hours optional.

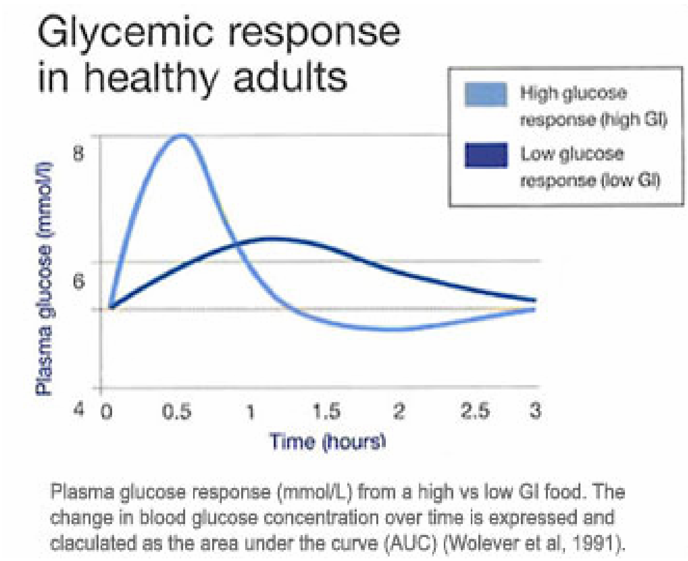
The testing of glycemic response at 3 hours is optional since the glycemic response is usually tested up to 2 hours (6, 7, 9). For the reference foods, the GI was considered as being 100%. Thus, each food has two values of GI (one by comparison with glucose, and the other by comparison with white bread). GI of different foods, others besides the reference food, represents the percent of the area under the glycemic curve (AUC = Area under a Curve) obtained by the measurement of glycemia up to 3 hours, after the ingestion of 50g HC both from the tested food as well as from the reference food (1, 6, 7).

If glucose is used as reference food (GI= 100), in order to convert from the index of glucose to that of white bread, the GI value for the tested food compared to glucose will be multiplied by 1.4 (4). If white bread is used as reference food (GI=100), in order to converse from the index of white bread to that with reference to glucose, the GI value for the tested food compared to white bread will be multiplied by 0.7 (4).

Example: When the white bread is the reference food (GI=100), the rye bread has GI=58 (see table 2). When glucose is the reference food (GI=100), the white bread has GI = 70, while the rye bread has GI=41 (58x0.7=41).

Here is a determining protocol of GI: minimum 10 healthy subjects receive a portion of glucose which contains 50 g HC and then its effect on the glycemic level is measured, by gathering simple blood (from the finger) every 15 minutes in the first hour, every 30 minutes in the second hour, and (optional) every 30 minutes in the third hour. For each subject, the curves are traced and the AUC of glycemic values is calculated. In other days, the same 10 subjects will consume other “testing food”, equivalents of 50g HC and the glycemic response will also be measured. The GI value of the tested food (%) is calculated for each subject, by dividing the AUC of the tested food to the AUC of the reference food and multiplying by 100. The final value of GI for the tested food is the average of the GI values for the 10 subjects (6, 9).

The glycemic curves for different foods differ, but not only as a surface of the area under the curve, but also as profile of the area, which should be known for each food recommended for diabetes for example (Figure 1).



Plasma glucose response (mmol/L) from a high vs low GI food. The change in blood glucose concentration over time is expressed and claculated as the area under the curve (AUC) (Wolever et al, 1991).

Figure 1. ***Gushers and Tricklers: Practical Use of the Glycemic Index*, American Diabetes Association, 2006 (6)**

In Romania, Prof. Dr. C. Ionescu Tirgoviste, was concerned with this field, making “tests at the table” with 25 g of HC of different origins, observing different increases of glycemic values (the sum of glycemia increase at 15, 30, 60, 90, and 120 min above the initial value) (Figure 2). These values were statistically significant in their large majority: glucose > fructose ($p < 0.02$); glucose > lactose, apple, potato, bread, rice, honey and carrots ($p < 0.01$); fructose > potato, bread, rice, honey and carrot ($p < 0.01$); fructose – lactose NS; lactose > apple ($p < 0,05$), potato ($p < 0,02$), bread, rice, honey, carrot ($p < 0,01$); apples > rice ($p < 0,05$); honey ($p < 0,02$); carrots ($p < 0,01$); apples–potatoes and honey–bread NS; potatoes–honey ($p < 0,02$), carrots ($p < 0,01$); potatoes–bread and potatoes–rice NS; bread > carrots ($p < 0,01$); bread–rice and bread–honey NS; rice > carrots ($p < 0,01$); rice–honey NS; honey > carrots ($p < 0,01$) (2, 3).

In figure 3 the comparative glycemic curves are presented after the ingestion of glucose, white bread, spaghetti, the authors metaphorically using the term of aspect of “gusher” for the curve of absorption of white bread compared to “trickler” for the GI of spaghetti.

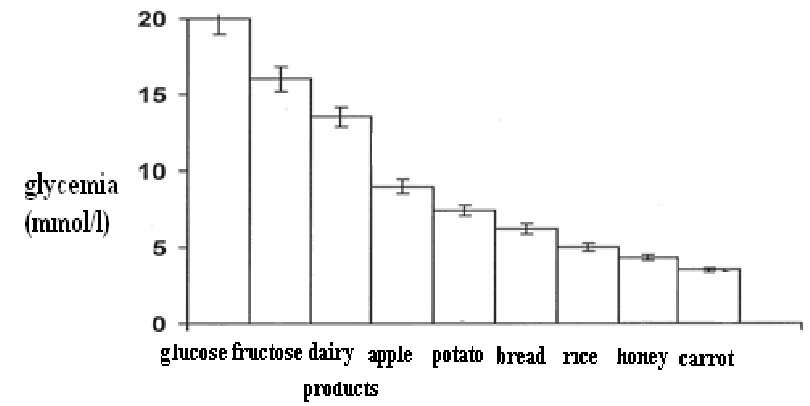
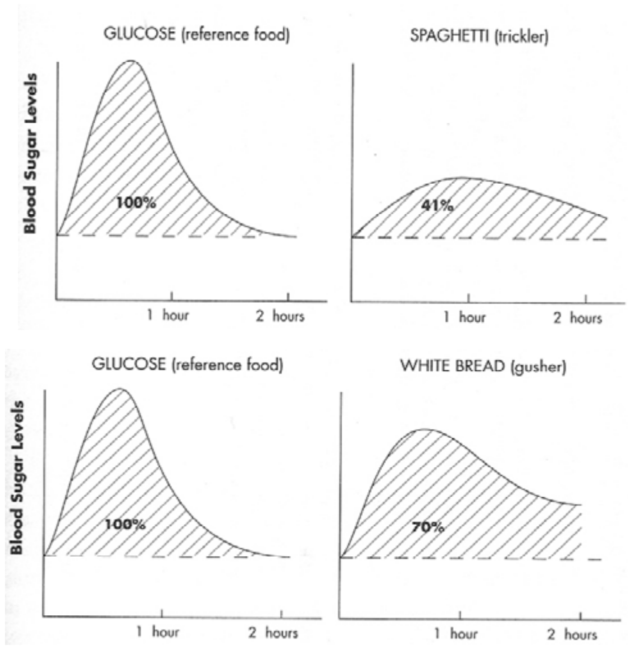


Figure 2 -modified after C. Ionescu Tirgoviste. The sum of glycemia increase at 15, 30, 60, 90 and 120 min above the initial value after the ingestion of 25 g HC of different origin



Adapted from *Good Carbs Bad Carbs* Reprinted courtesy of Marlowe & Company.

Figure 3- after Johanna Burani, *Gushers and Trickles: Practical Use of the Glycemic Index*, American Diabetes Association, 2006 (6)

According to GI (having as reference GI for glucose), foods are divided in:

- foods with high GI ≥70%
- foods with medium GI 56-69%
- foods with low GI ≤55% (5)

We hereby present GI of foods with reference to white bread and glucose (Table 2).

Table 2. The glycemic index of food (modified after Bantle, M.R. Harshman, W. Aldoori) (1, 10).

Food	GI (white bread GI=100)	GI (glucose GI=100)
Cereal derivates		
White bread	100	70
Whole bread	99	69,3
Rye bread	58	40,6
Off-corn flakes	106	74,2
Oat flakes	69	48,3
White rice	83	58,1
Roll	103	72,1
Spaghetti, macaroni	64	44,8
Salatini	103	72,1
Vegetables and fruit		
Boiled/ fresh carrots	85/35	59,5/24,5
Green peas	62	43,4
Freeze peas	74	51,8
Mashed potatoes	100	70
Fried potatoes	121	84,7
Sweet potato	74	51,8
Dry potatoes	116	81,2
New, boiled potatoes	81	56,7
Beans	62	43,4
Lentil	43	30,1
Plums	91	63,7
Apples	53	37,1
Bananas	79	55,3
Oranges	63	44,1
Grapefruit	36	17,17
Grapes	62	43,4
Pears	47	32,9
Melon	93	65,1
Dairy products		
Whole milk	43	30,1
Yoghurt with fruit	51	35,7
Yoghurt	20	14
Ice-cream	69	48,3
Appetizers		
Cola	93	65,1
Popcorn	79	55,3
Pretzels	119	83,3

Potato chips	80	56
Saccharides		
Glucose	138	96,6
Sugar	86	60,2
Fructose	30	21

Factors which influence GI

I. Factors related to foods

- HC concentration and their types: Foods which contain HC with rapid absorption have a high GI, determining rapid and significant increases of glycemia. Foods which contain HC with slow absorption have low GI, producing a gradual and insignificant increase of glycemia (9). Fructose is absorbed harder than glucose and it is transformed into glucose at the hepatic level, avoiding the postprandial glycemic increases (2). Potatoes have high GI, partially influenced by the preparing way (1). For patients with diabetes, pasta is preferred to potato (1). Some foods, though glucidic and caloric consistent, have a relatively low GI (beans, peas, lentil) (10). It has been noticed that foods with low GI (vegetables, rice, and barley) are associated on long term with an amelioration of the glycemic and lipid control (1)

- contents in food fibers: The food fibers soluble in water (pectins, gums, mucilages, some hemicelluloses) present in vegetables, fruits, oat, barley, lentil, roots, green leaves vegetables, form gels which retain a part of glucids and lipids, reducing their absorption rate (1). The soluble fibers prolong the time of gastric emptying, avoiding the supply of high quantities of HC to the intestinal lumen to be absorbed, thus reducing the postprandial glycemic response (1). The most efficient are the fibers with high viscosity, which, besides slowing the evacuation of the gastric content, prolong the digestion of complex HC (1).

- contents in lipids and proteins: By incorporating food in mixed lunches, GI is modified, products with different GI having the same effects on glycemic curve (1). Lipids and proteins delay the gastric emptying and slow down the digestion of starch (6), foods rich in lipids (ice-cream) increase glycemia a little compared with bread (1). As a consequence, GI does not correctly predict the postprandial glycemic response after complex lunches, so that the recommendation of foods with low GI in the diet of patients with diabetes is only partially justified (1).

- contents in acids: foods with acid contents delay the gastric evacuation and slow down the starch digestion. For example, sourdough wheat bread has GI = 54, while wonder white bread has GI = 73 (6).

- the presence of some hardly digestible starch forms, the size of starch particles, the gelatinizing degree of starch (1). The high variations of GI for certain foods (rice, with GI comprised between 54 and 132, and potato, with GI between 67 and 158) may be explained by the amylose/amylopectin report, amylose being much slower digested than the amylopectin from starch (4). Amylose has a lower molecular weight than amylopectin, a linear structure, it retains less water, and it has a slower digestion. For example: low GI –

beans GI = 28, rice Uncle Ben's GI = 50 (6). Amylopectin has a ramified structure, it retains much water, and it has a faster digestion. For example: high GI – red potatoes (GI = 85), rice Glutinous (GI = 98) (6).

- the hydric contents: water shouldn't be consumed during meals, since it exaggerates the postprandial rise of glycemia through the more rapid evacuation of foods from the stomach (10).

- the maturation degree of natural products

- the preparation of foods: cooked, boiled etc and their degree of thermic treatment. The latter influences their digestion rate. For example, spaghetti boiled for 10-15 minutes have a GI = 44, while those boiled for 20 minutes have GI = 64 (6)

- the presence of substances: other components from food, such as fitates, tannins, lectins, delay the gastric emptying (2)

- the physical shape of foods (even the shape of different types of pasta) (1).

II. Factors related to consumers: at the individual level, it seems that there is a consequent glycemic response towards the same HC products (1)

- the degree of mechanic treatment of food (mastication) (1)

- the degree of metabolic control (the patients with unsatisfactory control do not assimilate glucose well, no matter the source it comes from) (1, 2, 6)

- glucids digestion and absorption influence GI: in the intestine, glucids are found in an absorbable shape, as monosaccharides: glucose (the most abundant one), fructose, galactose, and pentoses (ribose and desoxyribose) (3). Disaccharides are transformed into monosaccharides in the small intestine through the action of some hydrolases, while polysaccharides (starch and glycogen) are digested under the action of amylases produced in the salivary glands and pancreas (3).

For humans, 80-90% of the ingested glucose quantity appears in the portal circulation in 4-5 hours, the rest of 10-20% being used in the intestinal mucosa for covering the local energetic needs. (3)

The increase of glycemia, induced by the intestinal absorption of glucose, decreases the hepatic production of glucose by approximately 50% (3). Approximately 100 g of glucids are absorbed in 2-4 hours, a period when the liver will accumulate almost 50 g glycogen: 10 g directly from glucose and 40 g synthesized from the lactate produced in the peripheral tissues (Cori cycle) (30).

Sugar is formally not indicated in the diet of patients with diabetes, but the majority of states accept it in the alimentation, in moderate quantities, without exceeding 5-7% of the caloric ratio, under conditions of regular physical effort, associated to mixed lunches, rich in alimentary fibers, for patients metabolically well equilibrated. Sugar has a hyperglycemia effect, corresponding to some equivalent quantities of HC from other foods, comparable to that of bread, potato and rice (1, 2).

Glycemic Load – GL: it is a concept introduced in 1997 by a group of researchers from Harvard University and it has as main purpose the quantification of complete glycemic effect of a portion from a certain aliment, estimating HC both qualitative and quantitative (40.

GL calculation: GL = GI/100 x quantity of HC ingested from the tested food (g) (5, 6, 7, 11, 12), where GI has glucose as reference.

According to GL, foods are divided in :

- foods with high GL ≥20
- foods with medium GL 11-19
- foods with low GL ≤10 (5).

Foods with low GL usually have a low GI; foods with medium or high GL may have a low to high GI (5).

Examples: For apple (GI=40), calculation of GL: 40/100 x 15 = 6, where 15 represents g HC of a portion of 100 g of apple (6).

Watermelon has high GI (72), but low GL. According to the formula, GL= 72/100 x 6 = 4.32, where 6 represents g HC of a portion of 120 g of watermelon (4).

½ cup of rice LG (GI=38) contains 22 g HC, according to the formula, GL = 38/100 x 22 = 8

1 ⅔ cup of rice LG (GI = 38) contains 73 g HC, GL = 38/100 x 73 = 28

½ cup of rice Glutinous (GI = 98) contains 29 g HC, GL= 98/100 x 29 = 28

2 ¼ cups of rice Glutinous (GI=98) contain 8 g HC, GL= 98/100 x 8 = 8 (6)

The effects of diet with high GI and high GL

Some observational studies made at Harvard University indicate the fact that a long term diet with high GL is an independent predictor for the risk of developing type 2 diabetes mellitus (type 2 DM), cardiovascular diseases and neoplasia (4, 13).

In *"Nurses' Health Study"* 88.802 women have been studied, presenting the alteration of glucidic metabolism, being monitored on a period of 18 years; 180 have been diagnosed with pancreatic neoplasm. For women with insulin resistance (IR), body mass index (BMI) ≥25 kg/ m² or low physical activity, it has been observed that the diet with high GL may increase the risk of pancreatic neoplasm (14).

For women, the hyperinsulinism appeared after the diet with high GI/GL ratio, may stimulate the ovarian secretion of androgens, with a risk of type 2 DM (15). In prospective studies, it has been shown that the diets with high GI/GL ratio are associated with a high risk of type 2 DM, coronary diseases and stroke (15).

NHANES III (National Health and Nutrition Examination Survey): 1988-1994, which included 13.907 American adults, with ages 20 years old, showed that the diet with high GI and GL is associated with low plasmatic concentration of HDL – cholesterol (7).

The high consumption, on long term, of HC with rapid absorption, may increase the risk of type 2 DM by two mechanisms: increase of IR and beta-cell pancreatic exhaustion (16). The high consumption of HC with high GI determines IR more important than HC with low GI. In prospective epidemiological studies, both the diets with high GI, as well as those with high GL are associated to a high risk of type 2 DM, both for women as well as for men (16). A diet with a high HC contents with rapid absorption and low in food fibers is associated to a high risk of type 2 DM (17). GL hasn't been significantly associated to the risk of diabetes (18). Pischon and collaborators have shown that the diet rich in HC with high GL is associated to low adiponectin for men with type 2 DM (19).

The benefits of the diet with low GI are: weight control (20), the decrease of the risk of cardiovascular disease (Lin et al. *Am J Clin*

Nutr. 2000; 71; 1455-1461, Oh et al. *Am J Epid.* 2005; 161), the decrease of the risk of type 2 DM for women (21) and men (22). The diet with low GI is a protective factor against obesity, colon cancer and breast cancer (4). Some studies have shown the fact that the GI of the diet is a good predictor of HDL-cholesterol (4). There are studies which have shown that the diet with low GI has improved the glycemic control, the sensibility to insulin (reducing the insulinemic level and the IR), the lipid profile and the weight control (4, 23, 24, 25); by assessing the effect of the low GI diet versus high GI on the insulinemic and glycemic response, for 32 patients with advanced coronary disease and IR, using the oral glucose tolerance test (OGTT), it has been observed that the insulinemic AUC after OGTT has been significantly reduced after 4 weeks for the group with low GI diet, the modification of the diet on short-term improving the sensibility to insulin for these patients (26); Jenkins and collaborators have shown for 6 healthy subjects that the diet with low GI mainly made of integral cereals, significantly reduces the C peptide level (by 32%) versus the high GI diet, mainly with refined cereals (16, 27).

For 902 women with type 2 DM from *Nurses' Health Study,* the high consumption of food fibers from cereals and fruit has been significantly associated to high adiponectin, no matter of age, smoking, alcohol, physical activity, aspirin use, Hb A1c, antecedents of arterial hypertension and hypercholesterolemia (19).

GL and GI are in inverse proportion correlated to the level of adiponectin, no matter of BMI (19).

In a study which included 162 patients with type 2 DM controlled by a low GI diet, the reduction of the reactive protein C concentration has been observed (28).

The meta-analysis of 14 studies, with a length of time of 2-52 weeks, which have compared the effect of low GI diet versus the conventional or high GI diet on the glycemic control for 356 patients with type 1 and 2 DM, by assessing Hb A1c and fructosamine level, has shown that the diet with low GI reduced HbA1c by 0.43% more than the diet with high GI and the protein glycosylation is reduced by 7.4% (23).

Analyzing 2810 patients with type 1 DM from EURODIAB Complications Study, GI has been independently correlated to HDL cholesterol and HbA1c, the latter being with 11% lower for patients from Southern Europe centers and with 6% lower for patients coming from the Northern, Western and Eastern Europe centers. The diet with low GI has been correlated with low HbA1c, no mater of fibers consumption (24).

GL offers better information than GI about weight, the control of type 2 DM, HDL plasmatic cholesterol, reactive protein C and protein glycosylation (18).

The high consumption of food fibers is associated with a low risk of diabetes (16). Cereals must be least refined in order to reduce the risk of diabetes (21, 22). For patients with diabetes, the replacement of HC with high GI with HC with low GI improves the glycemic control, while for the persons treated with insulin it reduces the hypoglycemic episodes (16). The replacement of products from white flour and potatoes with minimum refined integral cereals decreases the risk of cardiovascular diseases (16).

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