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Methods of lowering the glycemic index of food and their underlying mechanisms- a review

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Abstract

Introduction and purpose of review: The term glycemic index (GI) is the measure of how much a specific substance increases the postprandial blood glucose level [1]. Substances with lower GI promote a lower glycemic response and are said to promote satiety, postprandial insulin secretion and maintain insulin sensitivity and therefore help to control blood glucose concentrations [2]. According to guidelines on the management of patients with diabetes, type 2 diabetes mellitus patients' source of carbohydrates in diet should be whole grain cereal products especially with low GI [3]. Type 2 diabetes is a chronic, metabolic disease occurring mostly in adults. It leads to numerous chronic complications that include e.g. macroangiopathy, retinopathy, nephropathy, neuropathy and diabetic foot as well as vulnerability to infections [2]. These complications lower the quality of life, generate costs when treating them and eventually lead to death.

Currently there are about 422 million people with diabetes worldwide and the number is expected to rise [3]. Therefore it is crucial for patients to maintain their blood glucose at stable levels to prevent progression of the disease and its complications. The glycemic response can be modified by implementing a low GI diet. The aim of this study is to provide an overview of selected strategies lowering the glycemic index and the probable mechanisms by which they work.

Methods: For this review, articles in the Pubmed and Google Scholar databases were analyzed as well as the references of previously found articles.

Current state of knowledge: Existing studies show that some strategies alter the glycemic index and glycemic response that can help diabetic patients to better control their glucose blood level.

Summary: This review summarizes studies concerning methods of lowering the glycemic index and mechanisms of action of those specific methods.

Keywords: glycemic index, GI, postprandial glucose level, type 2 diabetes mellitus, metabolic disease

1. Background

The term glycemic index was first introduced in 1981 by D.J Jenkins and colleagues and was used to classify food based on how it affects the postprandial blood glucose level (blood glucose level 2 hours after food intake) relative to the same amount of carbohydrates [1]. Now, the GI value is the incremental area under the (blood glucose response) curve (IAUC) for the assessed substance, expressed as a percentage of an equal amount of the standard control (glucose) [6]. The formula for GI is shown below.

$$Glycemic\ index = \frac{blood\ glucose\ level\ after\ digestion\ of\ a\ product\ \ containing\ 50\ g\ of\ carbohydrates}{blood\ glucose\ level\ after\ ingestion\ of\ product\ containing\ 50\ g\ of\ glucose} \times 100\%$$

Fig. 1. Glycemic index formula.

This index rates carbohydrates on a scale from 1 to 100 with glucose (and sometimes white bread) being the reference food and having by definition the GI of 100. The GI values are divided into three categories according to the International Standards Organization. The cut points for this classification are [7]:

- high (GI > 70)
- medium (GI 56-69)
- low (GI <55)

Examples of foods divided into these GI groups are shown in the table below.

Grains and starches		
Low glycemic index	Medium glycemic index	High glycemic index
Heavy Mixed Grain Breads	White bread	Bread (White, Whole Wheat)
Sourdough Bread	Pita Bread (White, Whole Wheat)	Corn Flakes™ Cereal
Tortilla (Whole Grain)	Pumpernickel Bread	Jasmine Rice
Oats (Steel Cut)	Whole Grain Wheat Bread	Sticky Rice
Pasta (Al Dente, Firm)	Oats (Quick)	Potato (Red, White, Hot)
Rice (converted, parboiled)	Brown Rice	Potato (Instant Mashed)
Quinoa	Rice Noodles	Rice Cakes

Peas	Parsnip	Pretzels
Popcorn	Potato (Red, White, Cooled)	Soda Crackers
Fruits		
Apple	Banana (Ripe, Yellow)	Banana (Brown, Overripe)
Peach	Raisins	
Banana (Green, Unripe)	Grapes	
Berries	Pineapple	
Grapefruit		

Some fruits have no glycemic index value as they have less than 15 g of available carbohydrate per serving (e.g. lemon and lime) [8].

Vegetables		
Low glycemic index	Medium glycemic index	High glycemic index
Carrot (fresh and cooked)	Beetroot	Turnip
Zucchini	Cauliflower (cooked)	
Green vegetables (eg spinach, lettuce		
Milk, Alternatives and Other Beverages		
Almond Milk		Rice Milk
Cow Milk (Skim, 1%, 2%, Whole)		
Greek Yogurt		
Soy Milk		
Yogurt (Skim, 1%, 2%, Whole)		
Meat and Alternatives		
Baked Beans	Lentil Soup (ready-made)	
Chickpeas	Split Pea Soup (ready-made)	
Kidney Beans		
Lentils		

Table 1. Examples of foods divided into low, medium and high GI foods [8], [9].

Meat, poultry and fish are rich in protein and contain zero or very small amounts of carbohydrates, therefore they were not given a GI value in the classification. They are zero-glycemic foods [8].

The substances with lower GI raise the postprandial glucose levels to a lesser extent than those with medium or high GI. Therefore they are recommended in the diet of patients with metabolic diseases such as diabetes mellitus.

Type 2 Diabetes Mellitus (T2DM) is the most common type of DM. It is a chronic metabolic disease and a result of genetic predisposition and environmental factors combined. It is caused by impaired insulin secretion and its incorrect action on tissues- the feedback loops between them do not function properly.

The tissues become insulin resistant which means the insulin-sensitive tissues (liver, muscles and adipose tissue) do not respond to the hormone the right way. This resistance results in increased glucose production in the liver and decreased glucose uptake in muscle and adipose tissue as well as insulin overproduction in β-cells in order to compensate for higher glucose concentrations. Eventually excessive insulin production leads to beta cell exhaustion which makes compensation mechanisms no longer effective and hyperglycemia occurs [10].

T2DM is a progressive condition with various chronic complications such as retinopathy, nephropathy, neuropathy and diabetic foot as well as vulnerability to infections, osteoporosis, arthropathies and liver damage. The most severe complication is macroangiopathy causing cardiovascular diseases such as coronary disease, congestive heart failure and arterial hypertension. The majority of deaths in T2DM patients are caused by cardiovascular incidents [4], [11].

Currently there are about 422 million people with diabetes worldwide. In the past 3 decades the prevalence of type 2 diabetes has risen and is estimated to rise further up to 643 million by 2030 and 783 million by 2045. [5]. 6.7 million deaths in 2021 were associated with diabetes and its complications.

Furthermore, healthcare costs for patients with diabetes mellitus are up to three times higher than for the non-affected general population. In 2021 at least USD 966 billion was spent on treating diabetes mellitus and its related complications [12].

The data shows that the world epidemic of diabetes is not only a health but also an economic issue and effective pharmaceutical and non pharmaceutical strategies need to be implemented. T2DM management is complex and includes therapeutic education, physical exercise, psychological management, pharmacological treatment, reducing cardiovascular risks, treating complications and behavioral therapy which includes a healthy diet. According to guidelines on the management of patients with diabetes, the primary source of carbohydrates in diet should be whole grain cereal products especially with low GI, which helps to control blood glucose levels [3].The aim of this review is to sum up the methods of lowering the GI of food and their mechanisms.

2. What alters the glycemic index

The quality of diet is an important factor in preventing metabolic diseases as well as managing the course of diseases such as prediabetes and diabetes. Low glycemic index diets are suggested to control postprandial elevations of blood glucose and reduce the risk of dysglycemia [13], [14], [15].

The concept of glycemic index becomes more popular among the general public and the GI charts are easy to find, however there are a variety of factors affecting it, that might be helpful when included in diet, that are not yet common. These strategies should be popularized in society so that people create a habit of eating even more consciously.

The factors influencing GI include the combination of foods with different nutritional compositions, food processing such as cooking or freezing and addition of organic acids or soluble fibers. Implementing these methods to diet and lifestyle is convenient and does not require permanent carbohydrate reduction or avoidance of high– glycemic index carbohydrate foods [17].

2.1. Acetic acid

Acetic acid is an organic acid used in meal preparation in the form of vinegar. Vinegar is a aqueous solution obtained from the anaerobic conversion of sugars to alcohol and aerobic oxidation of that alcohol to acetic acid [16]. Several studies show that addition of vinegar in high-glycemic meals reduces the postprandial blood glucose concentration and insulin response to a significant extent [17], [18]. For example Sugiyama and colleagues measured the GI of white rice after adding either vinegar (11 g/portion) or pickled cucumbers (15 g vinegar/portion) which resulted in 25–35% reduction of GI value [19]. Then Brighenti et al added 17 mmol acetic acid in the form of a vinaigrette sauce with sliced lettuce and white bread and obtained 30% reduction of IAUC [20]. In another study with T2DM patients involved, the effect of adding vinegar to meals with a high vs low GI was compared. The group that got the meal with a high GI plus vinegar had a lower AUC compared to those without vinegar addition. On the contrary, no significant differences were observed between the groups with a low GI + vinegar diet compared to the same food with no acetic acid [18].
Gastric emptying, digestion, and absorption in the small intestine determine how fast glucose enters the blood enters the bloodstream [21]. Although the mechanism by which the acetic acid reduces the postprandial blood glucose is not fully clear, there are several hypotheses. One of them is that vinegar can lower gastric emptying by inhibiting digestive enzymes, for example α-amylase. Turning the digestion conditions more acidic may inhibit salivary α-amylase, as studies show that pH below 4.0 causes its deactivation. Vinegars used in the food industry have a pH between 2 and 3, so they may inactivate the enzyme at the beginning of the digestion process. This causes delaying of nutrients release until they reach the intestines [16], [17], [18]. Another mechanism involves acetic acid binding to and activating the free fatty acid receptor 2 (FFAR2) localized in the enteroendocrine L-cells of the human intestine. Animal models have shown that this activation can lead to the release of some hormones such as peptide Y-Y (PYY) and glucagon-like peptide-1 (GLP-1). The last hormone causes delayed gastric emptying and reduces appetite. Also there is evidence suggesting that SCFA (short chain fatty acids, so acetic acid) can directly or indirectly activate AMPK. They can stimulate the activation of AMPK in tissues for example the liver [24], [25]. When AMPK is activated, it can decrease gluconeogenesis and lipogenesis in the liver and cause glycogen replenishment [26], [27].
Despite its possible benefits regarding blood glucose level control, vinegar should be administered with caution as excessive amounts can cause adverse effects. There was a case of a 28-year-old woman admitted to the hospital after ingesting 250 mL of vinegar (i.e. 12.5 g of acetic acid) per day for 6 years. She had muscle cramps and hypokalemia. Her results showed urinary potassium wasting and abnormal sodium excretion in correlation to the

stimulated plasma renin activity. Her condition was proven to be caused by excessive vinegar intake [26].

2.2 Addition of macronutrients: fiber, fats and proteins.

Another way of altering the GI index of a meal is the addition of foods rich in protein, fiber and fat to carbohydrates. They can be added combined or solo. All of them delay gastric emptying, which means the food needs more time to go from stomach to the intestine. This reduces the rate of food absorption and results in a reduced glycemic response.

2.2.1. Proteins

Proteins, besides their effect on delayed gastric emptying, interact with starch. It has been observed that a protein matrix surrounding the starch granules in foods such as legumes forms some kind of a physical interaction inside the endosperm or cotyledon. This interaction seems to restrict the access of amylolytic enzymes to starch, so it limits the rate of α-amylolysis, which means it slows down carbohydrate breakdown [29], [30], [31].

2.2.2. Fats

Fat reduces the postprandial glucoses level by increasing the viscosity of the intestinal contents which has an effect on the rate of gastric emptying [32], [33]. High viscosity inhibits emulsification and precipitation has an impact on the emptying of nutrients.

2.2.3. Fiber

Dietary fiber (DF) makes up a group of carbohydrates that are resistant to hydrolysis by endogenous enzymes in the small intestine. The most important source of DF are plants. Fiber plays a role in the encapsulation of food particles, where cell walls may remain unbroken even after chewing and other stages of the digestion [34]. Some DF containing substances such as psyllium, soluble corn fiber, guar gum and polydextrose exert an effect on the function of the stomach that includes digestive tract passage time and chyme viscosity and this way they affect the nutrient passage. Viscous fibers also reduce the glucose absorption through the mucosa in intestines [35]. Lobos et al conducted a study that compared a meal with a high GI (2.2 g fiber) to another with a low GI (4.9 0.5g fiber), a 46% decrease in GR was obtained in IAUC [36]. In another study T2DM patients were given two doses of psyllium (6.8 or 13.6 g/day) for 12 weeks. It resulted in 25% GI and 39% GL reductions, giving a low-GI and low-GL food compared to gluten-free bread with medium GI and GL values. Additionally, both doses significantly reduced glycated hemoglobin levels after twelve weeks compared to the placebo [35].

2.3. Ripeness

During ripening, the texture of the eg fruits changes as a result of the hydrolysis of starches due to reduction of their fiber content during degradation of the cell walls. This way, sugars are formed that generate a sweeter taste. For fruits that continue ripening after being harvested (banana, apple, pear, kiwi, peach, melon and plum), the starch is converted to simple sugars (fructose and glucose) and increases its GI so at the same time its RG [37]. In a study using under- and over-ripe bananas (about 20 g of carbohydrate) was compared with an equivalent amount of white bread in 10 well-controlled Type 2 diabetic volunteers..In the course of the observation the IAUC of bananas increased due to ripening from 42% to 69% of the area obtained after white bread (control, GI=100) [38].

2.4. Food processing

2.4.1. Cooking

Structure and digestibility of starchy food are affected by processing methods, and this could influence glycemic response [39]. Cooking in general destabilizes starch granules, so that glucose chains are able to undergo gelatinization (a transition process of starch, by which the granules break down into a mixture of polymers-in-solution) [37], [39]. The process involves breaking of hydrogen bonds into amylose and amylopectin. Gelatinized starch is characterized by increased sensitivity to amylases, so is rapidly hydrolyzed to saccharides, resulting in increased digestibility [40]. Interestingly, it has been observed that the way of cooking has an impact on the GI value. There are differences in GI values between equivalent foods when prepared by boiling, roasting, frying or heated using a microwave. A study on processing sweet potatoes showed that boiling resulted in lower GI values than frying, baking, and roasting [41]. Another study showed differences between preparing oatmeal by traditional cooking, by heating in the microwave for 3 minutes and by heating in the microwave for 5 minutes. The results were as follows: conventionally heated oat flakes contained the lowest amount of starch and highest amount of carbohydrates easy to digest. The 5 min microwave oats heated also presented high amounts of carbohydrates easy to digest, though this amount was lower than for conventionally heated oat flakes. The lowest GI value and oats richest in starch were obtained after heating in the microwave for 3 minutes.

The probable explanation for this might be related to shorter time of processing with less extensive stirring, so less physical interaction between particles such as colliding. Also the shorter exposure to temperature that allows gel formation may be the reason. This way the amount of starch granules releasing amylose chains that are further subjected to α-amylase hydrolysis is limited [42].

2.4.2 Freezing

Procedures decreasing the moisture content of foods containing starch during storage or preparation influence the formation of gels, changing the pattern of food absorption [37]. Cooling conditions and freezing are proven to cause retrogradation of starch, which lowers the glycemic response. Retrogradation results in formation of a resistant starch, which means it cannot be digested by amylases in the small intestine, so it slows down digestion and thus the glycemic response. Importantly, freezing and defrosting makes food pass through retrogradation twice, once while freezing and then by defrosting. A study conducted by Burton et al showed a significant decrease in GI after freezing and defrosting [43].

2.5 Order of food consumption

Data from some studies suggests that the order of food intake affects the glycemic index. Varying combinations of order of consuming were compared with similar results. Carbohydrates consumed first result in glucose and insulin rise after 60 minutes of intake. Proteins with vegetables or vegetables alone eaten first gave attenuated postprandial glucose. This might happen because of fiber present in vegetables, that delays glucose absorption [44], [45].

3. Conclusions

The review showed various strategies that can alter the GI values by lowering it and thus providing a better management of blood glucose levels and the course of type 2 diabetes mellitus. It is important to spread information concerning those methods among patients to simplify planning healthy meals that reduce blood glucose fluctuations and so the risk of diabetes progress and complications.

Disclosure

Author's contribution

Conceptualization: Patrycja Sornek and Wiktoria Izdebska; Methodology: Jakub Stanek; Software: Klaudia Perkowska; Check: Anna Kaźmierczak; Formal analysis: Patrycja Sornek; Investigation: Patrycja Sornek and Jakub Stanek; Resources: Radosław Ciesielski; Data curation: Igor Pawlak and Wiktoria Izdebska; Writing- rough preparation: Agata Borkowska; Writing- review and editing: Anna Mich; Visualization: Anna Kiełb Project administration: Patrycja Sornek

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