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Review Article

Research progress on the glycemic index of baked food

Wenfeng Han[1], Po Qiu[2]* and Songtao Ge[1]

[1]*Rice Wine College, Zhejiang Industry Polytechnic College, Shaoxing, China*

[2]*Zhejiang Youshan Food Technology Co., Ltd, Shaoxing, China*

***Corresponding Author:** Po Qiu, Zhejiang Youshan Food Technology Co., Ltd, Shaoxing, China. **Phone:** +86-15039585425, **Email:** 419668281@qq.com

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Abstract

Baked foods with a low glycemic index (GI) can be beneficial for patients with diabetes. These foods help to reduce postprandial blood glucose levels after meals, reduce the amount of insulin requirements, and increase the sense of fullness in individuals with diabetes. However, it is important to note that glycemic index values can be influenced by several factors. This paper provides a comprehensive review of the impact of bakery processing technology and raw materials on the glycemic index of baked foods. It also provides an overview of the many types of low glycemic index baked foods and the latest research developments in this area. Furthermore, this study examines the challenges involved in developing these types of foods and discusses the potential future directions for low glycemic index baked foods.

Keywords: Glycemic Index; Baking; Processing Technology; Raw Materials; Low Glycemic Index Products

Introduction

The Glycemic Index (GI) is a physiological indicator that measures the speed at which the body digests and absorbs food, impacting blood glucose levels [1]. Dr. Jenkins from the University of Toronto introduced this concept in 1981. The Food and Agriculture Organization of the United Nations (FAO) and the World Health Organization (WHO) officially endorsed the GI method for categorizing carbohydrate-rich foods, in 1997. The proposal suggested combining the GI of food with its nutritional content to assist in making informed dietary choices. The FAO/WHO defines GI as the ratio of the area under the postprandial blood glucose response curve of food containing 50g of available carbohydrates to that of a standard reference food with the same equivalent quantity of carbohydrates [2]. Foods are categorized into high GI (above 70), medium GI (between 55 and 70), and low GI (55 or lower) based on the glycemic index scale [3].

Research indicates that consuming high GI foods can reduce the effectiveness of insulin and contribute to insulin resistance, which is unfavorable for the management and treatment of type II diabetes [4]. Conversely, long-term consumption of low GI foods has been shown to have a positive impact on regulating blood sugar levels and improving the management of type II diabetes. A certain study demonstrated that consuming low GI foods can effectively reduce both fasting and postprandial blood glucose levels in patients with type II diabetes [5]. Wang., *et al*. (2015) analysis revealed that compared to high GI foods, low GI foods had a significant impact on reducing glycosylated hemoglobin levels in diabetic patients [6]. On average, these foods resulted in a 9% decrease in glycosylated hemoglobin levels, which is comparable to the clinical effect of oral hypoglycemic drugs. Botero., *et al*. (2009) discovered that consuming low GI foods can increase the overall antioxidant capacity of diabetic patients, and potentially slow down the progression of diabetes and other related metabolic conditions [7]. Furthermore, low GI foods have demonstrated beneficial outcomes in the prevention and treatment of conditions such as obesity, cardiovascular disease, cancer, and Alzheimer's disease [8].

Baked foods are a convenient type of sustenance made from a combination of flour, yeast, salt, sugar, and water as basic raw materials. Additional ingredients such as oil, dairy products, eggs, and additives are also used in appropriate quantities. These ingredients undergo a series of complex processes to be baked and prepared. Baked foods not only provide rich nutritional value but also offer a wide variety of options, vibrant colors and complement the taste of tea before or after meals. Additionally, baked foods can serve as a primary food source or as thoughtful gifts. There is growing interest in the research and development of low GI baked foods in both domestic and international companies due to their suitability for low GI diets. This indicates positive prospects for the future. This paper explores the influence of baked foods processing technology and raw materials on the GI. It also outlines methods for reducing GI in various baked products. The aim is to provide a theoretical reference for the development of low GI baked foods.

The Influence of the bakery process on the GI of food

Baking is a food processing method that involves dry heat to induce starch gelatinization and protein coagulation, resulting in the process of ripening. This process triggers Maillard reactions between amino acids and reducing sugars in food ingredients, leading to the formation of complex aroma compounds and appealing colors. It is a crucial stage in the production of biscuits, bread, cakes, as well as in the processing of potatoes and sweet potatoes. Research by Allen., *et al*. (2012) revealed that the GI of sweet potatoes increases significantly after baking [9]. This increase is attributed to starch gelatinization, a process that breaks down starch into dextrin and maltose, making the sweet potatoes more easily digestible and absorbable by the body. The influence of the baking duration on the GI is primarily attributed to changes in the structure and digestion rate of starch in the food. Bosnians., *et al*. (2013) conducted a study and found that the duration of baking time impacts the level of starch regeneration and network structure formed during bread baking [10]. They also observed that extending baking time can effectively reduce the GI of the bread product. In their study on the effect of kneading time and blood glucose responses on bread, Yaregal., *et al*. (2022) found that bread kneaded for 15 minutes resulted in lower blood glucose responses compared to bread kneaded for 10 minutes [11]. This suggests that modifying the processing conditions can improve the bread's effect related to blood glucose level responses.

The influence of bakery ingredients on the GI of food

Bakery ingredients commonly include wheat flour, oils and fats, sugar, eggs, dairy products, and various additional components. Each ingredient is a complex system with various components that can impact the formation of resistant starch, the digestibility of starch, and ultimately influence the GI of bakery products.

Carbohydrates

Starch

Starch, the primary component in bakery foods, serves as the main source of energy for the human body. It can be classified into three main groups based on the rate at which it is digested: fast-digesting starch, slow-digesting starch, and resistant starch. Resistant starch, unlike other types of starch, cannot be digested and absorbed in the small intestine of humans. However, it can undergo partial fermentation by intestinal microorganisms in the large intestine, a process that has the potential to effectively reduce the GI. Research results of Zheng., *et al*. (2020) showed that high resistant starch rice tends to reduce blood glucose and glycated hemoglobin levels in patients diagnosed with type II diabetes mellitus to a certain extent [12]. Zhang., *et al*. (2019) also showed that the strength of the hypoglycemic effect of highly resistant starch rice, compared to regular rice, after a 2-hour postprandial period was not influenced by factors such as gender, age, body mass index, and admission glucose levels [13].

Starch can be classified into two types based on its structural characteristics: straight-chain starch and branched-chain starch. Compared to branched-chain starch, straight-chain starch has a lower molecular weight, fewer branches, fewer amylase action sites, and a spatial conformation that forms a helix, resulting in a denser structure. Due to the need for amylase to bind to the end of the starch chain to act on it, branched-chain starch has a greater number of endpoints compared to straight-chain starch. As a result, branched-chain starch is more likely to be degraded by amylase during *in vivo* digestion, leading to the production of glucose and a subsequent increase in blood glucose levels. Researchers found that straight-chain starch has the ability to create anti-digestive complexes with lipids, resulting in a decrease in the rate at which starch is digested [14]. Zeng., *et al*. (2015) found that straight-chain starch can decrease the degree of starch pasting, enhance crystallinity, and promote starch aging [15]. Srikaeo., *et al*. (2014) manipulated the ratio of various starch types in rice flour by adding high straight-chain corn starch [16]. The results showed that as the content of straight-chain starch in rice powder increased, the starch's ability to regenerate became stronger, leading to a significant reduction in the GI of the rice flour. Therefore, the GI of baked foods tends to be lower when the content of straight-chain starch in the ingredients is higher.

The number, size, and shape of pores and channels present on the surface of starch particles can also impact the digestibility of starch. This, in turn, determines the level of difficulty and the specific location where enzymes act upon starch. Gallant., *et al*. (1997) have shown that rice starch possesses peripheral pores connected to internal channels, resulting in an "inside-out" digestibility pattern [17]. This pattern facilitates the entry of amylase into the pores for enzymatic hydrolysis reactions. In contrast, potato starch and high straight-chain starch corn starch exhibit an "outside-in" manner of digestibility, which is more challenging. Amylase exhibits limited permeability into the starch granules, resulting in a lower starch digestion rate. This characteristic renders it particularly more suitable for diabetes patients. Therefore, when producing low GI bakery foods, it is advisable to use grain flour that has a high content of straight-chain starch, and resistant starch can be preferred as raw materials, as this will not negatively impact the process performance.

Dietary fiber

Dietary fiber refers to polymers of naturally occurring, extracted, or synthetic carbohydrates found in plants that cannot be digested or absorbed by the human small intestine. It includes substances such as cellulose, hemicellulose, pectin, inulin, and other dietary fiber monomer components. Dietary fiber improves insulin receptor sensitivity, resulting in the regulation of blood glucose levels in diabetic patients. There is a critical link between the amount of dietary fiber added and the GI of bakery foods. A study conducted by Kurek., *et al*. (2018), found that bread enriched with oat, flax, and apple dietary fibers had a GI of 38.58, 25.06, and 32.80, respectively, which represents a significant reduction in the GI compared to conventional bread [18]. Ng., *et al*. (2017) found that incorporating mushroom powder, which is high in dietary fiber, into cookies at a concentration of 8% of the total wheat flour resulted in a GI of 49 [19]. This addition improved the cookies' postprandial glycemic response. Regand., *et al*. (2011) found that dietary fiber increased the viscosity of the digestive system, decreased starch mobility, lowered the rate of digestion of starch, and decelerated the release of glucose [20]. Consequently, this led to a reduction in the GI of bakery foods. Oh., *et al*. (2014) conducted a comparative study on the effect of the solubility of dietary fiber on the digestive properties of bread and found that insoluble dietary fiber reduced the digestibility of starch [21]. Bernabe., *et al*. (2011) found that certain dietary fibers can impact human blood glucose levels by influencing insulin sensitivity [22]. Additionally, in terms of physical structure, dietary fibers have the ability to form spatial network scaffolds that encapsulate starch granules and hinder their breakdown by amylase, affecting the process of starch hydrolysis [23].

Other carbohydrates

Polysaccharides, oligosaccharides, sugar alcohols, L-arabinose, and allulose are additional carbohydrates and have great potential in reducing the GI of bakery foods. Wei., *et al*. (2022) found that fucoidan increased the densification of wheat starch granules, leading to a decrease in fast-digesting starch and an increase in slow-digesting starch [24]. Liu., *et al*. (2021) found that red tea, wolfberry, and mulberry leaf polysaccharides had hypoglycemic effects, resulting in reductions in blood glucose levels of 61.6%, 52.8%, and 53.8%, respectively [25]. Peng., *et al*. (2020) used resistant dextrin as a partial replacement for low-gluten flour and oligomeric isomaltose as a substitute for sucrose in biscuit production, achieving a GI of 39.6, which was significantly lower than that of regular biscuits [26]. Zhang., *et al*. (2020) added inulin and xylitol with low gluten wheat flour to produce insulin biscuits, which have a medium GI [27]. Seri., *et al*. (1996) found that L-arabinose can significantly inhibit the increase in blood glucose and insulin levels in rats after sucrose consumption, At a dosage of 100mg/kg, L-arabinose may suppress 64% of the increase in plasma insulin levels within 15 minutes of ingestion [28]. D-psicose has been shown to reduce postprandial blood sugar levels by inhibiting the activity of glucosidase and α-amylase [29]. Iida., *et al*. (2008) found that when healthy subjects consumed 75g of maltodextrin along with at least 5g or more D-psicose could reduce plasma glucose and insulin concentrations [30].

Protein

Protein is a key component of bakery food ingredients. The presence of protein not only improves the nutritional value of the food but also contributes to various processing properties and helps reduce the GI of the food. Studies have shown that protein and certain amino acids can slow down the gastric emptying rate, reduce postprandial glucose variability, and maintain lower glucose levels in the body [31]. Singh., *et al*. (2010) found that the *in vitro* digestibility of both maize and wheat flours, after removing the protein, was significantly higher compared to the digestibility of raw grain flours [32]. Ye., *et al*. (2018) investigated the changes in the digestive properties of rice flour by deproteinizing and found that the GI of the protein-removed rice flour was significantly higher [33]. The proteins in the food formed a cohesive structure with starch, wrapping around the surface of starch, and the glutenin, albumin, and globulin blocked the catalytic binding of amylase to starch granules, thereby alleviating starch hydrolysis and reducing the GI of the food [34]. In their study, Zhang., *et al*. (2012) found that in deproteinized wheat flour, the interaction between starch and amylase was facilitated, greatly improving the digestive properties of the wheat flour [35]. Grace., *et al*. (2020) demonstrated that the GI of bread with added yogurt and curd cheese was reduced in comparison to that of normal bread [36].

Fat

Fat is a collective term used to describe glycerides composed of glycerol and fatty acids. Substances that have a liquid state at room temperature are generally referred to as oils, whereas substances that have a solid state at room temperature are known as greases. The addition or removal of fat in bakery foods or the reduction of fat content in ingredients both affect the GI of the final product. According to Annor., *et al*. (2013) found that *in vitro* digestibility was ranked as follows: millet starch > defatted millet flour > millet flour, with the GI of defatted millet flour being significantly higher [14]. A study conducted by Srikanlaya., *et al*. (2017) found that the GI of bread decreased sequentially to 83.10, 80.27, and 76.80 when butter was added to the bread in a sequential trend of 10%, 20%, and 30% of the flour, respectively [37]. Chen., *et al*. (2022) also found that the addition of a complex combination of fat and corn straight-chain starch into cookies reduced the *in vitro* digestibility and the postprandial blood glucose values of the cookies [38]. Although the addition of fat can reduce the GI of bakery foods to some extent, it is important to note that high-fat foods are not recommended for people with diabetes. Excessive amounts of fat intake might reduce insulin sensitivity, which is detrimental to maintaining healthy long-term blood glucose levels.

Other components

In addition to these basic components, the presence of polyphenols, glycoproteins, and minerals in bakery food ingredients also impacts the GI. Yiling *et al*.(2021) found that lignans, polyphenols from sweet potato stems, and isoquercetin significantly inhibited α-glucosidase and α-amylase activities, resulting in a reduction of the GI of bakery foods [39]. In their study, Tormo., *et al*. (2004) found that white kidney bean glycoprotein exhibits hypoglycemic effects on Wistar rats, obese rats, and diabetes model mice [40]. Furthermore, it has the potential to mitigate the damaging effects of type II diabetes on the pancreas, kidneys, and liver. Ma., *et al*. (2018) added white kidney bean glycoprotein at a 30% additive level to four different convenience porridges, resulting in a reduction of the GI of all porridges to less than 55 [41]. In addition, relevant studies have shown that minerals such as chromium and zinc can influence the synthesis and secretion of insulin, as well as its concentration in the body. This, in turn, has a significant role in regulating blood glucose levels in humans [42,43].

Biscuits

Biscuits are bakery foods made primarily from wheat flour as the main raw material, supplemented with sugar, oil, eggs, and dairy products. They have low water content and high nutritional value, making them suitable for consumption by all social classes. However, the biscuits consumed on a daily basis typically have a high GI, which is not beneficial for managing blood glucose levels in humans. Currently, the primary procedure for producing low-GI biscuits involves incorporating resistant starch or dietary fiber into wheat flour to reduce GI. In a study conducted by Maria., *et al*. (2017), it was found that cookies with a high fiber content from type 4 resistant starch can reduce the area under the postprandial blood glucose response curve (0-120 minutes) by 44% in healthy adults [44]. Additionally, these cookies were found to decrease serum insulin levels by 46%. Bakar., *et al*. (2020) added unripe banana peel powder into the biscuits, resulting in a significant increase in dietary fiber content and a significant decrease in starch digestion rate and GI [45]. Naseer., *et al*. (2021) developed a low GI rice powder biscuit by modifying the baking conditions and composition of ingredients, utilizing high straight-chain starch rice powder and carboxymethyl cellulose as the primary raw materials [46].

Incorporating whole wheat flour or mixed grain flour into biscuit recipes can also reduce the GI. Klunklin., *et al*. (2018) utilized a mixture of wheat flour and purple rice powder, along with galangal and green-lipped mussel powder, to make wheat-purple rice biscuits. This biscuit exhibited a reduction in *in vitro* starch digestibility and GI by 18.95% and 6.18% respectively, compared to regular cookies [47]. Jariya., *et al*. (2018) investigated the effect of Pedada flour in the production of biscuits and found that when the ratio of Pedada powder to taro starch was 2:8, the GI of the biscuits was 48.83 [48]. Li (2020) enhanced the nutritional quality of potato cookies by adding oat bran and inulin, resulting in a low GI of 44.64, which led to a better organoleptic evaluation [49]. Vujic., *et al*. (2014) added amaranth and soybean powder to wheat flour into the biscuit preparation, resulting in a GI of 44.9 and 52.5, indicating that they are both classified as low GI foods [50]. Zhu., *et al*. (2024) found that adding Cyperus esculentus and Pueraria thomsonii to crispy biscuits resulted in a hypoglycemic effect, and the sensory evaluation of these biscuits was favorable [51]. Hussain., *et al*. (2020) mixed water chestnut powder and barley powder in a 70:30 ratio to create low-GI cookies [52].

Bread

Bread is a type of bakery food produced primarily from wheat flour as the main raw material, along with yeast, eggs, oil, sugar, salt, and other supplementary ingredients. The dough is prepared by mixing these ingredients with water, followed by processes such as modulation into the dough, dividing, forming, rising, baking, and cooling. Consumers choose this kind of convenience food item due to its mild-flavored taste and portability. However, bread's GI is elevated due to the specificity of raw materials and production methods. Recently, there has been a growing interest in the concept of combining coarse and fine grains to make low GI bread, making it a prominent area of focus in food research. Yan (2020) added 20% potato flour, 9% inulin, 4% erythritol, and 2% sugarcane extract to the flour during the bread-making process, resulting in bread with a GI of 31.08 [53]. Zhang., *et al*. (2014) added kelp and black rice to the flour mixture, achieving a GI of 47.4 for the bread [54]. Xu (2020) used chickpea starch to replace the high-gluten wheat flour, producing bread with a GI of 45.9 [55]. Yang (2020) replaced part of the high-gluten wheat flour with oat flour, soybean powder, and almond powder to create bread with a low GI below 55 [56]. Li., *et al*. (2021) developed a low-GI bread flour suitable for household use, consisting of 49.68% gluten flour, 16.93% chickpea flour, 7.90% oat fiber, 7.00% wheat fiber, 5.98% pea protein flour, and 3.39% flaxseed flour. Digestion modeling estimated the GI of this bread to be 47.6 [57]. Although these production methods have the potential to reduce the GI of bread, they also present the challenge of compromising the texture and taste of the final product.

Cake

Cake is a traditional Western pastry, prepared by combining eggs, sugar, and wheat flour as the main ingredients through the process of beating and baking. Cake is a confectionary food type with a high sugar content, making it unsuitable for diabetic patients. Consequently, the development of low-GI cake has been a prominent area of focus in current research on low-GI bakery products. Jun., *et al*. (2014) conducted a study where they added dietary fiber-rich apple peels into the cake. They found that adding 3% apple peels to the cake mixture resulted in a decrease in its GI [58]. A Chinese invention patent revealed a method for substituting gluten and buckwheat for a portion of wheat flour and used xylitol and maltitol to replace sucrose in cake production. This method not only enhances the nutritional value of the product but also reduces the GI [59]. A recent Chinese invention patent disclosed a method of replacing sugar with yogurt and a variety of low-GI fruit juices. This approach also involves using various low-GI raw materials, such as unsweetened skimmed milk powder, to create cakes with an improved texture and reduced GI levels [60]. Zhou., *et al*. (2018) found that adding figs, papaya, and dragon fruit to the cake can result in a low-GI cake due to their sugar-lowering properties [61]. According to Wang., *et al*. (2022), cakes made with xylitol instead of white sugar, buckwheat flour, and soybean flour instead of wheat flour, exhibited a blood glucose generation index of 33.1 as determined by a fingertip blood sampling [62].

Problems and prospects

Diabetic patients must adhere to strict dietary restrictions for an extended period to regulate their blood glucose levels. However, prolonged food avoidance can result in nutritional imbalances and increase the risk of developing new diseases. Low-GI bakery foods offer a more balanced dietary approach for diabetic patients, aiding in the management of diabetes. Consequently, these foods hold great potential for future development. However, the current low-GI bakery products still have some shortcomings.

Primarily, while changing the related process can help in reducing the GI of bakery products to some degree, at present, the main method to reduce the GI still relies on incorporating low-GI food ingredients to change the formula. However, the method of producing low-GI bakery products remains limited. The raw materials used in low-GI bakery meals, such as buckwheat, beans, and other grains. The processing of these ingredients is relatively challenging, resulting in a final product with a poor taste. Given these problems, it is imperative that we conduct further in-depth research on the mechanism of GI reduction. At the same time, there is a requirement for increased investment in the exploration of additional low-GI food ingredients. With the availability of improved methods for reducing the GI of food and a wider range of low-GI food ingredients, there is a potential for a greater variety of low-GI bakery food. This could lead to further development in the standardization and popularization of low GI bakery foods.

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Conflict of Interest

All authors declare that they have no conflict of interest.

Ethical Approval

This paper does not contain any studies with human participants or animals performed by any of the authors.

Informed Consent

Not applicable.

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