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Low glycemic index food products using microorganisms

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Abstract
The rising prevalence of metabolic disorders like diabetes and obesity has increased the demand for low glycemic index (GI) foods, which help regulate blood glucose levels and support metabolic health. Microorganisms play a pivotal role in the development of such functional foods through fermentation and enzymatic modifications. These processes reduce carbohydrate digestibility, increase resistant starch content, and produce bioactive compounds such as exopolysaccharides (EPS), short-chain fatty acids (SCFAs), and γ-aminobutyric acid (GABA). Fermentation by microorganisms such as *Lactobacillus*, *Bifidobacterium*, and *Monascus* not only lowers the GI of foods but also enhances their nutritional and sensory properties. This review examines the mechanisms by which microorganisms influence glycemic response and highlights the applications of fermented low-GI foods—such as dairy, cereals, and soy products—in managing chronic conditions and improving gut health. Advancing microbial-based strategies offers a sustainable and innovative approach to combat metabolic diseases and promote long-term health.

Keywords: Glycemic index, lactic acid bacteria, mechanism, *Monascus*

1. Introduction
The global increase in cases of diabetes and metabolic syndrome highlights the pressing necessity for novel dietary approaches aimed at effectively regulating blood glucose levels. The interest in including low glycemic index (GI) foods has grown markedly since they lead to a more gradual and controlled increase in blood sugar levels when set against high GI options. Conventional dietary methods aimed at reducing the GI of foods typically involve alterations in meal composition and various food processing techniques. Nevertheless, recent breakthroughs in food science have revealed the promising potential of utilizing microorganisms to develop low GI food products [1]. Microorganisms, particularly those participating in fermentation processes, are integral to modifying the carbohydrate profile of food substances, consequently diminishing their glycemic impact. Lactic acid bacteria, which encompass varieties such as *Lactobacillus* and *Bifidobacterium*, undertake fermentation that is known to produce bioactive compounds that positively impact glucose metabolism. Some bacterial varieties can change carbohydrates into organic acids and different metabolites, which might obstruct the digestion and absorption of sugars, ultimately causing a lower glycemic response [2].

Microorganisms have been used to create low GI meals to make fermented foods including sourdough bread, yogurt, natto, tempeh, kimchi, and sauerkraut. For example, when bread dough is fermented by LAB, the resulting product may have a substantially lower GI than non-fermented bread. Similarly, because of the metabolic processes of advantageous microbes, fermented soy products like natto and tempeh have lower glycemic indices [3]. The interaction of food matrices and microbes presents a viable path toward the creation of functional foods that regulate blood sugar levels.

This review article explores the different ways that microorganisms reduce the GI of foods, the kinds of microbes that are used, and the health advantages of eating these fermented low GI foods. By examining these facets, we hope to demonstrate how microbial fermentation might be used to develop novel dietary solutions that promote metabolic health.

2. Understanding Glycemic Index and Glycemic Load: Definitions and Classification
A numerical scale called the GI calculates how much blood glucose levels rise after

consuming a food item. GI and carbohydrate content per serving are combined to create glycemic load (GL), which offers a more thorough assessment of a food's effect on blood sugar [4]. Rice, white bread, and sugary drinks are high-GI foods, whereas lentils, beans, nuts, and some fruits are low-GI meals. On a scale of 0 to 100, GI measures the increase in blood glucose levels following the consumption of particular foods [5]. Foods are categorized as:

- Low GI (≤55): Lentils, beans, nuts, seeds, some fruits.
- Medium GI (56-69): Whole-wheat bread, oatmeal, brown rice.
- High GI (≥70): White bread, sugary drinks, pastries, white rice [5].

Foods packed with fiber, protein, or healthy fats that have a low glycemic index slow down the absorption and digestion of sugars and carbohydrates [6]. The legumes like lentils and chickpeas, whole grains like quinoa and oats, fruits like apples and berries, nuts and seeds like almonds and chia seeds, and non-starchy vegetables like spinach and broccoli are a few examples of low GI foods [7]. Better control of blood sugar, better gut health due to the higher fiber content, increased satiety for weight management, and a lower risk of chronic diseases like type 2 diabetes [8] and cardiovascular disease are some of the benefits of consuming low-GI foods [9]. Conversely, foods with a GI of 70 or higher cause an abrupt spike in blood glucose level due to the fact they are rapidly absorbed and digested. Usually refined or processed, these foods don't include enough protein or fiber for regulating the release of glucose [10]. Examples include refined grains such as white bread and rice, sugary foods like candies and soft drinks, starchy vegetables like potatoes, and processed snacks like chips [11]. Consuming high-GI meals on a regular basis can raise your risk of obesity, cardiovascular disease, type 2 diabetes, and insulin resistance [8].

2.1. Traditional fermented foods and beverages

Traditional fermented foods and beverages from various areas, exhibiting their nutritional value. Fermented products such as Japanese miso and natto, Korean doenjang, meju, and chungkookjang, and Indonesian tempeh are examples of fermented soybean products that are high in vitamins B1, B2, B3, and B6, as well as essential minerals (Ca, Fe, Na, and K), amino acids (lysine, histidine, and arginine), and fatty acids (linolenic and oleic acid). These products have special health advantages, supporting improved nutrition absorption and gut health [12]. Vitamins C, B1, B2, and B3, as well as minerals like calcium and magnesium, are abundant in fermented cabbage products, such as Korean kimchi and European, Chinese, and American sauerkraut. These foods support immune and cardiovascular health because they contain a range of amino acids, including arginine and lysine, as well as good fatty acids [13].

3. Glycemic index reduction using microorganism

A natural and efficient method of lowering the glycemic index (GI) of foods is the use of microorganisms, particularly lactic acid bacteria (LAB), which include *Lactobacillus* species, *Streptococcus* species, *Leuconostoc* species, and other microorganism are *Saccharomyces cerevisiae*, *Zymomonas mobilis*, *Monascus* species, and other fermentative microbes. These microbes alter the digestion and structure of carbohydrates, which lowers the postprandial glycemic response [14].

3.1. Microorganism in fermented foods

The action of microorganisms including bacteria, yeasts, and molds gives fermented foods their distinct flavors, textures, and health advantages. These microbes create metabolites such as organic acids, alcohol, gasses, and bioactive substances by fermenting the sugars and other nutrients in the raw materials. These metabolic products improve the food's nutritional value and functional qualities in addition to preserving it [15]. The microorganisms present in the fermented food is listed in the table 1.

3.2. Modulating Food Glycemic Response by Microorganisms

Through fermentation, microorganisms modify the structure and composition of carbohydrates, which helps to modulate the glycemic response of meals. This process lowers postprandial blood glucose levels by delaying the digestion of carbohydrates and the absorption of glucose. Important microbial processes that reduce the glycemic index (GI) of different diets include the creation of beneficial compounds, the enzymatic modification of starch, and the production of organic acids [16]. *L. mesenteroides*, *L. plantarum*, and *L. acidophilus* are examples of lactic acid bacteria (LAB) that produce lactic acid during fermentation. This lactic acid reacts with starch molecules to create resistant starch (RS). A slower release of glucose results from resistant starch's resistance to small intestine enzymatic breakdown. Additionally, amylase, the enzyme that converts starch to glucose, is less active when the food matrix is acidified by lactic acid. The glycemic response is considerably decreased by these two effects [17].

3.3. Mechanisms of GI Reduction by Microorganisms

Through a variety of metabolic processes, microbes can change the structure of carbohydrates, their digestibility, and the absorption of glucose, which lowers the glycemic index (GI) of diets. These processes include fermentation and resistant starch formation, enzymatic starch modifications, the production of bioactive substances, and the formation of organic acids. Example of the microorganism and their impact listed in table 2.

3.3.1. Fermentation and Resistant Starch Formation

Microbial fermentation facilitates the conversion of digestible starch into resistant starch (RS), which is indigestible by human digestive enzymes. The following causes this: Lactic Acid Bacteria (LAB) by generating lactic acid, strains such as *L. plantarum* and *L. acidophilus* reduce the pH of the food matrix. Retrogradation, the process by which gelatinized starch recrystallizes into a less digestible form to generate resistant starch, is facilitated by the acidic environment. Without creating a sharp increase in blood sugar, resistant starch enters the colon and is digested by the gut bacteria to produce short-chain fatty acids (SCFAs) [18].

During fermentation, microorganisms produce a variety of enzymes, including glucosidases, amylases, and proteases, which alter starch and its digestibility [19]. Partial hydrolysis of starch lowers the glycemic load by breaking down complex carbohydrates into smaller, less digestible components. The structure of starch molecules, such as the branching patterns in amylopectin, is altered by enzymatic action, increasing their resistance to digestion [20]. For instance, *A. oryzae*, which is used to make miso and soy sauce, contains amylases that make carbs less digestible (21). When utilized in tempeh fermentation, *R. oligosporus* breaks down complex carbohydrates into forms that are harder to digest [22].

3.3.2. Organic Acid Production

Lactic acid, acetic acid, and propionic acid are among the organic acids that microorganisms—particularly LAB and acetic acid bacteria (AAB)—produce during fermentation. The following mechanisms are how these acids affect GI, the inhibition of enzymes: Organic acids slow down the conversion of starch to glucose by inhibiting α-amylase activity. Delays in Gastric Emptying: Organic acids slow down the rate at which the stomach empties, which causes glucose to enter the bloodstream gradually. Reduction of Starch Hydrolysis: When organic acids interact with starch, they create complexes that are difficult for enzymes to break down, like amylose-lipid complexes, which decrease the starch's digestibility [23].

3.3.3. Production of Sugar Alcohols

Microorganisms such as LAB produce sugar alcohols, such as sorbitol and mannitol. The glycemic response is reduced by these sugar alcohols' slower absorption in the digestive system [24]. The sugar alcohol produced by LAB represented in the table 3.

3.3.4. Exopolysaccharide (EPS) Synthesis

Certain strains of lab derived LAB (*L. rhamnosus*, *L. delbrueckii*) and yeast (*S. cerevisiae*) produce exopolysaccharides during fermentation. There are two types of EPS, homo-polysaccharides: Composed of one type of monosaccharide (e.g., glucose or fructose) and hetero-polysaccharides: Contain two or more types of monosaccharides, contributing to their functional diversity [25].

To lower the GI in the food, EPS increases the viscosity of the food matrix, forming a physical barrier that slows down the diffusion and absorption of glucose in the intestines as well as the digestion and absorption of carbohydrates. Because of its gel-like consistency, EPS slows the pace at which glucose diffuses over the intestinal wall by forming a protective layer surrounding carbohydrates in the intestinal lumen. As prebiotics, EPS specifically promotes the growth of good gut bacteria such as *Akkermansia muciniphila* and *Bifidobacterium*. Short-chain fatty acids (SCFAs), such butyrate and propionate, are produced as a result, and they improve insulin sensitivity, control glucose metabolism, and lessen systemic inflammation [26].

3.3.5. Formation of Anti-Obesity Metabolites

Gamma-aminobutyric acid (GABA), conjugated linoleic acid (CLA), and short-chain fatty acids (SCFAs) are all products of microbial fermentation. These metabolites help lower GI by improving insulin sensitivity and having hypoglycemic effects. SCFA generated when the intestinal microbiota ferments resistant starch in the colon. Acetate, propionate, butyrate, and other SCFAs improve insulin sensitivity, control glucose metabolism, and lessen blood glucose increases after meal [27]. Proteolytic enzymes in fermented dairy products produce bioactive peptides that imitate insulin and improve cells' absorption of glucose [28].

3.4. Lowering Glycemic Index Using *Monascus*

The filamentous fungal genus *Monascus* is well known for its use in food fermentation, including red yeast rice. Its ability to lower the glycemic index (GI) of foods high in carbohydrates has drawn a lot of attention because of its metabolic processes and the beneficial substances it produces [29]. The production of bioactive metabolites during fermentation, such as Monacolin K (a natural statin), which improves insulin sensitivity and increases glucose absorption, is one of the main ways that *Monascus* decreases GI. Pigments with antioxidant qualities, such as rubropunctatin and monoscorubrin, lower oxidative stress, which is associated with better glucose metabolism. Additionally, it has been demonstrated that γ-Aminobutyric Acid (GABA), which is produced during *Monascus* fermentation, can enhance glucose tolerance and regulate insulin release [30].

4. Applications of low glycemic index food

Foods with a low glycemic index (GI) have several uses, particularly in the management and prevention of chronic illnesses. Because they help control blood glucose levels and reduce postprandial surges, these meals are especially advantageous for people with diabetes. Low-GI foods enhance glycemic control and lower the risk of diabetic consequences including neuropathy and cardiovascular disease by releasing glucose gradually and steadily. They are also essential to weight-loss plans because their prolonged energy release helps suppress appetite and lower total caloric intake, which helps people avoid overeating. Low-GI foods are therefore beneficial for reducing obesity and the health problems that go along with it [8, 9].

Moreover, low-GI diets have been linked to a reduced risk of developing insulin resistance, metabolic syndrome, and certain types of cancer. Incorporating low-GI foods into daily diets promotes sustained energy levels and long-term health, making them an essential component of a balanced and preventative dietary approach.

Table1: Microorganism in fermented foods and their nutritional benefits

Food	Identified Microorganisms	Region	Nutritional Benefits	References
Kimchi	*L. mesenteroides*, *L. sakei*, *L. plantarum*, *L. citreum*, *L. gasicomitatum*, *L.* gelidum, L. *brevis*, *Weissella koreensis*, *W. confusa*, *L. curvatus*	Korea	Rich in vitamins C and K, probiotics, and antioxidants	[31]
Miso	*A. oryzae*, *S. cerevisiae*	Japan	Rich in vitamins C and K, probiotics, and antioxidants	[32]
Natto	*Bacillus subtilis*	Japan	Rich in vitamins C and K, probiotics, antioxidants and fiber	[32]
Sauerkraut	*L. mesenteroides*, *L. fallax*, *Leuconostoc* sp., *L. plantarum*, *L. brevis*	China	Anti-inflammatory, low calorie and anticancer	[33]
Sourdough	*Fructilactobacillus sanfranciscensis*, *L. reuteri*, *L. panis*, *L. pontis*, *L. frumenti*, *Leuconostoc*, Weissella, *S. cerevisiae*	Europe	Low glycemic index, improved mineral absorption.	(34)
Kombucha	*S. cerevisiae*, *Acetobacter xylinum*	Global	Contains organic acids and antioxidants.	[32]
Kefir	*L. delbrueckii subsp. Bulgaricus*, *L. helveticus*, *L. brevis*, *L. plantarum*, *L. kefiranofaciens*, *L. lactis subsp. Lactis*, *Streptococcus thermophilus*, *Kluyveromyces marxianus*, *Candida inconspicua*, *C. maris*, *S. cerevisiae*	North Caucasus Mountains	Rich in vitamins C and K, probiotics, and antioxidants, bone health and digestive health	[32]
Yogurt	*S.thermophilus*, *L. delbrueckii subsp. bulgaricus*	Middle East	High in calcium, protein, and probiotics for gut health.	[35]
Gochujang	*B. amyloliquefaciens*, *B. licheniformis*, *B. subtilis*, *B. velezensis*, *Oceanobacillus* sp., *C. lactis*, *Zygosaccharomyces rouxii*	Korea	Rich in vitamins C and K, probiotics, antioxidants and fiber	[36]
Soy Sauce	*A. oryzae*, *L. delbrueckii*	East Asia	Source of umami flavor and fermented peptides.	[32]
Pozol	*Lactobacillus*, *A. azotophilum*	Pre-Columbian Mesoamerica	Rich in vitamins C and K, probiotics, antioxidants	[37]
Tempeh	*L. plantarum*, *R. oligosporus*, *L. fermentum*, *L. reuteri*, *L.s lactis*	Indonesia	Source of protein, vitamins, and isoflavones.	[38]

Table 2: Mechanisms of glycemic index reduction by specific microbial processes

Mechanism	Microorganisms Involved	Key Metabolites/Processes	Impact on Glycemic Response	Example Foods	References
Fermentation	*L. plantarum*, *L. acidophilus*, *L. mesenteroides*	Production of lactic acid, resistant starch formation	Delays starch digestion, reduces α-amylase activity	Sourdough, Kimchi	[39]
Enzymatic Starch Modification	*A. oryzae*, *R. oligosporus*	Production of amylases and proteases	Alters starch structure, reducing digestibility	Miso, Soy Sauce, Tempeh	[40]
Exopolysaccharide (EPS) Synthesis	*L. rhamnosus*, *S. cerevisiae*	Viscous matrix formation	Slows glucose diffusion and intestinal absorption	Yogurt, Kefir	[41]
Organic Acid Production	*L. casei*, *Acetobacter spp.*	Acetic acid, propionic acid, lactic acid	Reduces enzyme activity, slows gastric emptying	Kombucha, Pickled Vegetables	[42]
Sugar Fermentation	*S. cerevisiae*, *Z. mobilis*	Conversion of sugars to ethanol and carbon dioxide	Decreases total sugar content	Beer, Bread	[24]
SCFA Production	*Bifidobacterium spp.*, *L. fermentum*	Acetate, propionate, butyrate	Improves insulin sensitivity, enhances glucose metabolism	Probiotic Supplements	[43]
Production of Bioactive Metabolites	*Monascus spp.*, *Lactobacillus spp.*	γ-Aminobutyric acid (GABA), conjugated linoleic acid (CLA)	Enhances glucose tolerance, reduces inflammation	Red Yeast Rice, Fermented Dairy	[44]

Table 3: Different sugar alcohol production by LAB and the example organism

Sugar Alcohol	Glycemic Index	Producing LAB	Common Food Applications	Fermentation Pathway	Role in Glycemic Management	References
Sorbitol	9.0	*L. casei*, *L. plantarum*	Sugar-free gums, candies	Glucose reduction via sorbitol dehydrogenase	Slower absorption reduces postprandial glucose spikes	[45]
Mannitol	0.0	*L. brevis*, *L. intermedius*, *L. reuteri*, *L. mesenteroides*	Sugar-free syrups, processed foods	Fructose conversion via mannitol-1-phosphate dehydrogenase	Reduces overall sugar content in foods	[24]
Erythritol	0.0	*L. florum*, *L. citreum*, *Oenococcus kitaharae*	Baked goods, beverages	Fermentation of glucose and erythrose-4-phosphate	Does not raise blood sugar; ideal for insulin resistance	[46]
Xylitol	13.0	*L. lactis*	Chewing gums, toothpaste	Xylose reduction via xylitol dehydrogenase	Slower metabolic rate helps maintain stable glucose levels	[47]

5. Conclusion

The development of low glycemic index (GI) food products using microbes is a promising strategy for improving human health and controlling metabolic diseases including obesity and diabetes. Microorganisms such as *Lactobacillus*, *Bifidobacterium*, and *Monascus* change the structure and digestibility of carbohydrates, decrease the amount of quickly digested sugars, and increase the synthesis of bioactive substances like short-chain fatty acids, γ-aminobutyric acid (GABA), and exopolysaccharides through fermentation and enzymatic processes. These changes enhance a food's nutritional profile and functional advantages in addition to lowering its GI. Additionally, fermented low-GI foods have shown great promise in lowering the risk of chronic diseases, enhancing gut health, and controlling blood glucose levels. Microbial fermentation helps close the gap between old methods and contemporary health requirements in the manufacture of low-GI foods. This strategy enables the development of novel, functional foods that meet the rising demand for dietary choices that are both sustainable and health-conscious. Future studies should concentrate on improving fermentation techniques and microbial strains to increase the scalability and effectiveness of producing low-GI foods while maintaining safety and sensory acceptability. By providing easily accessible and reasonably priced methods of controlling glycemic response and enhancing general health, incorporating these developments into dietary practices can have a substantial positive impact on public health.

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