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Functional Food Development for Metabolic Health: A Review of Dietary Strategies for Preventing Obesity and Type 2 Diabetes

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Abstract: The global increase in obesity and incidence rate of type 2 diabetes (T2D) poses a major challenge to the global public health system. Metabolic diseases, such as insulin resistance, chronic inflammation, and glucose metabolism disorders, are the root causes of these two diseases. Functional foods refer to products that have health benefits in addition to core nutritional components, and are promising dietary therapies for preventing and treating metabolic diseases. This review attempts to summarize the scientific evidence for the main dietary components, namely high-protein products, dietary fiber and prebiotics, low glycemic index (GI) components, and phytochemicals. Research has shown that these ingredients can significantly increase satiety, improve insulin sensitivity, balance gut microbiota homeostasis, and alleviate postprandial blood sugar spikes. In addition, this article also delves into technical strategies to enhance the efficacy of functional foods, including ingredient engineering, fermentation process optimization, sensory balance formula design, and advanced packaging technology. These innovative methods are crucial for ensuring product stability and increasing consumer acceptance. Functional foods have enormous development opportunities, but their cultivation still faces many challenges, including insufficient stability of active ingredients, differences in consumer taste preferences, and globally unified regulations. In the future, in-depth research on personalized nutrition methods and active promotion of consumer education are crucial for achieving breakthroughs. By deeply integrating high-tech innovations in nutrition science and food technology, as well as public health promotion measures, functional foods will become a shining star in preventing metabolic diseases worldwide.

Keywords: Metabolic health, Functional foods, Obesity, Type 2 diabetes, Dietary strategies

1. Introduction

Obesity and type 2 diabetes (T2D) have become important public health problems worldwide, causing heavy economic and health burdens to society. According to the data of the World Health Organization (WHO), by 2022, the global obese population will exceed 650 million [1], and the prevalence of diabetes is expected to increase significantly in the coming decades [2]. Both conditions are tightly linked to metabolic dysfunction, hallmarked by insulin resistance, chronic

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low-grade inflammation, and perturbed glucose homeostasis. Therefore, the prevention of metabolic diseases through dietary interventions and nutritional strategies is increasingly receiving attention.

Functional foods are those that deliver health benefits beyond basic nutrition [3]. In recent years, research has found that functional foods containing dietary fiber, prebiotics, high-quality protein, low glycemic index (GI) components, and plant active substances have a positive effect on improving metabolic health. For example, dietary fiber can regulate intestinal flora and reduce postprandial blood glucose response, thus preventing diabetes [4].

Although functional foods have great potential in the field of metabolic health, they still face many challenges in the actual development process, such as the stability of active ingredients, the acceptance of product taste, and shelf-life issues [5]. Therefore, overcoming these challenges through advanced ingredient engineering technology, food processing technology, formula design, and innovative packaging technology is currently an important research direction. In addition, issues of consumer acceptance, regulatory approval, and scientific dissemination are also important obstacles in the current process of promoting functional foods [6].

This paper aims to explore the current strategies of functional food for preventing obesity and type 2 diabetes, review the latest research progress, and analyze the existing challenges and future development directions. By integrating research results from clinical, nutritional, and food technology fields, this article will provide reference for the development and application of functional foods in the future.

2. Understanding metabolic dysregulation

Obesity and type 2 diabetes (T2D) have become important public health problems worldwide, causing heavy economic and health burdens to society. According to the data of the World Health Organization (WHO), by 2022, the global obese population will exceed 650 million (World Health Organization, 2022), and the prevalence of diabetes is expected to increase significantly in the coming decades [2]. Both pathologies are rooted in metabolic dysregulation, marked by insulin resistance, chronic inflammation, and disrupted glucose homeostasis. Therefore, the prevention of metabolic diseases through dietary interventions and nutritional strategies is increasingly receiving attention.

2.1. Obesity and Type 2 Diabetes: a metabolic overview

Obesity is a chronic disease characterized by excessive accumulation of fat in the body, typically diagnosed by a body mass index (BMI≥30 kg/m^2). Long-term obesity will lead to a series of metabolic problems such as insulin resistance, dyslipidemia and hypertension, which together increase the risk of type 2 diabetes [7]. Type 2 diabetes is a chronic metabolic disease characterized by insulin resistance and impaired islet function, which leads to a long-term increase in blood sugar levels, thus causing extensive damage to cardiovascular, renal and nervous systems [8].

Insulin resistance plays a central role in the pathological process of obesity and type 2 diabetes. Excessive adipose tissue, especially visceral fat, can lead to chronic low-level inflammation and dysfunction of adipose tissue, thereby causing damage to the insulin signaling pathway and reducing tissue sensitivity to insulin [9]. In addition, obesity is also closely related to the imbalance of intestinal flora. The change of intestinal flora may further aggravate the metabolic disorder and promote the development of obesity and diabetes [10].

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2.2. Role of diet and nutritional components

Diet plays a key role in preventing and managing obesity and type 2 diabetes. Numerous studies have shown that a balanced and nutrient-rich diet can significantly improve metabolic health. For example, the Mediterranean diet model has been proved to be able to effectively reduce the risk of cardiovascular disease, improve insulin sensitivity, and reduce the incidence rate of diabetes because it is rich in monounsaturated fatty acids, dietary fiber and polyphenols [11].

Specific nutritional components also have a significant impact on metabolic health. High-fiber foods significantly improve blood glucose control and insulin sensitivity by delaying glucose absorption, promoting satiety, and improving gut microbiota [12]. Protein intake helps control weight and blood sugar levels by promoting muscle mass maintenance and increasing postprandial satiety [13]. In addition, limiting refined carbohydrates and reducing sugar intake are widely considered important strategies for preventing obesity and improving sugar metabolism [14].

Therefore, reasonable diet structure and intake of key nutrients are expected to effectively prevent and alleviate metabolic diseases such as obesity and type 2 diabetes.

3. Functional foods and their role in metabolic health

3.1. High-protein foods

High-protein food plays an important role in improving metabolic health, and preventing obesity and type 2 diabetes (T2D). Research has shown that increasing protein intake in moderation can effectively enhance satiety, reduce overall food intake, and promote weight management [13]. A high-protein diet can also help maintain muscle mass, especially during weight loss, by increasing basal metabolic rate and improving glucose metabolism.

Whey protein, as one of the representatives of high-quality proteins, is widely used in the development of functional foods. Whey protein is not only rich in essential amino acids, but also has good digestion and absorption properties, which can rapidly increase the concentration of amino acids in plasma, promote muscle synthesis, and suppress appetite [15]. A systematic review suggests that whey protein supplementation can significantly improve insulin sensitivity and reduce postprandial blood glucose levels [16].

In addition, plant-based proteins such as soy protein and pea protein have also received widespread attention due to their low calorie, high fiber, and rich functional components. A randomized controlled trial found that intake of soy protein can effectively reduce fasting blood glucose, improve insulin resistance, and have a positive lipid-lowering effect [17]. Therefore, the application of high protein foods in the field of functional foods has significant potential, and through rational product design and technological innovation, it is expected to provide more choices for improving metabolic health.

3.2. Dietary fiber and prebiotics

Dietary fiber and prebiotics play an important role in metabolic health. Dietary fiber helps to reduce postprandial blood glucose response by delaying gastric emptying and glucose absorption rate. A systematic review shows that the increase of dietary fiber intake significantly improves the blood sugar control of diabetes patients, and can reduce the risk of diabetes [12]. Probiotics such as inulin and resistant starch regulate gut microbiota structure, producing beneficial short-chain fatty acids (SCFAs), further improving insulin sensitivity and reducing inflammatory responses [10].

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3.3. Low Glycemic Index (GI) foods

Low glycemic index (GI) food is widely recognized in the prevention of obesity and diabetes because it can slowly release glucose and keep blood sugar stable. Epidemiological studies have confirmed that long-term consumption of a low GI diet can significantly reduce the risk of type 2 diabetes [18]. For example, oats, legumes, and whole-grain foods have lower glycemic index (GI) values, which not only effectively control postprandial blood glucose responses, but also prolong satiety, thereby helping with weight management and improving metabolic health.

3.4. Phytochemicals and bioactive compounds

Plant chemicals such as polyphenols, flavonoids, and other bioactive compounds are widely present in fruits, vegetables, and tea, and have been proven to have anti-inflammatory, antioxidant, and insulin sensitivity-improving effects. For example, catechins in green tea can improve obesity and insulin resistance by regulating fat metabolism and increasing energy expenditure [19]. In addition, flavonoids such as quercetin effectively alleviate chronic inflammation by inhibiting the inflammatory pathway, thereby further preventing and improving metabolic disorders [20].

4. Technological strategies in functional food development

4.1. Ingredient engineering

Ingredient engineering involves modifying or strengthening functional food ingredients to enhance their functional effectiveness and stability. For example, nanoencapsulation technology can effectively protect active ingredients from oxidation, photolysis, and thermal degradation, improving their bioavailability and stability. Liposomes and nanoemulsions are widely used nanoembedding technologies that have been proven to significantly improve the absorption rate of plant polyphenols, probiotics, and other active ingredients [21].

4.2. Processing technology

Food processing technology has a significant impact on the nutritional characteristics and stability of bioactive substances in functional foods. For example, fermentation processes can generate new functional compounds or enhance the activity of existing functional components through microbial metabolism. A study found that fermented soybean products can significantly increase the bioavailability of isoflavones, and improve their antioxidant and anti-inflammatory effects [22]. In addition, low-temperature processing techniques such as cold pressing are widely used to produce functional beverages rich in polyphenols and vitamins.

4.3. Formulation and sensory balance

The success of functional foods relies on a balance between nutritional efficacy and sensory acceptance. Reasonable formula design not only needs to consider the concentration and combination of functional ingredients but also needs to balance the taste, texture, and flavor of the product. For example, although high-fiber foods have good metabolic health benefits, they often have a rough or bitter taste. By using natural sweeteners, such as steviol glycosides or erythritol, the taste of high fiber foods can be effectively improved, thereby increasing consumer acceptance [23].

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4.4. Packaging and shelf-life considerations

Packaging technology is crucial in functional foods, as it can not only extend the shelf life of products but also maintain the stability of active ingredients in food. Active packaging technologies, such as antioxidant packaging, antibacterial packaging, and modified atmosphere packaging (MAP) have been widely used in the field of functional foods. Modified atmosphere packaging effectively delays oxidation reactions and microbial growth by adjusting the gas ratio inside the packaging, significantly extending the shelf life of food and maintaining its sensory quality and nutritional value [24].

5. Challenges and future perspectives

Although functional food has great potential in improving metabolic health and preventing obesity and diabetes, there are still many challenges in the process of development and promotion. Firstly, the stability and bioavailability of active ingredients are technical challenges in the development of functional foods. Further research is needed on how to effectively protect these ingredients from losses during processing and ensure their activity is maintained during storage and consumption [21].

Secondly, the sensory acceptance of functional foods is one of the important factors for market success. Functional ingredients often have a negative impact on the texture, flavor, and overall sensory attributes of food. Balancing nutritional benefits with consumer taste preferences is an important issue that developers must face.

In addition, unclear regulatory policies and standards also limit the promotion and market acceptance of functional foods. Different countries and regions have different definitions, approval procedures, and health declaration standards for functional foods, and a unified international standard is also waiting to be established to promote the global development of functional foods [5].

In the future, the development of precision nutrition and personalized functional foods will become an important trend. With the help of genomics, big data analysis, and artificial intelligence technology, we can more accurately identify individuals' nutritional needs and develop functional foods for specific populations or individuals. Meanwhile, strengthening consumer education and enhancing public awareness and acceptance of functional foods are also key to future development.

6. Conclusion

Functional food has significant potential in preventing and managing metabolic diseases such as obesity and type 2 diabetes. This article reviews the roles of key functional ingredients such as high-protein foods, dietary fiber and prebiotics, low-glycemic-index foods, and phytochemicals, demonstrating their importance in improving metabolic health. At the same time, key technical strategies involved in the development of functional foods were also discussed, including ingredient engineering, processing technology, formula design, and packaging and shelf-life management.

However, despite significant research progress, the functional foods field still grapples with key challenges. These include ensuring the stability of active ingredients, achieving sensory acceptance among consumers, and navigating inconsistent international regulations. Future research should therefore concentrate on boosting the bioavailability of these actives, refining their sensory profiles to enhance consumer appeal, and advancing globally harmonized standards. Additionally, precision nutrition and personalized food development are emerging as pivotal trends in functional foods.

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Ultimately, sustained innovation and informed consumer choices will position functional foods as a global catalyst for better health.

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