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Functional foods against metabolic disorders: A review

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Abstract
The increasing incidence of metabolic diseases, which include obesity, insulin resistance, and type 2 diabetes, has led to an increasing need for complementary therapies to address these health issues. Functional foods, which contain bioactive compounds such as polyphenols and omega-3 fatty acids, have been shown to have beneficial effects on metabolic health, including the treatment of obesity and diabetes. This introduction explores the potential of functional foods to prevent or treat metabolic diseases by examining the impacts of certain bioactive chemicals on important metabolic health pathways present in these foods along with some recent approaches like nutrigenomic and the interaction of bioactive compounds of functional foods to treat metabolic disorders by altering gene expression. Through an examination of the scientific literature authored by a range of writers, we are able to identify the many viewpoints and continuing investigations that highlight the importance of functional food within the current nutritional context.

Keywords: Functional foods, bioactive compounds, metabolic disorders, omega-3 fatty acids, human health

Introduction
The idea of functional foods transcends the conventional perspective of food as just a supply of necessary nutrients, marking a paradigm change in our understanding of nutrition. Nutraceuticals, or functional foods, are characterized as food items that have potential physiological and therapeutic benefits in addition to their fundamental nutritional value (Hasler, 2002) [8]. The investigation of functional foods has accelerated recently due to a growing understanding of the close relationship between nutrition and health.
Functional foods are a broad category of goods that include anything from probiotic-rich yogurts and fortified cereals to herbal teas and oils with added omega-3 fatty acids (Martinez Steele *et al.,* 2017) [13]. The investigation of the bioactive substances found in these foods and their potential to prevent or treat a range of medical disorders has piqued the attention of the scientific community. The market for functional foods is growing as people seek proactive ways to well-being and become more health aware. This indicates a dynamic interaction between public health, medicine, and food science. Tewari *et al.* (2022) [6] reported that functional foods can improve our health and well-being by lowering our chance of contracting specific illnesses or ailments. In order to meet nutritional needs and shield the body from many illnesses and ailments like diabetes, cancer, obesity, and cardiovascular disease, among others, functional foods should be a balanced part of a regular diet. It is used as dietary supplements and a general term for nutraceuticals (probiotics, prebiotics, synbiotics, etc.). Probiotics, prebiotics, and functional foods rich in a variety of nutrients that are useful in day-to-day living are also included in this group of nutraceuticals.
This review article will be summarized regarding functional foods and their effects on different metabolic disorders.

Metabolic Disorders
Metabolic disorders are a broad category of health problems defined by abnormalities in the body's normal metabolic functions, which include energy synthesis, usage, and storage (Byrne *et al.*, 2009) [3]. These illnesses may impact many organ systems, resulting in a wide range of symptoms and problems. The complex interaction of genetic genetics, lifestyle variables, and environmental effects all contribute to the development and progression of metabolic diseases, making them a major worldwide health problem.

An imbalance in essential physiological processes, such as glucose and lipid metabolism, insulin sensitivity, and energy homeostasis, is at the heart of metabolic diseases. This imbalance often leads to illnesses such as obesity, insulin resistance, type 2 diabetes, and dyslipidemia, each of which poses unique problems to general health. The frequency of metabolic diseases has grown significantly in recent years, along with changes in dietary habits, sedentary lifestyles, and rising obesity rates (Ormazabal *et al*., 2018) [18].

Understanding metabolic disorders is critical for doctors, researchers, and the general public, since these problems affect not just individual health but also contribute to the global burden of chronic diseases. This overview prepares the reader for a more in-depth examination of individual metabolic diseases, their underlying processes, and the many methods to prevention, treatment, and intervention.

Diverse Aspects of Functional Foods

a) **Antioxidant-rich Superfoods:** Certain functional foods, such as berries and dark green vegetables, are praised for having a high antioxidant content. According to Robertfroid (Robertfroid, 2000) [19], antioxidants are essential for scavenging free radicals, promoting cellular health, and perhaps reducing the risk of illnesses linked to oxidative stress.
b) **Gut Health Benefits of Probiotics:** Probiotics are good bacteria that are added to the gut and may be found in fermented foods like kefir and yogurt. These microbes might improve immunological function, improve digestion, and possibly have favorable impacts on mental health (Hasler, 2002) [8].
c) **The Benefits of Omega-3 Fatty Acids for Heart Health:** Omega-3 fatty acid-enriched functional foods, such flax seeds and fatty fish, have been linked to cardiovascular advantages. According to Mozaffarian and Wu (Mozaffarian & Wu, 2018) [16], these substances may enhance lipid profiles, decrease blood pressure, and lessen inflammation.
d) **Spices and Herbs for Healing Culinary Treats:** Herbs and spices not only provide taste to functional meals but also introduce bioactive chemicals that may have positive effects on health. For instance, curcumin, which has anti-inflammatory qualities, is present in turmeric (Tapsell *et al.*, 2006) [24].

The complex nature of functional meals is becoming more and clearer as study continues. In addition to their nutritional worth, these foods include substances that have the potential to favorably affect a variety of physiological processes, therefore improving people's general well-being.

The objective of this introduction is to provide a thorough summary of the dynamic field of functional foods, emphasizing their potential benefits for disease prevention and health promotion. Through an examination of the scientific literature authored by a range of writers, we are able to identify the many viewpoints and continuing investigations that highlight the importance of functional foods within the current nutritional context.

Effects of functional foods against metabolic disorders

The rising incidence of metabolic illnesses, which include obesity, insulin resistance, and type 2 diabetes, has led to an increasing need for complementary therapies to address these health issues. Functional foods are a new and exciting direction in the pursuit of metabolic well-being. They are a class of food products that go beyond simple nutritional content to provide possible physiological advantages. This introduction explores the potential of functional foods to prevent metabolic diseases by examining the impacts of certain bioactive chemicals on important metabolic health pathways present in these foods (Fu *et al*., 2022) [5].

Functional meals have the ability to lower inflammation, increase insulin sensitivity, and modify the gut flora. Bioactive substances such as omega-3 fatty acids, polyphenols, and probiotics are added to these meals. The complicated roles that these functional food components play in influencing metabolic processes are becoming apparent as research progresses. The goal of this study is to learn more about how including functional foods into diet programs may be a pleasant and complete way of boosting metabolic health and preventing the development or worsening of metabolic illnesses (Misra *et al*., 2021) [14].

Role of Omega-3 Fatty Acids in Metabolic Disorders

Omega-3 fatty acid-rich functional foods like flax seeds and fatty fish (like salmon and mackerel) have been shown to be effective in reducing the symptoms of metabolic disorders. According to Mozaffarian and Wu (Mozaffarian & Wu, 2018) [16], omega-3 fatty acids have anti-inflammatory qualities, enhance insulin sensitivity, and help control lipid metabolism. As a result, they may lower the risk of diseases including insulin resistance and dyslipidemia.

The bioactive constituent’s omega-3 fatty acids, namely docosahexaenoic acid (DHA) and eicosapentaenoic acid (EPA), are recognized for their anti-inflammatory properties. According to Oh *et al*. (Oh *et al.*, 2010) [17], these fatty acids are essential for controlling the release of pro-inflammatory cytokines and lowering the inflammatory response in adipose tissue. Chronic inflammation is known to contribute to insulin resistance and disruption of lipid metabolism in the setting of metabolic diseases.

Research indicates that via altering intracellular signaling pathways, omega-3 fatty acids may improve insulin sensitivity. It has been shown that EPA and DHA enhance insulin-stimulated glucose uptake in skeletal muscle cells by encouraging the activation of insulin receptors (Oh *et al.*, 2010; Weichhart & Säemann, 2009) [17, 25]. Additionally, by affecting the expression of genes involved in lipid oxidation and lipogenesis, these fatty acids help regulate lipid metabolism and may even enhance lipid profiles (Weichhart & Säemann, 2009) [25].

Omega-3 fatty acids have been shown to have beneficial impacts on metabolic health, including the treatment of obesity and type 2 diabetes. These advantages also extend to the cardiovascular system. Functional foods high in omega-3s provide a tailored approach to addressing inflammation and insulin resistance in the setting of metabolic diseases, constituting a dietary strategy that extends beyond basic nutrition.

Impact of polyphenol-rich foods on insulin sensitivity

Insulin sensitivity has been linked to several functional foods, especially those high in polyphenols like dark chocolate, green tea, and berries. With their ability to favorably impact insulin signaling and glucose metabolism, polyphenols have anti-inflammatory and antioxidant qualities that may be useful in the therapy and prevention of metabolic diseases (Mozaffarian & Wu, 2018; Pastoriza *et* *al.*, 2016) [16, 27].

Plant-derived polyphenols, such as flavonoids and phenolic acids, have a variety of biological functions. Research suggests that by altering intracellular signaling pathways involved in glucose absorption and utilization, these bioactive compounds may improve insulin sensitivity (Anhê *et al.*, 2015; Hooper *et al.*, 2017) [28, 29]. Quercetin and anthocyanins, two flavonoids present in berries, have been shown to enhance insulin sensitivity by affecting the activation of the insulin receptor substrate (IRS) and subsequent signaling cascades (Anhê *et al.*, 2015) [28].

Improvements in insulin sensitivity have also been associated with the use of green tea, which is high in catechins. By altering important proteins implicated in insulin-stimulated pathways, catechins, in particular epigallocatechin gallate (EGCG), may improve insulin signaling and increase glucose uptake in skeletal muscle cells (Mozaffarian & Wu, 2018; Park *et al.*, 2012) [16, 30]. Furthermore, dark chocolate, which has been shown to contain flavonoids like epicatechin, may improve insulin sensitivity due to its vasodilatory and anti-inflammatory properties (Grassi *et al.*, 2005; Mastroiacovo *et al.*, 2015) [31, 32].

Polyphenols' influence on insulin sensitivity is partly attributed to their anti-inflammatory characteristics. Metabolic diseases are characterized by chronic low-grade inflammation, which polyphenols may reduce by enhancing the action of insulin (Mozaffarian & Wu, 2018) [16]. All things considered, including functional foods high in polyphenols into the diet provides a tasty and perhaps therapeutic way to improve metabolic health.

Probiotics and Gut Microbiota in Metabolic Health

Probiotic-rich functional foods like yogurt and fermented dairy products help maintain the proper balance of gut bacteria. According to a new study, metabolic health is correlated with a healthy gut microbiota, which affects things like inflammation and energy metabolism. Probiotics may influence the makeup of the gut microbiota, which may have an effect on metabolic diseases including type 2 diabetes and obesity (Hill *et al.*, 2018; Tanida *et al.*, 2015) [9, 23].

Probiotics are living microorganisms that, when taken in sufficient quantities, boost the host's health. These good bacteria, which are mostly from the Lactobacillus and Bifidobacterium genera, work by altering the gut microbiota and improving the gastrointestinal tract's performance (Hill *et al.*, 2018) [9].

Studies reveal that the gut microbiota is essential for metabolic functions, such as regulating host metabolism and obtaining energy from food (Tanida *et al.*, 2015) [23]. Dysbiosis, or imbalances in the gut microbiota, has been linked to diseases including insulin resistance and obesity. By encouraging the development of beneficial bacteria and inhibiting the proliferation of potentially dangerous germs, probiotics may aid in the restoration of a balanced microbiota (Hill *et al.*, 2018) [9].

Probiotics may benefit metabolic health, according to a number of studies. For instance, investigations on humans and animals have shown that certain strains of Bifidobacterium and Lactobacillus increase insulin sensitivity and decrease inflammation (Hill *et al.*, 2018; Tanida *et al.*, 2015) [9, 23]. Additionally, probiotic fermentation products such short-chain fatty acids may ameliorate insulin resistance and have an impact on host metabolism (Hill *et al.*, 2018) [9].

Including probiotic-rich functional foods in the diet like yogurt made with living cultures offers a delicious and perhaps medicinal way to promote gut health and metabolic balance.

Insulin Resistance and Type 2 Diabetes

Insulin resistance, a condition in which cells are less receptive to insulin's regulatory signals, eventually leading to decreased glucose absorption, is a common manifestation of metabolic diseases. This process is critical in the development and progression of type 2 diabetes, a chronic metabolic disease with a high worldwide incidence (American Diabetes Association, 2021) [1].

Insulin resistance develops as a result of a number of variables, including genetic predisposition, sedentary lifestyle, and high caloric consumption, especially of refined carbs and saturated fats (Scheen, 2018) [21]. As the cells in the body become less sensitive to insulin, glucose accumulates in the circulation, leading to hyperglycemia - a hallmark feature of type 2 diabetes.

Furthermore, chronic inflammation is linked to insulin resistance and the development of type 2 diabetes. Inflammatory processes affect insulin signaling pathways, worsening insulin resistance and decreasing glucose metabolism further (Wellen & Hotamisligil, 2005) [26]. The complicated interaction of genetics, lifestyle, and inflammatory pathways highlights the importance of insulin resistance as a key component in the spectrum of metabolic diseases.

Type 2 diabetes, defined by persistently increased blood glucose levels (Garai *et al*., 2023) [6], offers serious health hazards. Diabetes that is uncontrolled may lead to consequences such as cardiovascular disease, renal failure, and neuropathy (American Diabetes Association, 2021) [1]. Managing and preventing type 2 diabetes requires a complex strategy that includes lifestyle changes, pharmaceutical therapies, and, perhaps, the introduction of functional foods containing bioactive components such as polyphenols and omega-3 fatty acids.

Obesity and Dyslipidemia

Obesity, a common metabolic condition, results from an imbalance in energy intake and expenditure, resulting in an abnormal buildup of adipose tissue. This syndrome is closely connected to insulin resistance and persistent low-grade inflammation, which creates an environment permissive to the development of a variety of metabolic problems, including dyslipidemia (Kershaw & Flier, 2004; Saltiel & Olefsky, 2017) [11, 20].

Dyslipidemia is characterized by higher triglycerides, decreased high-density lipoprotein (HDL) cholesterol, and changes in the composition of low-density lipoprotein (LDL) cholesterol. These lipid abnormalities lead to atherosclerosis and cardiovascular disease, exacerbating the health consequences of obesity (Grundy *et al.*, 2018) [7].

In obese people, adipose tissue undergoes dynamic changes, generating pro-inflammatory cytokines and adipokines. Not only do these molecules aggravate insulin resistance, but they also contribute to dyslipidemia by affecting lipid metabolism in the liver and peripheral organs (Kershaw & Flier, 2004; Saltiel & Olefsky, 2017) [11, 20]. The complicated interplay between adipose tissue, inflammation, and lipid homeostasis highlights the linked nature of obesity and dyslipidemia within the metabolic disease spectrum.

Furthermore, the idea of metabolically healthy obesity, in which obese people have a better lipid profile and are less likely to have metabolic problems, adds richness to our understanding of the obesity-dyslipidemia association (Stefan *et al.*, 2013) [22]. Nonetheless, the overwhelming agreement highlights the need for comprehensive therapies that address both obesity and dyslipidemia in order to reduce cardiovascular risks and improve metabolic health.

Probiotics and Gut Microbiota in Metabolic Health

Yogurt and fermented dairy products, which include probiotics, have an important role in changing the balance of gut microbiota, regulating numerous aspects of metabolic health. According to a new study, maintaining a healthy gut microbiota is closely related to metabolic well-being, influencing parameters including energy metabolism, inflammation, and insulin sensitivity (Hill *et al.*, 2018; Tanida *et al.*, 2015) [9, 23].

Probiotics, which are living bacteria with proven health benefits, are predominantly found in the *Lactobacillus* and *Bifidobacterium* genera. These beneficial bacteria help to regulate metabolic processes by contributing to the complicated ecology of the gut microbiota (Hill *et al.*, 2018) [9].

According to research, dysbiosis, or an imbalance in gut microbiota composition, is linked to metabolic illnesses such as obesity and insulin resistance (Tanida *et al.*, 2015) [23]. Probiotics may help to correct these imbalances by encouraging the development of helpful bacteria while suppressing the growth of potentially dangerous germs.

Several studies have shown that probiotics have the ability to improve metabolic health. Specific strains of *Lactobacillus* and *Bifidobacterium*, for example, have been associated to improved insulin sensitivity and reduced inflammation (Hill *et al.*, 2018; Tanida *et al.*, 2015) [9, 23]. Furthermore, probiotic fermentation products, such as short-chain fatty acids, have been shown to modulate host metabolism and improve insulin resistance (Hill *et al.*, 2018) [9].

Incorporating probiotic-rich functional foods into the diet, such as yogurt containing live cultures, is a convenient and tasty way to maintain gut health while perhaps alleviating metabolic problems.

Nutrigenomic effect of functional foods on metabolic disorders

Nutrigenomics, a burgeoning field examining the intricate interplay between nutrition and an individual's genetic makeup, unveils the promising therapeutic dimensions of various functional foods in combating metabolic disorders. Polyphenol-rich foods, such as berries, green tea, and dark chocolate, emerge as epigenetic influencers capable of modulating gene expression associated with oxidative stress and inflammation. These polyphenols act as potent modifiers, orchestrating changes in the activity of crucial transcription factors and signaling pathways intricately involved in metabolic regulation (Mondal & Panda, 2020) [15]. Omega-3 fatty acids, abundant in fatty fish, flaxseeds, and walnuts, orchestrate nuanced alterations in gene expression pertinent to lipid metabolism and inflammation. Through intricate interactions with nuclear receptors and the modulation of inflammatory gene expression, omega-3 fatty acids contribute to the enhancement of lipid profiles and a reduction in inflammatory responses, crucial factors in mitigating metabolic disorders. Fiber-rich foods, exemplified by whole grains and legumes, exhibit their impact on gene expression related to glucose metabolism and insulin sensitivity. Notably, these dietary fibers wield a twofold influence, not only shaping the composition of the gut microbiota but also instigating the production of short-chain fatty acids that serves as a complex signaling mechanism profoundly affecting host metabolism. This holistic understanding of nutrigenomics underscores the tailored potential of incorporating these functional foods into dietary patterns, offering a meticulous and personalized approach for the prevention and management of metabolic disorders through the nuanced modulation of gene expression and intricate signaling pathways (Kaur *et al.*, 2018; Lagoumintzis & Patrinos, 2023) [10, 12].

Table 1: Functional foods that possessed the nutrigenomic effect against metabolic disorders [Source: Felisbino, *et al*., 2021]

Sl. No.	Associated genes	Function of gene	Potential bioactive compounds of foods to alter the expression of gene
1.	AGER gene	Specific recipient of advanced glycation end products.	Curcumin has the potential to exhibit antioxidant and anti-inflammatory properties, offering the ability to alleviate oxidative stress caused by AGEs. This is achieved by inhibiting the expression of the AGER gene in mouse liver cells and cardiac tissue. Additionally, curcumin showcases its capability to interact with transcription factors such as NFκB, leading to a reduction in gene transcription.
2.	ENPP1 gene	Transmembrane glycoprotein with effect on insulin signaling and glucose metabolism.	There is a lack of articles on the impact of foods or bioactive compounds on the modulation of the ENPP1 gene. However, it has been observed that zinc deficiency can impede the functions of specific ectoenzymes, including ENPP1.
3.	ESR1 gene	It encodes a transcription factor that responds to the action	In a CACO-2 cell study, high folic acid concentrations were found to induce methylation in the ESR1 gene. Zebularine decreased gene methylation, while genistein led to hypermethylation of the ESR1 gene promoter. Resveratrol increased ESR1 gene expression, and EGCG induced hypermethylation of ESR1, resulting in a non-significant decrease in expression.
4.	FFAR1 gene	Metabolic regulation of insulin secretion and hepatic glucose uptake *in vitro*.	Human cell studies reveal that anthocyanins in purple corn can activate the FFAR1 gene, a promising marker for addressing type 2 diabetes and its complications. Additionally, specific polyphenols, including anthocyanin, have been identified as capable of triggering the FFAR1 gene in pancreatic beta cells, indicating their potential role in diabetes prevention and treatment.
5.	FTO gene	It forms a nuclear protein involved in insulin signalling, ROS production, and adipose tissue development.	Research in humans and animals has linked the Mediterranean diet to the FTO gene, associated with type 2 diabetes onset. Although there's some indication that the diet may counter the genetic predisposition linked to the FTO gene, the underlying mechanism remains unclear.
6.	G6PC gene	Liver glucose production during fasting or T2DM.	EGCG consumption is linked to gluconeogenesis regulation by inhibiting glucose-6-phosphatase gene expression. Saffron stigma extract decreased G6PC gene expression in

			diabetic rats, while quercetin activated AMPK, downregulating the gene and reducing hepatic glucose production, as AMPK negatively controls G6PC.
7.	HNF4A gene	Regulator of hepatic gluconeogenesis and insulin secretion.	Luteolin, a natural flavone found in chamomile, peppers, and celery tea, lowers lipid levels in mouse cells through epigenetic mechanisms. It achieves this by suppressing the HNF4A gene and is linked to histone H3 acetylation.
8.	IGF2BP2 gene	Regulator of cellular metabolism.	Reduced dietary protein is associated with higher IGF2BP2 levels, but there is no scientific evidence on how polyphenols or the Mediterranean diet affect this gene's expression.
9.	IRS1 gene	Insulin signalling.	At low concentrations, EGCG inhibits gluconeogenesis without activating the IRS-1 gene in isolated hepatocytes. Polyphenol-rich green tea increases IRS1 gene expression in rat muscle. The ethyl acetate fraction from Molineria latifolia, rich in polyphenols, improves insulin sensitivity in diabetic rats by activating IRS1/AKT and modifying the phosphorylation of serine and tyrosine residues in related genes.
10.	NFE2 gene	Regulator of the expression of antioxidant proteins.	Human and animal studies suggest that EGCG and curcumin intake is associated with increased NFE2 levels. These compounds, serving as epigenetic agents, diminish gene methylation and activate the gene. Both EGCG in green tea and curcumin inhibit DNA methyltransferase and modulate histone modifications.
11.	NFE2L2/NRF2 gene	Regulator of the expression of antioxidant proteins.	Curcumin mitigates oxidative stress across various tissues through epigenetic demethylation, activating the NFE2L2/NRF2 gene, suggesting potential applications in diabetes prevention and treatment.
12.	NFKB1, NFKB2 gene	Transcription factor involved in anti-inflammatory pathways.	Flavonoids like fisetin, apigenin, quercetin, chrysin, isoliquiritigenin, rutin, genistein, and others demonstrate anti-inflammatory, antioxidant, and anti-apoptotic properties. These bioactive compounds inhibit NF-κB, primarily by reducing protein phosphorylation. This capability enhances vascularization in diabetes, lowering the risk of hypertension, as observed in diverse tissues of both humans and animals.
13.	PARP1 gene	DNA damage signalling.	Curcumin protects pancreatic islet cells from streptozotocin exposure by decreasing reactive oxygen species (ROS) generation, inhibiting poly ADP-ribose polymerase-1 enzyme activation (encoded by the PARP1 gene), and preventing depletion of ROS levels in scavenging enzymes. In HUVECs cells, flavonoids like rutin, quercetin, and flavone inhibit PARP activation, mitigating diabetes-related complications. These compounds interact with transcription factors and modulate gene expression.
14.	PCK1, PCK2 gene	The PCK1 gene carries the code for the formation of an enzyme called phosphoenolpyruvate caboxycin (PEPCK). This enzyme is a limiter of gluconeogenesis, that is, it regulates the speed of this process.	The polyphenol-rich Juniperus procera plant effectively reduces PEPCK gene expression in the liver and kidney cells of diabetic rats, showcasing its potential as a treatment for hyperglycemia with anti-inflammatory and hypoglycemic benefits.
15.	PI3KR1 gene	It forms a protein involved in insulin signalling, cancer, and cytokines or involved in the immune system, and also in adipocyte maturation.	Limited scientific literature is available on nutrigenomics and the PI3KR1 gene.
16.	PRKAA2 gene	It encodes the protein kinase that is activated by AMP molecules. The general function of this protein is to turn on important metabolic pathways for energy production and turn off the pathways that spend a lot of ATP, controlling the body's need for energy according to the situation.	Rat studies reveal that quercetin, present in foods such as red onions, broccoli, and apples, exhibits anti-inflammatory, antioxidant, and anti-apoptotic properties. It promotes glucose uptake in skeletal muscle by inducing GLUT4 translocation through AMPK activation. Moreover, in the liver, it activates AMPK and diminishes hepatic glucose production by inhibiting glucose-6-phosphatase.
17.	SIRT1 gene	It encodes the protein called Sirtuin 1 that belongs to the family of proteins that interact with the genetic material causing deacetylation of histone, that is, it is able to inactivate genes by an epigenetic mechanism.	Resveratrol, a potent activator of SIRT genes, is employed for diabetes treatment by normalizing blood sugar levels, improving insulin sensitivity, reducing liver glucose production, and regulating mitochondrial and lipid metabolism. Nevertheless, its effects are concentration-dependent, and high doses may potentially harm human muscle cells and inhibit mitochondrial respiration.
18.	SLC2A1, SLC2A4 genes	They encode glucose transporters (GLUT 1 and GLUT 4).	Various polyphenols, encompassing catechins, flavonoids, phenolic acids, and others, have been linked to the augmentation of glucose transporter expression in both animal and human cells.
19.	TCF7L2 gene	Wnt signaling (β cell proliferation and secretion of the insulin).	The gene is actively expressed in adipose tissue and has been associated with diabetes risk through SNPs. In a randomized clinical trial with individuals at high cardiovascular risk, adherence to a Mediterranean diet was observed to mitigate the adverse effects of the rs7903146 (TT) polymorphism. This dietary approach resulted in reductions in fasting blood glucose and lipid levels, along with a preventive effect against stroke.

Conclusion

The increasing prevalence of metabolic diseases, including obesity, insulin resistance, and type 2 diabetes, has led to a growing need for supplementary interventions. In response to this demand, research has highlighted the therapeutic potential of functional foods - those rich in bioactive substances such as omega-3 fatty acids and polyphenols - in promoting metabolic health. These compounds exhibit a range of beneficial effects, contributing to the management and prevention of metabolic disorders. By focusing on the interactions of functional foods with significant metabolic pathways, the capacity of functional foods not only alleviate metabolic disorders but also serve as potential preventive measures. Additionally, recent studies extend beyond traditional approaches by considering the emerging field of nutrigenomics, which investigates how dietary components influence gene expression and molecular processes related to metabolic health.

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