
**ISSN Print:** 2664-844X
**ISSN Online:** 2664-8458
NAAS Rating (2026): 4.97
IJAFS 2026; 8(7): 32-40
www.agriculturaljournals.com
Received: 05-04-2026
Accepted: 09-05-2026

**Anjali Soni**
Guru Jambheshwar University of Science and Technology, Hisar, Haryana, India

**Aradhita Barmanray**
Guru Jambheshwar University of Science and Technology, Hisar, Haryana, India

**Mukesh**
Guru Jambheshwar University of Science and Technology, Hisar, Haryana, India

**Corresponding Author:**
**Anjali Soni**
Guru Jambheshwar University of Science and Technology, Hisar, Haryana, India

# The role of nutrigenomics in shaping the future of food science

**Anjali Soni, Aradhita Barmanray and Mukesh**

**DOI:** https://www.doi.org/10.33545/2664844X.2026.v8.i7a.1646

**Abstract**
Nutrigenomics is a growing interdisciplinary field that explores how genetic differences affect our response to dietary components. This knowledge helps develop personalized nutrition strategies to enhance health and prevent diet-related diseases. Advances in this area have supported precision nutrition based on individual genetic profiles, along with improvements in biofortification and the development of functional foods. The approach addresses major global health issues such as obesity, diabetes, and heart disease by leveraging genetic insights to improve food quality, fortification, and safety. Although the field has expanded quickly, significant research gaps remain, especially the need for large-scale, long-term clinical studies and for better integration of multi-omics data—such as genomics, transcriptomics, metabolomics, and epigenomics—into dietary research. Evidence indicates that gene-diet interactions can significantly affect metabolic outcomes in conditions such as Type 2 Diabetes and obesity. However, many existing studies are observational and vary widely in their methods. The global market for precision nutrition reflects the increasing importance of this discipline, with an expected compound annual growth rate of 16.2%, rising from USD 6.09 billion in 2024 to USD 12.89 billion by 2029. These trends underscore the need for rigorous clinical trials and comprehensive omics-based research to unlock the full potential of nutrigenomics to guide future nutritional therapies and food innovation.

**Keywords:** Nutrigenomics, omics technologies, epigenetics, nutrient-gene interaction, food fortification

## Introduction
Our diet has a significant impact on our bodies. The wide variety of foods we eat daily, each containing numerous components, can strain our biological systems (Pray, 2018). Foods and nutrients play a crucial role in public health, affecting illness prevention and overall well-being through personalized dietary recommendations (Meiliana & Wijaya, 2020) [19]. Nutritional requirements vary by age, gender, and physiological state (Tomar *et al*., 2017) [40]. Undernutrition continues to be a significant issue for a large portion of the population. Obesity and related chronic diseases of lifestyle, such as type 2 diabetes, cardiovascular diseases, and cancers, are on the rise, driven largely by overnutrition. Overnutrition is growing worldwide, but undernutrition is the bigger problem in India, with both occurring alongside vitamin deficiencies (Anjana *et al*., 2017) [2]. Anaemia rates (14-88%) and insufficient dietary iron are prevalent, with 44-66% of wealthy children lacking vitamins A, B2, B6, B12, and C. Micronutrient deficiency among high-income school children in India. In 2005, chronic diseases such as diabetes, cancer, obesity, and respiratory and cardiovascular diseases were responsible for 60 per cent of deaths worldwide. By 2020, it is estimated that 80% of the global disease burden will be due to non-communicable diseases (NCDs) and 7 in 10 deaths in developing countries will be from NCDs. Nutrigenomics is important for tackling the increasing problems of undernutrition and overnutrition (Reddy *et al*., 2018) [31]. A fresh perspective on nutrition has emerged, acknowledging the interaction between nutrients and genes, which can modify our body's molecular processes. Nutrigenomics and nutrigenetics are two fascinating fields that explore the relationship between our genetics and diet, aiming to enhance health through tailored dietary strategies. Nutrigenomics has emerged as a transformative discipline that examines how dietary components interact with the human genome to influence gene expression, metabolic pathways, and disease risk Kore, 2008 [16].

Expanding research in humans, animals, and cell cultures shows that dietary nutrients and bioactive compounds can modulate gene expression in multiple ways (Valdés *et al*., 2021) [45].

Nutrigenomics utilises biochemistry, physiology, nutrition, genomics, proteomics, metabolomics, transcriptomics, and epigenomics to investigate the intricate relationships between genes and nutrients at the molecular level (Törrönen *et al*., 2006) [41]. Researching these gene-nutrient interactions will help develop personalised dietary guidelines tailored to individuals' genotypes. Although research has advanced substantially, a significant challenge persists: the limited integration of genomic knowledge into conventional food science practices, which restricts the translation of molecular findings into practical food innovations and population-level dietary strategies (Sikalidis, 2019) [35]. This study is guided by the hypothesis that "nutrigenomics can revolutionize food technology through genotype-specific nutrition, " enabling the creation of foods and dietary interventions tailored to individual genetic profiles. Building on this premise, the primary objective of this work is to explore how nutrigenomics influences future directions in food science, focusing on its applications, analytical tools, and emerging ethical challenges (Reen *et al*., 2015) [32]. Positioned within the broader scientific context of nutrient-gene interactions and the expanding landscape of omics technologies, this introduction establishes the foundation for understanding how nutrigenomics can reshape personalized nutrition, functional food development, and precision-based dietary recommendations.

According to Rahman & Muhammad (2023) [30], Nutritional deficiencies in both macronutrients and micronutrients can influence the onset and development of diseases. Nutrition and genetics are interconnected, influencing each other at the genetic and cellular levels (Meiliana & Wijaya, 2020) [19]. This emerging field unites scientists, lawmakers, and healthcare professionals to provide personalized nutritional guidance and prepare functional meals that cater to individual health needs (Uthpala *et al*., 2020) [43]. Recent years have also illuminated individual genetic differences; for example, the intake of saturated fat and cholesterol may induce specific degenerative changes in one individual while leaving another unaffected. Each genetic variation clearly illustrates the relationship between the foods we consume, their effects on our genes, and the resulting outcomes (Singh *et al*., 2019) [38].

**Origin and concept of nutrigenomics:** The term "nutrigenomics" was first explained by Peregrin (2001) [28] and later reviewed by Van Ommen and Stierum (2002) [46]. A key concept in furthering nutrigenomics is designing personalized dietary plans based on individual genetic profiles to enhance epigenetic effects and leverage genetic predisposition. Additionally, developing functional foods informed by nutrigenomics findings represents a significant application at the intersection of food science and technology, particularly in the context of functional foods and supplements (Sikalidis, 2019) [35]. Amin *et al*. (2012) [1] discussed the HAP MAP project, exploring DNA behaviour during meiosis and recombination. Launched in the US, this program aims to better understand how gene, environmental, and dietary interactions contribute to prevalent diseases and is supported by the U.S. Department of Health and Human Services. The use of food and related substances to enhance genetic potential and performance, and to reduce illness risk, is likely (Milner, 2006) [21]. The concept that diet affects health is a time-honoured principle. Nutrigenomics encompasses established interactions between food and genetic inheritance, referred to as 'inborn errors of metabolism,' which have traditionally been addressed through dietary manipulation (Nunes *et al*., 2018) [24]. The effects of these changes on our health are genuinely fascinating.

With the exciting advancements in nutrigenomics and nutrition signalling, we are getting closer to understanding the link between aging and cancer. Additionally, fields such as proteomics, lipidomics, metabolomics, and microbiomics provide further insights into how our bodies respond to various foods and supplements (Riscuta, 2016) [33]. Nutrigenomics applies insights into genetic predispositions to modify disease risks through dietary treatments in clinical or direct-to-consumer settings (Simopoulos, 2002) [36]. It also enables the creation of appealing, scientifically tailored foods, as consumers expect enjoyment even from health-focused products. Nutrition assessment and intervention are crucial for preventing or reducing the onset of diseases to which individuals may be prone. Figure 1 depicts how food components can interact with genetic material to form biomolecules that promote cellular homeostasis (Aruoma *et al*., 2019) [3].

**The Role of Nutrigenomics in Shaping the Future of Food Science:** Nutrigenomics is redefining the very foundations of food science by linking individuals' genetic blueprints to their nutritional needs. In the coming decades, food science will shift from mass production to genotype-specific food design, in which bioactive compounds, fortification strategies, and processing methods are optimized to account for genetic variability. Advances in *omics* technologies—particularly genomics, metabolomics, and proteomics—will allow researchers to design foods that not only prevent disease but also enhance gene expression linked to longevity and wellness. This transition positions nutrigenomics as the cornerstone of precision food science, integrating molecular biology, biotechnology, and functional food innovation to create a sustainable, health-centric global food system.

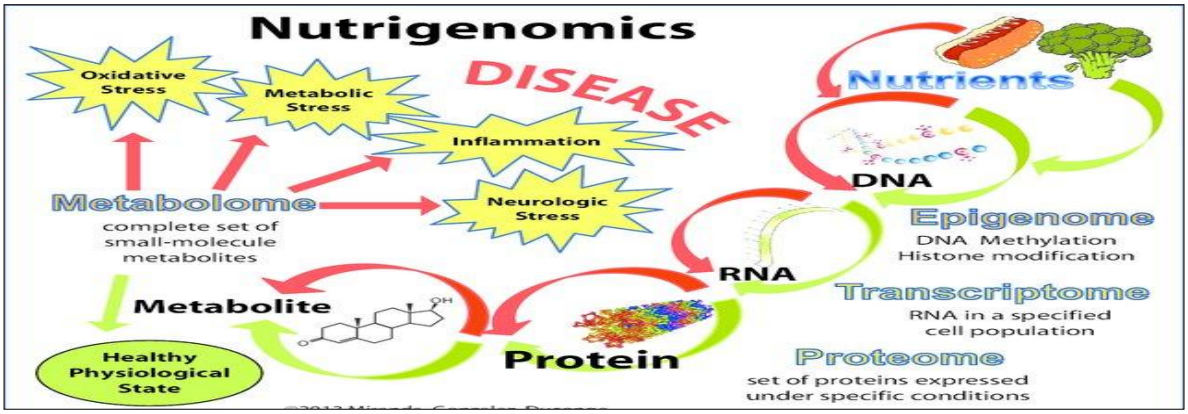


**Fig 1:** Nutrigenomics' effects on gene expression, influencing biochemical routes and endpoints (Gonzalez *et al*., 2015)

**Goal:** The primary aim of nutrigenomics is to facilitate personalized nutrition by tailoring dietary advice to an individual's genetic makeup, thereby enhancing health, preventing nutrition-related chronic diseases, and improving treatment outcomes. Tailoring dietary treatments to an individual's genetic makeup helps prevent and manage chronic illnesses. The goal is to create customized meals that optimize health and delay the onset of illness (Garg *et al*., 2014) [11].

**Nutrigenetics**

This field examines how an individual's genetic makeup influences dietary choices. In Table 1, which compares nutrigenomics and nutrigenetics. While some outcomes may lead to improved health, wellness, and performance, others may pose risks, including food allergies, intolerances, and increased vulnerability to chronic diseases (Singh & Sharma *et al*., 2019) [38].

**Table 1:** Comparison between Nutrigenomics and Nutrigenetics

| Aspect | Nutrigenomics | Nutrigenetics |
|---|---|---|
| Definition | The study of how foods impact metabolic pathways and gene expression. | Examines the impact of genetic differences on nutritional response. |
| Focus | Gene regulation driven by nutrients | Dietary response driven by genes |
| Objective | Enhance gene expression for well-being. | Adapt your diet to your genetic profile. |
| Applications | Biofortification and Functional Foods, | Tools for customized diet therapy |
| Tools | Metabolomics, Transcriptomics, | SNP analysis, genotyping |
| Example | For instance, Omega-3's impact on FADS genes | Lactose intolerance and the LCT gene |

**Tools of nutrigenomics:** Figure 2 shows that food omics is an emerging field that employs advanced omics technology to investigate the connections between food and nutrition, ultimately improving consumer confidence, well-being, and health (Singh *et al*., 2017) [37]. The term "-ome" was introduced initially by molecular biologists and bioinformaticians. Today, biologists often incorporate "omics" concepts into high-throughput experiments to enhance their understanding of molecular systems. Omics involves various techniques, such as nuclear magnetic resonance (NMR), mass spectrometry (MS), next-generation sequencing (NGS), and DNA or cDNA microarrays, to analyze functions and interactions of biomolecules. It primarily focuses on the central dogma, including the genome, transcriptome, and proteome, thus covering genomics, transcriptomics, and proteomics. As molecular knowledge and technology advance, the number of new "-ome" and "-omics" terms is rapidly increasing (Vailati-Riboni *et al*., 2017) [44]. The advancement of high-throughput omics technologies has initiated research in nutrigenomics. Additionally, data on clinical, lifestyle, environmental, dietary, and demographic factors were collected (Gupta *et al*., 2020) [13]. Table 2 provides a brief overview of how proteomics, metabolomics, genomics, and transcriptomics are applied in food technology (Uthpala, 2020) [43]. According to Soni *et al*. (2011) [39], Foodomics can be used to understand post-harvest phenomena that relate genetic and environmental responses to the stress adaptation of foodborne pathogens, ensuring effective food processing, preservation, and sanitation. Ibáez *et al*. (2013) [15] define proteomics as the comprehensive study of the proteome, encompassing protein expression, structure, localization, and interactions. This discipline seeks to detect abnormal protein structures and evaluate how food components influence protein synthesis. As new technologies for analyzing protein expression develop, proteomics has emerged as an advanced tool in nutritional research. Odriozola and Corrales (2015) [25] note that techniques such as mass spectrometry are used to analyze complex proteomes and peptidomes. Meanwhile, metabolomics studies the composition and functions of metabolites. In food science, nutrigenomic research provides insights into how dietary components such as carbohydrates, proteins, lipids, carotenoids, vitamins, minerals, flavonoids, and edible phytochemicals affect the body (Badimon *et al*., 2017) [4]. Nutrigenomics also extends to areas such as food safety, meal authenticity, studies on genetically modified organisms (GMOs), and personalized meal planning. QuEChERS, which stands for quick, easy, cheap, effective, rugged, and safe, is a method established by foodomics for detecting pesticide residues in food. This method employs immuno-affinity column clean-up techniques in food analysis (Singh *et al*., 2017) [37]. Research using foodomics has examined carnosic acid (CA) and carnosol (CS), key compounds in rosemary, to investigate their efficacy in inhibiting the growth of colon cancer cells, specifically HT-29 (Singh *et al*., 2017) [37].


**Fig 2:** An introduction of nutrigenomics: using omics technology to study how diet interacts with the host (genome) (León *et al*., 2018) [17].

| Tools of Foodomics | Objectives | Challenges |
|---|---|---|
| Genomics | Explore the organization and function of genomic elements. Identify genomic variations in DNA (e.g., SNPs, CNVs) and assess their significance. Develop genome-based strategies for early detection, diagnosis, and treatment of disease. | DNA sequence information is inherently static and does not directly convey biological mechanisms. Due to cellular heterogeneity, investigating biological problems often requires a single-cell approach, which can make it challenging to reach realistic conclusions. |
| Proteomics | Grasp the functions and frameworks of proteins in various biological processes. Evaluate the effects of genetic modifications and biological stress on protein structure and functionality. Investigate protein interactions, such as protein-protein, DNA-protein, and protein-drug interactions. | Isolating and purifying most proteins can be challenging. Proteomics alone cannot address all of these factors. |
| Transcriptomics | Transcriptomics examines the transcriptome by analyzing messenger RNA (mRNA) to study gene expression. It employs cDNA or oligonucleotide microarray technology to analyze gene expression (mRNA) in a biological sample at a particular time and under defined conditions. Microarrays are a robust tool for investigating interactions between diet and genes. They facilitate the quantification and cataloguing of all transcript species, such as mRNAs, noncoding RNAs, and small RNAs. Moreover, they enable the measurement of differential gene expression across various conditions and the associated biological implications. | Transcripts are regulated by various biological processes and molecules (e.g., miRNAs), so transcriptomics alone cannot fully capture gene expression. |
| Metabolomics | To conduct metabolic profiling and fingerprinting under various biological conditions, including disease, stress, and infection and discovering new disease indicators (markers). By analyzing metabolic profiling and fluxes, it seeks to link genotype to phenotype. | It is almost impossible to conclude solely from metabolome data. Creating a reliable and accurate marker requires extensive data. |

**Epigenetics:** In 1942, Conrad Waddington introduced the term "epigenetics, " which combines "epigenesis" and "genetics." This concept encompasses the developmental processes from conception through to the whole organism. Currently, key areas of interest include DNA methylation and chromatin remodelling. Figure 3 illustrates that epigenetics explores how modifications to proteins and DNA influence the interactions between DNA and histones. This can lead to changes in chromatin structure without changing the underlying nucleotide sequences. Epigenetics includes information passed through gene expression, with modifications that happen gradually, build up over time, and can often be reversed. Many studies have shown how genes influence cycle regulation and DNA methylation (Nasir *et al*., 2022) [22]. The epigenetic mechanism involves modifications to DNA and proteins that alter chromatin structure through interactions between DNA and histones, even when the nucleotide sequence remains the same. These changes transmit information through gene expression (Nielsen *et al*., 2012) [23]. Additionally, specific nutrients are involved in DNA methylation and histone modification. As mentioned, dietary and environmental factors affect epigenetics by interacting with genes through nutrients. Specific bioactive food components and micronutrients are associated with DNA methylation, gene expression, histone modifications, and metabolic regulation. Significant deficiencies in nutrients, insufficient methyl donors, or disruptions in methyltransferases can result in gene mutations (Nasir *et al*., 2022) [22]. This occurs due to the activation of promoter genes and hypo- or hypermethylation of DNA, which silences tumour suppressor genes as we age, ultimately increasing the risk of cancer development. For example, in folate metabolism, folic acid—a vitamin essential for maintaining genetic stability—ensures an adequate supply of deoxyribonucleotides, which are necessary for DNA replication. It acts as a universal methyl donor and is vital for DNA methylation processes, functioning as a cofactor for enzymes involved in nucleotide and thymidylate synthesis, a component of RNA (Sales *et al*., 2014) [34].


**Fig 3:** Dietary mutagens alter DNA methylation, which triggers the activation of oncogenes and causes cancer (Nasir *et al*., 2022) [22]

**Dietary impact:** Enhancing diets could prevent one in five deaths globally, underscoring the vital role of nutrition in maintaining health and preventing disease. While epidemiological studies suggest a strong connection between certain foods or dietary patterns and health outcomes, there is a notable lack of human intervention studies evaluating their effectiveness. Findings from studies conducted in controlled environments, focusing on specific foods and diets, have yielded less conclusive outcomes (Brennan & Roos, 2021) [6].

| Nutrients | Dietary impact | References |
|---|---|---|
| PUFAs Of the Omega-3 Form (Ω-3 PUFAs) | • Reducing triglyceride levels after meals and having anti-inflammatory benefits.<br>• Cardiovascular system protection: effects. | Tomar *et al*., 2017 [40] |
| Apolipoprotein E (Apo E) {E2, E3 And E4} | • Around 25% of the population carries the Apo E4 allele, which increases their risk of cardiovascular disease (CVD) and typically leads to elevated levels of LDL cholesterol. For these individuals, a low-fat diet is more beneficial. | Tomar *et al*., 2017 [40] |
| Tea (Camellia sinensis) | • Low prevalence of chronic diseases, like cardiovascular disease and cancer, in which oxidative stress is crucial. | Peluso *et al*., 2017 [27] |
| Green Tea Extract | • Blood glucose reduction.<br>• Prevent obesity and type 2 diabetes mellitus (T2DM) | Bae *et al*. (2013) [5]. |

**Nutrient-Gene Interactions:** The "one size fits all" strategy in dieting serves as the basis for the "Healthy Eating Pyramid" theory. However, genetic differences will affect the significance of nutrients for each person. People will benefit from the specific dietary recommendations, and the interplay between genetic variability and dietary variables will yield additional benefits. A variety of nutrients in the diet play important roles in immune function, hormone regulation, detoxification, and other metabolic processes. Many phytochemicals, such as curcumin, resveratrol, genistein, and daidzein, act as ligands for transcription factors, directly influencing gene expression. Nutrigenomics focuses on variations in single-nucleotide polymorphisms (SNPs) and DNA sequences. One or more SNPs may change in response to dietary variables that increase or decrease illness risk (Gupta *et al*., 2020) [13].

| Nutrients | Gene | Interaction | Health Implication | References |
|---|---|---|---|---|
| Omega-3 fatty acids | FADS1 & FADS2 | Regulates the metabolism of fatty acids | Cardiovascular and inflammatory disease risk | Tomar *et al*., 2017 [40] |
| Sodium and potassium | Angiotensinogen (AGT), Aldosterone Synthetase | Modulates the renin-angiotensin system (RAS) and influences blood pressure (BP). | Increase In Blood Pressure (BP), Weight Loss | Garg *et al*., 2014 [11] |
| Caffeine | CYP1A2 gene | Caffeine metabolism affects | Lower risk of breast cancer. Risk of developing hypertension | Palatini *et al*., 2009 [26] |
| Folate | MTHFR | Variants in the MTHFR gene affect folate metabolism and, consequently, homocysteine levels. | Increased Risk of Cardiovascular Diseases | Garg *et al*., 2014 [11] |
| Vitamin D | VDR | Variations in the VDR gene affect vitamin D receptor activity and calcium absorption. | Risk Of Osteoporosis, Immune Dysfunction. | Garg *et al*., 2014 [11] |
| Resveratrol | BRCA1 | It plays an epigenetic role in inhibiting the silencing of the tumor suppressor gene BRCA1. | Anticancer Ability | Nasir *et al*., 2022 [22] |
| Genistein | BTG3 | Tumor Suppressor Genes | Anti-Cancer Properties | Nasir *et al*., 2022 [22] |
| Protein | APOA1 | Positively associated with higher levels of high-density lipoprotein cholesterol. | CVD | Sikalidis (2019) [35]. |

**Applications in Food**

a) **Functional and Fortified Foods:** Functional and fortified foods are a key aspect of nutrigenomics, where bioactive substances are added to diets to promote genotype-based health benefits. Many natural components have demonstrated antioxidant, anti-inflammatory, and disease-preventive effects, including curcumin from turmeric, lignans from flaxseed and sesame, ellagic acid derivatives, and resveratrol from grapes and red wine (Tsao, 2010) [42]. Similarly, a large part of Asian diets includes foods derived from soy, which may help explain the region's relatively low rates of cardiovascular disease. Clinical studies show that compounds such as genistein and daidzein support osteoporosis treatment, enhance cardiovascular health, reduce menopausal symptoms, and prevent cancer (Giordano *et al*., 2015; Fritz *et al*., 2013) [12, 10]. Nutrigenomic foods such as Tulsi, ginger, carrots, and soybeans have been shown to modify genes associated with oxidative stress, diabetes, and inflammation in the context of metabolic diseases. Incorporating these into formulated products and premix powders illustrates how functional food innovations can target genetic pathways involved in disease (Yadav *et al*., 2017) [47]. These examples highlight how the design of diets aimed at improving metabolic health and managing chronic diseases is directly shaped by nutrient-gene interactions.

b) **Molecular Markers and Supply Chain Optimization:** The discovery of "process markers, " or molecular indicators that improve quality assurance, guide processing decisions, and support industrial-scale food production, has been made possible by emerging genomic technologies. For example, fermentation, heating, and drying significantly influence the flavor and fragrance profiles in tea production. Producers can enhance processing methods and increase yield without compromising sensory quality by understanding the molecular basis of these processes (Brown & Van der, 2007) [7]. Additionally, molecular markers are key in predicting shelf life and maintaining freshness in perishable foods. One well-known example is broccoli, whose rapid post-harvest fading reflects natural leaf senescence, which is influenced by both environmental and genetic factors. Advances in postharvest handling techniques for broccoli, lettuce, and other leafy greens have been enabled by insights from senescence-related genetics (Brown & Van der, 2007) [7]. Furthermore, food labelling and authentication rely heavily on molecular verification. For instance, distinguishing authentic Basmati rice from hybrids or non-Basmati varieties preserves product value and consumer confidence. These examples demonstrate how molecular markers enhance postharvest management, food quality assurance, and supply chain transparency.

c) **Nutrigenomic Ingredients and Bioactive Compounds:** The molecular basis of nutrigenomic interventions involves bioactive substances that directly influence metabolic pathways and gene expression. Tea's catechins, especially EGCG, which have been associated with lower risks of cancer, heart disease, and osteoporosis (Peluso & Serafini, 2017; Butt *et al*., 2015) [27, 8], exemplify how natural compounds can modify physiological processes. Similarly, fenugreek seed powder has hypoglycemic effects due to compounds such as trigonelline and 4-hydroxyisoleucine, making it particularly useful for managing type 2 diabetes. Other bioactives, such as omega-3 fatty acids (DHA and EPA), are crucial for reducing inflammation and lowering the risk of heart disease and various cancers. Additionally, conjugated linoleic acid (CLA) supplementation has been shown to significantly reduce body fat and improve lipid profiles. These findings demonstrate that selecting and incorporating bioactives into food formulations aimed at specific metabolic and genetic outcomes is guided by nutrigenomic research.

d) **Consumer Health and Market Perspectives:** Foods with genetic and metabolic benefits are becoming increasingly popular, which is driving demand for items supported by scientific validation that promote personalized health outcomes. The variety of health-conscious meals has grown thanks to nutrigenomics, from metabolically active herbal blends to polyphenol-rich beverages. The market for nutrigenomic foods, such as soy-based functional products, tea extracts, fenugreek-enriched items, and omega-3-fortified foods, is expanding as consumers become more aware of the connection between diet and chronic disease risk, for costly products like Basmati rice, where genetic verification safeguards consumer confidence and ensures that labels remain accurate, transparent, and authentic. According to market trends, nutrigenomic foods meet customer goals such as sustainability, natural ingredients, and personalized nutrition, while also supporting disease prevention. This shift highlights that future product development in the food industry must leverage genetic insights, molecular profiling, and bioactive research (Zhao *et al*., 2023).

**Food Fortification Based on Genetic Profile:** Food fortification informed by genetic profiles, also known as personalized nutrition or nutrigenomics-based fortification, tailors' nutrient supplementation to an individual's unique genetic composition. This method acknowledges that genetic variations influence how people metabolize and react to various nutrients.

| Genetic Marker/Gene | Nutrient Affected | Impact of Genetic Variation | Fortification Approach | Example | References |
|---|---|---|---|---|---|
| MTHFR (C677T) | Folate | Decreased capacity to convert folic acid into active methyl folate. | Fortify with methylated folate instead of folic acid | Fortified grains or supplements with methyl folate | Garg *et al*., 2014 [11] |
| VDR (Vitamin D Receptor) | Vitamin D | Alters vitamin D absorption and metabolism | Higher levels of vitamin D fortification in food/supplements | Vitamin D-fortified dairy or beverages | Cashman *et al*., 2016 [9] |
| HFE (C282Y, H63D) | Iron | Risk of iron overload (hemochromatosis) or deficiency | Tailor iron fortification (increase or avoid) | Iron-fortified cereals or iron-free products | Hurrell, 2007 [14] |
| FADS1/2 | Omega-3 Fatty | Reduced efficiency in | Fortify with preformed | Omega-3 fortified eggs | Koletzko *et al*, |

| | | | | | |
|---|---|---|---|---|---|
| | Acids | converting plant-based ALA to DHA/EPA | DHA/EPA from marine sources | or dairy products | 2019 |
| SLC23A1 | Vitamin C | Reduced ability to transport and absorb vitamin C | Increase vitamin C fortification in juices or supplements | Fortified fruit juices | Michels *et al*., 2013 [20] |
| APOE (E2, E3, E4) | Cholesterol and Fat Metabolism | Variants influence lipid metabolism and cardiovascular risk | Fortify with omega-3 or plant sterols for heart health | Sterol-enriched spreads | Mahley *et al*., 2000 [18] |
| TCN2 (Transcobalamin) | Vitamin B12 | Impaired vitamin B12 transport | Fortify with bioavailable forms like methylcobalamin | Fortified cereals or plant-based milks | Quadros *et al*., 2013 [29] |

**Challenges and Ethical Considerations**

Nutrigenomics has promising prospects, but it also raises significant moral and legal issues. Employers, insurers, and marketers risk abusing this data in the absence of robust protections. Furthermore, discrepancies may arise due to the high expense of genetic testing and precision diets, which raises questions regarding access and justice. Explicit and comprehensive informed consent is necessary to guarantee that participants are aware of the possible consequences of disclosing their genetic information. To safeguard consumer rights and ensure appropriate consent, international regulations should also be in place when businesses market genetic data (WHO, 2024). Ultimately, we need clear rules, inclusive policies that take everyone into account, and strong ethical standards to guarantee that nutrigenomics promotes global health equity and does not exacerbate already-existing disparities.

**Limitation**

Nutrigenomics certainly holds significant potential for advancing human well-being, yet it also has challenges. This technology presents several key concerns (Amin *et al*., 2012) [1].

- Individuals often have reduced interest in genetic testing due to fears of data misuse. Employers can legally refuse employment to applicants based on genetic test results, and there is no existing legislation to mitigate this risk.
- Managing genetic information raises concerns. What if someone discovers they are highly susceptible to a particular condition, such as stroke?
- If something is inevitable, he may adopt a fatalistic attitude, enjoying smoking, drinking, and eating freely. Conversely, the news might frighten him into changing their lifestyle. However, this anxiety can lower the quality of life and raise blood pressure, increasing stroke risk.

Understanding how foods and their components influence health is crucial for developing functional foods. Numerous epidemiological studies have established links between food consumption and the incidence and severity of diseases. However, identifying bioactive compounds in foods and elucidating their mechanisms of action can be challenging.

**Recent Advances, Research Gaps, and Future Directions**

Recent advances in nutrigenomics include food-derived epigenetic regulators, microbiome-influenced metabolism, and AI analysis. However, translating these findings into practical food products and large-scale strategies faces hurdles, primarily due to limited clinical validation and limited access in low- and middle-income countries, driven by ethical, privacy, and cost issues. Nutrigenomics has the potential to revolutionize food science by tailoring diets to individuals' genetics, thereby impacting public health, food technology, and nutrition strategies. It explores how nutrients interact with genes, offering personalized recommendations that could reduce health disparities through accessible screening tools and multi-omics data. Developing region-specific fortification models and fostering collaboration among experts are key steps to turning nutrigenomics into a precise, lasting discipline. Since diet influences disease risk via genetic interactions, understanding these can improve prevention. Though still evolving, nutrigenomics aims to personalize nutrition, emphasizing prevention over treatment, echoing Hippocrates' quote about healing with food. It enhances understanding of individual dietary needs, requiring collaboration across various fields, and increasingly includes research and coursework in graduate programs. Its main goal is personalized nutrition for health and disease prevention.

**References**


1. Amin T, Mahapatra H, Bhat SV, Gulleria SPS. Application of nutrigenomics in food industry: A review. Indian Horticulture Journal. 2012;2(3-4):54-59.
2. Anjana RM, Deepa M, Pradeepa R, Mahanta J, Narain K, Das HK, *et al*. Prevalence of diabetes and prediabetes in 15 states of India: results from the ICMR-INDIAB population-based cross-sectional study. The Lancet Diabetes & Endocrinology. 2017;5(8):585-596.
3. Aruoma OI, Hausman-Cohen S, Pizano J, Schmidt M A, Minich DM, Joffe Y, *et al*. Personalized nutrition: translating the science of nutrigenomics into practice: proceedings from the 2018 American College of Nutrition Meeting. Journal of the American College of Nutrition. 2019;38(4):287-301.
4. Badimon L, Vilahur G, Padro T. Systems biology approaches to understand the effects of nutrition and promote health. British Journal of Clinical Pharmacology. 2017;83(1):38-45.
5. Bae KC, Park JW, Na AY, Kim SJ, Ahn S, Kim SP, *et al*. Effect of green tea extract/poly-γ-glutamic acid complex in obese type 2 diabetic mice. Diabetes & Metabolism Journal. 2013;37(3):196-206.
6. Brennan L, de Roos B. Nutrigenomics: lessons learned and future perspectives. The American Journal of Clinical Nutrition. 2021;113(3):503-516.
7. Brown L, van der Ouderaa F. Nutritional genomics: food industry applications from farm to fork. British Journal of Nutrition. 2007;97(6):1027-1035.
8. Butt MS, Ahmad RS, Sultan MT, Qayyum MMN, Naz A. Green tea and anticancer perspectives: updates from last decade. Critical Reviews in Food Science and Nutrition. 2015;55(6):792-805.

9. Cashman KD, Dowling KG, Škrabáková Z, Gonzalez-Gross M, Valtueña J, De Henauw S, *et al*. Vitamin D deficiency in Europe: pandemic?. The American Journal of Clinical Nutrition. 2016;103(4):1033-1044.
10. Fritz H, Seely D, Flower G, Skidmore B, Fernandes R, Vadeboncoeur S, *et al*. Soy, red clover, and isoflavones and breast cancer: a systematic review. PLoS One. 2013;8(11):e81968.
11. Garg R, Sharma N, Jain SK. Nutrigenomics and nutrigenetics: Concepts and applications in nutrition research and practice. Acta Medica International. 2014;1(2):124-128.
12. Giordano E, Dávalos A, Crespo M, Tomé-Carneiro J, Gómez-Coronado D, Visioli F. Soy isoflavones in nutritionally relevant amounts have varied nutrigenomic effects on adipose tissue. Molecules. 2015;20(2):2310-2322.
13. Gupta E, Shyam H, Devi S, Maurya NK. Nutrigenomics in Functional Foods and Personalized Nutrition. Gedrag & Organisatie. 2020;33(2):670-686.
14. Hurrell RF. Iron fortification: its efficacy and safety in relation to infections. Food and Nutrition Bulletin. 2007;28(4 Suppl 4):S585-S594.
15. Ibáñez C, Simó C, García-Cañas V, Cifuentes A, Castro-Puyana M. Metabolomics, peptidomics and proteomics applications of capillary electrophoresis-mass spectrometry in Foodomics: a review. Analytica Chimica Acta. 2013;802:1-13.
16. Kore KB, Pathak AK, Gadekar YP. Nutrigenomics: emerging face of molecular nutrition to improve animal health and production. Veterinary World. 2008;1(9):285-288.
17. León C, Cifuentes A, Valdés A. Foodomics applications. In: Comprehensive Analytical Chemistry. Vol. 82. Elsevier; 2018. p. 643-685.
18. Mahley RW, Rall Jr SC. Apolipoprotein E: far more than a lipid transport protein. Annual Review of Genomics and Human Genetics. 2000;1(1):507-537.
19. Meiliana A, Wijaya A. Nutrigenetics, nutrigenomics and precision nutrition. The Indonesian Biomedical Journal. 2020;12(3):189-200.
20. Michels AJ, Hagen TM, Frei B. Human genetic variation influences vitamin C homeostasis by altering vitamin C transport and antioxidant enzyme function. Annual Review of Nutrition. 2013;33(1):45-70.
21. Milner J. The promise of Nutrigenomics. In: Nutrigenomics and Beyond. Washington (DC): The National Academies Press; 2006. p. 3-6.
22. Nasir A, Bullo MMH, Ahmed Z, Imtiaz A, Yaqoob E, Safdar M, *et al*. Nutrigenomics: Epigenetics and cancer prevention: A comprehensive review. Critical Reviews in Food Science and Nutrition. 2022;60(8):1375-1387.
23. Nielsen DE, El-Sohemy A. A randomized trial of genetic information for personalized nutrition. Genes & Nutrition. 2012;7(4):559-566.
24. Nunes MA, Rodrigues F, Vinha AF, Alves RC, Oliveira MBPP. Polyphenols: Properties, Recovery, and Applications. Porto: University of Porto; 2018. p. 103-115.
25. Odriozola L, Corrales FJ. Discovery of nutritional biomarkers: future directions based on omics technologies. International Journal of Food Sciences and Nutrition. 2015;66(Suppl 1):S31-S40.
26. Palatini P, Ceolotto G, Ragazzo F, Dorigatti F, Saladini F, Papparella I, *et al*. CYP1A2 genotype modifies the association between coffee intake and the risk of hypertension. Journal of Hypertension. 2009;27(8):1594-1601.
27. Peluso I, Serafini M. Antioxidants from black and green tea: From dietary modulation of oxidative stress to pharmacological mechanisms. British Journal of Pharmacology. 2017;174(11):1195-1208.
28. Peregrin T. The new frontier of nutrition science: Nutrigenomics. Journal of the American Dietetic Association. 2001;101(11):1306-1307.
29. Quadros EV, Sequeira JM. Cellular uptake of cobalamin: transcobalamin and the TCblR/CD320 receptor. Biochimie. 2013;95(5):1008-1018.
30. Rahman MNA, Muhammad NH. Precision nutrition: using nutrigenetic and nutrigenomic concepts in personalized nutrition. Nutrition. 2023;6(2):7-14.
31. Reddy VS, Palika R, Ismail A, Pullakhandam R, Reddy GB. Nutrigenomics: Opportunities & challenges for public health nutrition. The Indian Journal of Medical Research. 2018;148(5):632-641.
32. Reen JK, Yadav AK, Singh J. Nutrigenomics: concept, advances and applications. Asian Journal of Dairy and Food Research. 2015;34(3):205-212.
33. Riscuta G. Nutrigenomics at the interface of aging, lifespan, and cancer prevention. The Journal of Nutrition. 2016;146(10):1931-1939.
34. Sales NMR, Pelegrini PB, Goersch M. Nutrigenomics: definitions and advances of this new science. Journal of Nutrition and Metabolism. 2014;2014:Article ID 202759.
35. Sikalidis AK. From food for survival to food for personalized optimal health: A historical perspective of how food and nutrition gave rise to nutrigenomics. Journal of the American College of Nutrition. 2019;38(1):84-95.
36. Simopoulos AP. Genetic variation and dietary response: nutrigenetics/nutrigenomics. Asia Pacific Journal of Clinical Nutrition. 2002;11(Suppl 6):S117-S128.
37. Singh P, Rani R, Singh B, Dharaiya C, Thompkinson DK. Technical Article. Indian Journal of Dairy Science. 2017;70(2):142-148.
38. Singh R, Sharma L. Nutrigenomics: A combination of nutrition and genomics: A new concept. Journal of Physiology, Nutrition and Physical Education. 2019;4(1):417-421.
39. Soni KA, Nannapaneni R, Tasara T. The contribution of transcriptomic and proteomic analysis in elucidating stress adaptation responses of *Listeria monocytogenes*. Foodborne Pathogens and Disease. 2011;8(8):843-852.
40. Tomar N, Gupta C, Kaushik M, Wadhawan A. Nutrigenomics: A perio-nutrition interrelationship. Journal of Oral Research and Review. 2017;9(1):32-36.
41. Törrönen R, Kolehmainen M, Poutanen K. Nutrigenomics-new approaches for nutrition, food and health research. Kuopio: Food and Health Research Centre; 2006. p. 1-43.
42. Tsao R. Chemistry and biochemistry of dietary polyphenols. Nutrients. 2010;2(12):1231-1246.
43. Uthpala TG, Fernando HN, Thibbotuwawa A, Jayasinghe M. Importance of nutrigenomics and nutrigenetics in food science. Journal of Science and Technology. 2020;3(4):88-95.

44. Vailati-Riboni M, Palombo V, Loor JJ. What are omics sciences?. In: Periparturient diseases of dairy cows: a systems biology approach. Cham: Springer; 2017. p. 1-7.
45. Valdés A, Alvarez-Rivera G, Socas-Rodríguez B, Herrero M, Ibanez E, Cifuentes A. Foodomics: Analytical opportunities and challenges. Analytical Chemistry. 2021;94(1):366-381.
46. Van Ommen B, Stierum R. Nutrigenomics: exploiting systems biology in the nutrition and health arena. Current Opinion in Biotechnology. 2002;13(5):517-521.
47. Yadav Ruchi, Mishra S. A study on development of products using nutrigenomics premix powder and its sensory evaluation. International Journal of Food Science and Technology. 2017;7(3):19-28.