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Review Article

Functional foods and nutraceuticals in type 2 diabetes: A public health nutrition perspective on equity, food systems, and sustainable diets

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Highlights/Key Messages

- Functional foods aid in Type 2 diabetes prevention and metabolic balance.
- Equity and access must guide functional food policy and practice.
- Sustainable, local food systems enhance health and resilience.
- Science, culture, and policy must unite for nutrition justice.
- From products to systems: nutrition innovation for all.

Background
Type 2 diabetes mellitus (T2DM) is a major and growing global public health challenge, driven by rapid nutrition transitions, sedentary lifestyles, and inequities in access to healthy diets. Functional foods and nutraceuticals have gained increasing attention as potential dietary strategies to improve metabolic health; however, their population-level relevance remains uncertain.

Objective
To synthesise current evidence on the role of functional foods and nutraceuticals in the prevention and management of T2DM, with emphasis on public health nutrition, equity, and food system implications.

Methods
This narrative, integrative review draws on literature from major scientific databases, including PubMed, Scopus, Web of Science, and Google Scholar, covering the period 2000–2025. Studies were included if they examined functional foods, dietary patterns, or nutraceuticals in relation to glycaemic control, insulin sensitivity, or metabolic outcomes. Evidence from clinical, epidemiological, and preclinical studies was synthesised qualitatively, with greater weight given to systematic reviews and well-designed human studies.

Results
Diets rich in whole, minimally processed foods—such as legumes, whole grains, fermented products, fruits, and vegetables—are consistently associated with modest improvements in glycaemic control and metabolic outcomes. Bioactive compounds, including polyphenols, dietary fibre, and omega-3 fatty acids, contribute to these effects, particularly when consumed as part of overall dietary patterns. In contrast, evidence for nutraceuticals is variable and context-dependent, with outcomes influenced by formulation, dosage, and study design. The expanding nutraceutical market raises concerns regarding affordability, regulatory oversight, misinformation, and unequal access, potentially reinforcing existing health inequities.

Conclusion
Functional foods and nutraceuticals can support the prevention and management of T2DM, but their impact is greatest when embedded within equitable, culturally appropriate, and sustainable dietary strategies. Public health efforts should prioritise food-based approaches, strengthen regulation of nutraceutical claims, and integrate functional foods into broader nutrition and food-system policies to ensure accessible, population-level benefits

Keywords: type 2 diabetes, functional foods, nutraceuticals, public health nutrition, food systems, equity.

Introduction

Type 2 diabetes mellitus (T2DM) represents one of the most pressing global public health challenges of the 21st century. According to estimates from the International Diabetes Federation (IDF), 589 million people aged 20-79 had diabetes globally in 2021 (IDF, 2025). This figure is projected to rise to 643 million by 2030 and 783 million by 2045, with the disease primarily affecting low- and middle-income countries, posing substantial challenges to global health systems (IDF, 2025). According to the IDF, over a million children and adolescents have diabetes, in addition to adults. Early exposure to poor dietary practices and obesogenic food environments has caused this shift (Magliano et al., 2021). Its growing prevalence is closely linked to rapid urbanisation, population ageing, and profound changes in dietary and lifestyle patterns (Huang et al., 2025; Okoduwa et al., 2015). Recent global assessments show that diet-related factors now account for a substantial proportion of T2DM disability-adjusted life years (DALYs) and mortality, surpassing many other modifiable risks (Xie et al., 2025; Okoduwa & Abdulwaliyu, 2022). This increasing burden is closely linked to ongoing global dietary shifts characterised by greater consumption of energy-dense, highly processed foods and reduced intake of traditional, nutrient-rich diets (Marume et al., 2025). These dietary changes are deeply embedded within globalised food systems and marketing practices that prioritise affordability, convenience, and shelf life over nutritional quality. The proliferation of ultra-processed foods has been directly associated with a higher risk of T2DM, insulin resistance, and inflammation, emphasising the urgency of diet-centred prevention strategies (Li et al., 2025; Delpino et al., 2021).

The nutrition transition has also intensified social and health inequities. In low- and middle-income countries (LMICs), rising rates of T2DM coexist with persistent undernutrition, forming a double burden of malnutrition within populations and even households (Bailey & Okoduwa, 2025a; Popkin & Ng, 2021). Economic disparities influence dietary access and exposure: while higher-income groups may benefit from diversified diets and health-promoting foods, lower-income groups often rely on low-cost, energy-dense, nutrient-poor options (Darmon & Drewnowski, 2015; Drewnowski, 2009). Such inequities are compounded by food system dynamics—including trade policies, aggressive marketing of unhealthy foods, and limited infrastructure for distributing fresh produce—that disproportionately affect vulnerable populations. Consequently, T2DM prevalence reflects not only biological susceptibility but also social determinants of health, including poverty, education, and urban food environments (Bailey & Okoduwa, 2025a; Roy et al., 2023; Popkin & Ng, 2021). Addressing T2DM, therefore, requires an integrative approach that situates dietary interventions within socially just and sustainable nutrition frameworks, ensuring equitable access to healthy food environments for all populations.

Within this broader context, functional foods and nutraceuticals have emerged as potential adjuncts in the prevention and management of T2DM. Functional foods—such as legumes, whole grains, fermented dairy, fruits, and vegetables—contain naturally occurring bioactive compounds (e.g., polyphenols, dietary fibres, omega-3 fatty acids) that can improve glycaemic control, lipid metabolism, and inflammation. Similarly, nutraceuticals—bioactive components concentrated in supplement form—may enhance insulin sensitivity and oxidative balance (Lam et al., 2025; Alkhatib et al., 2017; Mirmiran, 2014). However, while the scientific evidence supporting these benefits is expanding, translating these benefits into population-level impact remains uneven. Market-driven nutraceutical products are often expensive, poorly regulated, and inaccessible to lower-income groups, raising concerns about equity and health justice. In contrast, traditional and culturally embedded functional foods—often derived from local plant-based sources—represent sustainable, affordable, and socially acceptable tools for promoting metabolic health (Vignesh et al., 2024). To achieve public-health relevance, functional-food and nutraceutical strategies must be integrated into national dietary guidelines, agricultural policy, and community nutrition programs rather than remain confined to commercial or individualised health markets.

Despite promising data, several challenges constrain the effective integration of functional foods into diabetes-prevention frameworks. Heterogeneity in study designs, inconsistent product formulations, and limited long-term trials restrict the generalisability of evidence. Moreover, lack of policy coherence between agricultural production, nutrition policy, and food regulation—particularly regarding nutraceutical marketing claims and consumer protection—undermines effective translation. Finally, there is a pressing need for interdisciplinary research linking nutritional biochemistry, food-systems science, and social equity to inform context-specific strategies (Lam et al., 2025).

Future efforts should emphasise food-system resilience, local innovation, and sustainable diets that combine traditional knowledge with modern nutrition science. By embedding functional foods and nutraceuticals in policies that promote food sovereignty and equitable access, countries can advance diabetes-prevention strategies that are not only effective but also socially and environmentally sustainable. Therefore, this paper aims to synthesise evidence on functional foods and nutraceuticals for Type 2 diabetes from a public health nutrition perspective—highlighting their potential roles, challenges, and policy opportunities within equity-focused and sustainability-oriented food systems.

Methods

This review adopts a narrative and integrative approach to synthesise current evidence on functional foods and nutraceuticals in the prevention and management of Type 2 diabetes mellitus (T2DM), with a focus on public health nutrition, equity, and food systems.

Literature Search Strategy

A comprehensive literature search was conducted across major scientific databases, including PubMed, Scopus, Web of Science, and Google Scholar. The search covered publications from 2000 to 2025, with emphasis on recent studies (post-2015) to reflect current scientific and policy developments. Keywords and search combinations included:

"functional foods," "nutraceuticals," "type 2 diabetes," "glycaemic control," "bioactive compounds," "dietary patterns," "public health nutrition," and *"food systems."* Reference lists of relevant articles were also screened to identify additional sources.

Inclusion and Exclusion Criteria

Studies were included if they:

- Examined functional foods, dietary patterns, or nutraceuticals in relation to T2DM prevention or management;
- Included human clinical trials, observational studies, systematic reviews, or meta-analyses;
- Reported outcomes related to glycaemic control, insulin sensitivity, inflammation, or metabolic health;
- Addressed public health, food systems, or equity dimensions where relevant.

Studies were excluded if they:

- Focused solely on Type 1 diabetes or unrelated metabolic conditions;
- Were not available in English;
- Lacked sufficient methodological detail or scientific rigour;
- Examined isolated compounds without relevance to dietary or public health contexts.

Evidence Synthesis and Quality Considerations

Given the heterogeneity of study designs and outcomes, a formal meta-analysis was not conducted. Instead, findings were synthesised narratively, with an emphasis on the consistency of evidence across study types and populations. Greater weight was given to systematic reviews, meta-analyses, and well-designed clinical trials, while preclinical studies were used primarily to support mechanistic understanding.

The strength of evidence was interpreted qualitatively, considering study design, sample size, reproducibility, and real-world applicability. Particular attention was given to the translational relevance of findings within diverse socioeconomic and food system contexts.

Conceptual Framework

Functional foods and nutraceuticals occupy an evolving space at the intersection of nutrition science, public health, and global food systems. Their conceptual relevance extends beyond biochemical mechanisms to encompass broader social, economic, and environmental determinants shaping dietary choices, access, and health outcomes. Understanding their role in Type 2 diabetes mellitus (T2DM) management, therefore, requires an integrated, systems-based perspective that connects individual physiology with population health and sustainable food environments (Fekete et al., 2025).

From Mechanistic Pathways to Systems Thinking

Traditional frameworks for functional foods and nutraceuticals have emphasised biological pathways — such as modulation of oxidative stress, improvement of insulin sensitivity, or restoration of β-cell function. While these mechanisms remain important, they represent only one dimension of a complex nutritional system. A systems-oriented approach expands this view by acknowledging that the metabolic impact of these foods is mediated by contextual factors — including dietary patterns, socio-economic status, food availability, and cultural eating practices (Popkin & Ng, 2021; Affret et al., 2017).

In this broader perspective, functional foods (e.g., whole grains, legumes, fermented dairy, and plant-based products) are not merely vehicles for bioactive compounds; they are part of dietary ecosystems that interact with agriculture, trade, and health systems. Their accessibility and impact are thus contingent on the structure and equity of the food system itself (Li et al., 2025).

Defining Functional Foods and Nutraceuticals in the Public Health Context

While the terms *functional foods* and *nutraceuticals* are often used interchangeably, their public health implications differ.

- **Functional foods** can be broadly described as foods that, beyond providing basic nutrition, contribute to improved physiological functions or reduced disease risk when consumed as part of regular dietary patterns (Marcìa-Fuentes et al., 2025). They may be whole, fortified, enriched, or enhanced foods that improve physiological functions or help reduce disease risk, in addition to offering essential nutrients
- **Nutraceuticals** are typically defined as concentrated bioactive compounds derived from food sources and consumed in supplemental forms, often at doses exceeding those obtained through conventional diets (Espín et al., 2007).

From a public health nutrition perspective, functional foods are aligned with sustainable dietary guidance; they can be culturally adapted, locally produced, and integrated into traditional cuisines. Nutraceuticals, however, often reflect market-driven innovation, which may limit accessibility due to cost, intellectual property rights, and regulatory disparities (Lam et al., 2025). An equity-focused conceptual model, therefore, prioritises functional foods that are affordable, community-based, and environmentally sustainable, while situating nutraceuticals as potential adjuncts that require clear regulation and evidence-based validation.

To clarify these distinctions and their implications for public health nutrition, Table 1 contrasts functional foods and nutraceuticals through a policy, equity, and food systems lens. Rather than focusing solely on biochemical mechanisms, the comparison highlights differences in accessibility, affordability, cultural relevance, regulatory oversight, sustainability, and population-level applicability. This framing underscores why functional foods—embedded within traditional diets and supported by coherent food and nutrition policies—are more readily aligned with equitable and sustainable diabetes prevention strategies, whereas nutraceuticals require careful regulation and should be positioned as adjuncts rather than as primary public health interventions.

Table 1. Comparison of functional foods and nutraceuticals from a public health nutrition, policy, and equity perspective.

Dimension	Functional Foods	Nutraceuticals
Definition	Natural or minimally processed foods that provide health benefits beyond basic nutrition when consumed as part of regular diets	Concentrated bioactive compounds derived from foods and consumed in supplement-like forms (capsules, powders, extracts)
Typical examples	Whole grains, legumes, fermented foods, fruits, vegetables, nuts, seeds	Curcumin capsules, resveratrol supplements, herbal extracts, and omega-3 capsules
Mode of consumption	Integrated into habitual meals and dietary patterns	Taken separately from meals, often as pills or powders
Evidence base	Strong population-level and dietary pattern evidence linking regular intake to improved metabolic outcomes and reduced T2DM risk	Evidence shows modest benefits in controlled settings, with high heterogeneity in formulation, dose, and outcomes
Effect size and consistency	Generally modest but consistent benefits when consumed regularly as part of a balanced diet	Modest and variable effects; results depend on dose, formulation, and study design
Accessibility	Widely accessible, especially when locally produced and culturally embedded	Often limited by cost, availability, and commercial distribution channels
Affordability	Generally affordable and scalable, particularly in traditional diets and LMIC contexts	Frequently expensive and marketed as premium health products
Cultural relevance	Strong alignment with traditional cuisines, food heritage, and local food systems	Often culturally disconnected and framed through biomedical or commercial narratives
Equity implications	Can reduce health inequities when supported by food system and policy interventions	Risk of widening inequities by concentrating benefits among higher-income groups
Regulatory status	Governed primarily through food safety and dietary guidelines	Regulatory frameworks vary widely; often weak oversight of health claims
Risk of misinformation	Lower risk when promoted through dietary guidelines and public health messaging	High risk due to exaggerated marketing claims and "natural equals safe" narratives
Food system integration	Closely linked to agriculture, sustainability, biodiversity, and local food economies	Largely detached from food systems; often reliant on industrial extraction processes
Environmental sustainability	Supports sustainable diets, agroecology, and lower environmental footprints	Potential sustainability concerns related to intensive extraction and overharvesting
Public health role	Core component of population-level diabetes prevention and management strategies	Adjunct role; not suitable as a stand-alone public health intervention
Policy priority	Highly recommended for inclusion in dietary guidelines, subsidies, and community programs	Conditional—requires strong regulation, evidence validation, and consumer protection

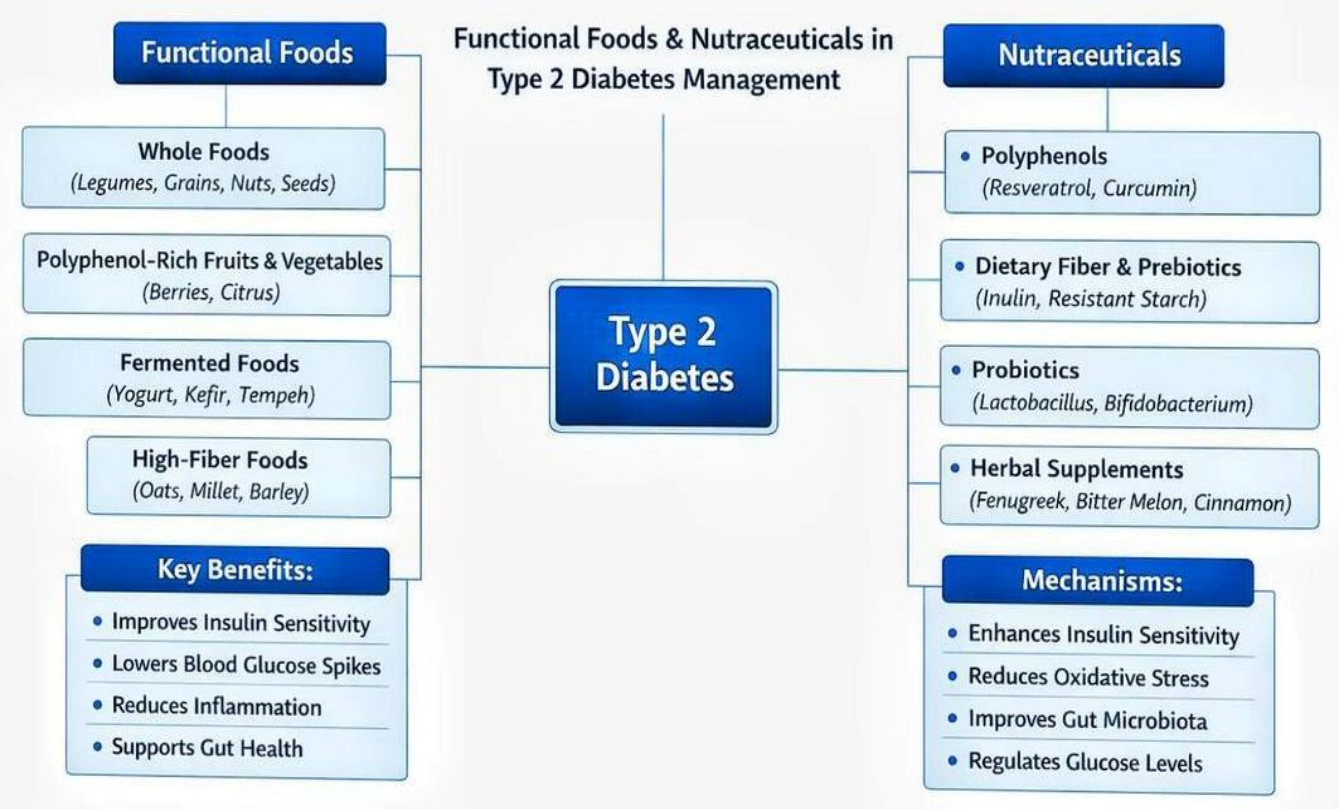


Figure 1. Conceptual framework of functional foods and nutraceuticals in type 2 diabetes management

Integrating Equity and Food System Determinants

To operationalise this framework, the role of social determinants of health must be central. Nutrition behaviours—including the ability to incorporate functional foods into diets—are shaped by systemic factors such as food system design, income, education, gender norms, and geography, which collectively influence access to, affordability of, and choices within food environments (Gyawali et al., 2024). Disparities in access to fresh, nutrient-dense foods and reliance on ultra-processed products can exacerbate the risk of T2DM among marginalised populations (Marume et al., 2025).

An equity-oriented framework thus requires multi-level interventions:

- **Policy level:** Integration of functional foods into national dietary guidelines, subsidies for local production, and regulation of nutraceutical claims.
- **Community level:** Culturally appropriate education on traditional foods and food preparation practices.
- **Individual level:** Behaviour change strategies that promote dietary diversity and sustainable consumption patterns.

Through this systems approach, functional foods and nutraceuticals become not isolated health tools, but levers for improving food environments and reducing chronic disease inequities.

Conceptual Model Overview

Figure 2 illustrates the integrative conceptual model linking functional foods and nutraceuticals with metabolic health outcomes for Type 2 diabetes. The framework emphasises the intersection of dietary behaviours, food system factors, and an equity- and sustainability-lens, highlighting how individual and societal determinants collectively influence diabetes prevention and management. This integrative framework aligns with global calls for nutrition-sensitive food systems and reflects the World Health Organisation's emphasis on integrating metabolic health promotion with the Sustainable Development Goals (SDGs 2, 3, and 12).

The framework depicts the interconnected layers of influence on metabolic health, beginning with the biological effects of functional foods (inner core) and extending outward to dietary behaviours, cultural practices, and the broader food system and policy environment. Equity and sustainability are cross-cutting dimensions that shape access, inclusion, and environmental impact. Together, these layers illustrate a systems-based approach to integrating functional foods and nutraceuticals into equitable, sustainable strategies for diabetes prevention and management.

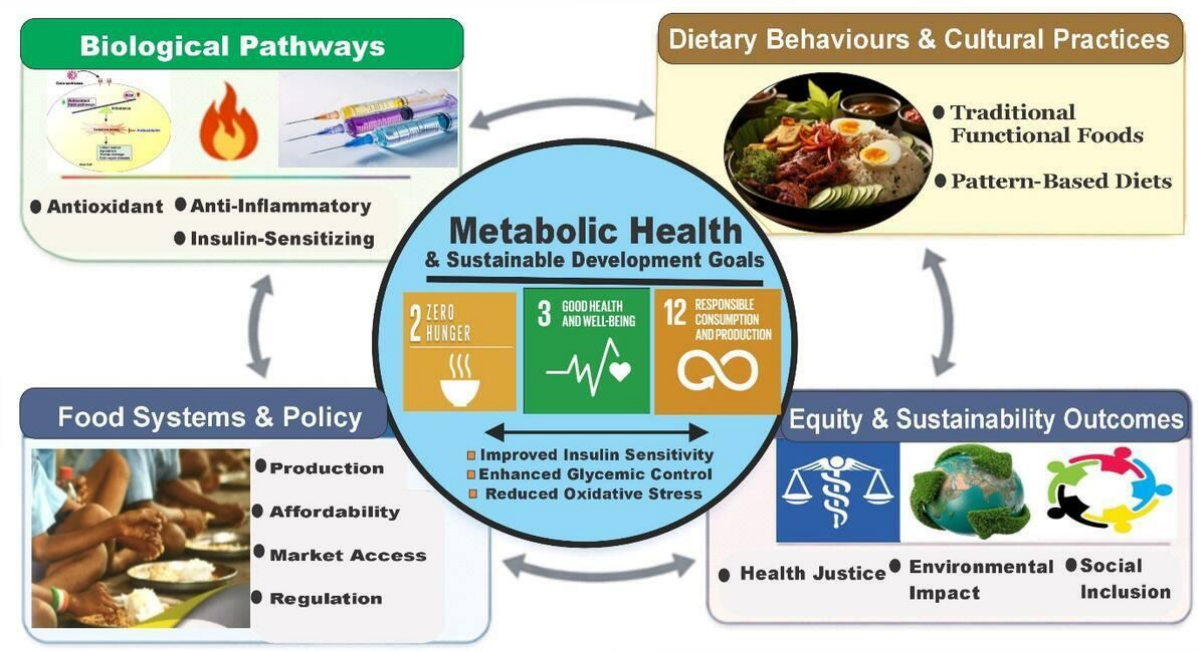


Figure 2. Integrative Conceptual Model of Functional Foods and Nutraceuticals for Type 2 Diabetes in a Public Health Nutrition Context.

Functional Foods and Nutraceuticals with Anti-Diabetic Potential

Whole Foods and Fermented Products

Evidence from cohort studies and controlled interventions generally supports the association between diets centred on whole, minimally processed foods and reduced risk or improved management of Type 2 diabetes (T2DM), although effect sizes vary across populations and study designs. Whole grains, legumes, nuts, and seeds—rich in fibre, resistant starch, and plant proteins—moderate postprandial glucose responses and enhance insulin sensitivity (Reynolds & Mitri, 2024). These foods underpin dietary patterns such as the Mediterranean and DASH diets, for which there is relatively strong and consistent evidence from long-term observational studies and clinical trials demonstrating metabolic benefits, particularly when adherence is sustained.

Fermented foods such as yoghurt, kefir, tempeh, and

traditional fermented vegetables provide probiotics and bioactive peptides that improve gut microbial balance, intestinal barrier function, and control of inflammation (Guadalupe et al., 2025). Importantly, fermented foods are not only biologically active but also culturally adaptable and economically feasible, making them valuable tools for community-based diabetes prevention efforts. Promoting the consumption of these traditional, accessible foods supports both nutritional equity and sustainability, aligning metabolic benefits with food sovereignty and local dietary heritage.

Bioactive Components in Everyday Diets

Bioactive compounds such as polyphenols, omega-3 fatty acids, and dietary fibres have been associated with improvements in glycaemic control and lipid metabolism; however, these effects are generally modest and context-dependent. Evidence from clinical and epidemiological studies suggests that benefits are more consistent when these compounds are consumed as part of whole dietary patterns rather than as isolated interventions (Li et al., 2019).

Functional fibres and prebiotics also promote beneficial gut bacteria, enhancing short-chain fatty acid (SCFA) production and improving insulin sensitivity. The inclusion of these foods in national dietary guidance can yield measurable metabolic benefits at scale, particularly when paired with policies that promote affordability and local sourcing (Nitzke et al., 2024).

Traditional Herbal and Plant-Based Interventions

Medicinal plants such as bitter melon (*Momordica charantia*), fenugreek (*Trigonella foenum-graecum*), cinnamon, turmeric, and ginseng have long histories in traditional medicine systems. Clinical trials suggest modest improvements in fasting glucose and HbA1c for certain preparations; however, substantial heterogeneity in study design, dosage, and standardisation limits the comparability and generalisability of these findings. (Okoduwa et al., 2024; Kim et al., 2023; Kim et al., 2022).

Rather than being promoted as universal "superfoods," these traditional botanicals should be contextualised within culturally specific dietary practices and evaluated for safety, sustainability, and equitable access. Public health programs can support local production, standardisation, and safe use—particularly in low- and middle-income countries where these plants are indigenous and affordable.

Integrating Evidence into Public Health Nutrition Practice

A growing body of evidence supports the role of functional foods as adjuncts to lifestyle and pharmacological management of T2DM. However, their population-level impact depends less on isolated bioactive effects and more on their integration into accessible, culturally relevant dietary patterns and food systems (Alkhatib et al., 2017). As summarised in Table 1, food-based functional nutrition strategies are more compatible with equitable, scalable, and sustainable public health action than market-driven nutraceutical approaches.

The public health nutrition approach should therefore prioritise food-based interventions over supplement-based ones and link functional foods to agricultural and sustainability policies that ensure equitable access. Community education should be encouraged that emphasises dietary patterns rather than individual "superfoods." Such integration transforms the functional food concept from a market product into a socially grounded nutrition strategy that can advance both metabolic and social well-being (Mirmiran, 2014; Feket, 2025).

Evidence from Preclinical and Clinical Studies

Translational Relevance of Preclinical Insights

Evidence from experimental and laboratory-based studies provides important insights into the biological pathways through which functional foods and nutraceuticals may influence glucose metabolism. Laboratory and animal models consistently demonstrate that bioactive compounds — such as polyphenols, flavonoids, omega-3 fatty acids, and probiotic strains — influence glucose metabolism by enhancing insulin receptor activity, modulating the gut microbiota, and reducing oxidative stress and inflammation (Aguerd et al., 2025). However, while these findings offer important biological credibility, their translation into public health nutrition requires careful contextualization. Most mechanistic data arise from controlled environments using standardised extracts and high doses that may not reflect real-world diets or culturally relevant food intake patterns. Thus, the challenge is not only to prove biological plausibility but also to ensure that these effects can be achieved through affordable, sustainable, and culturally appropriate dietary practices.

Clinical Evidence and Population-Level Implications

Clinical trials evaluating functional foods and nutraceuticals demonstrate modest yet generally consistent metabolic benefits; however, the strength of the evidence varies considerably by intervention type, study duration, and population characteristics. Importantly, findings are more robust when interpreted within the context of overall dietary patterns rather than isolated compounds, highlighting the need for caution in extrapolating to population-level recommendations.

Gut-Targeted Interventions (Probiotics, Prebiotics, Synbiotics)

Meta-analyses of human trials reveal that probiotic and prebiotic supplementation can improve fasting glucose, HbA1c, and inflammatory markers in individuals with T2DM (Shalbaf et al., 2025). Importantly, many traditional fermented foods—such as yoghurt, kefir, and regional vegetable ferments—naturally contain beneficial microbial strains. Public health translation thus lies not in expensive supplements but in supporting community access to safe, affordable fermented foods and integrating them into culturally appropriate meal patterns (Guadalupe et al., 2025).

Plant Bioactives and Polyphenols

Curcumin, resveratrol, catechins, and related polyphenols have demonstrated modest improvements in glycaemic and inflammatory markers in clinical studies; however, findings remain inconsistent across trials due to differences in formulation, bioavailability, and study design (Thota et al., 2018). Rather than promoting isolated supplements, dietary guidance should emphasise locally available plant-based foods—such as turmeric, berries, green tea, and leafy greens—that naturally provide these compounds and align with regional food traditions.

Traditional Botanicals and Functional Herbs

Evidence supports small but significant glucose-lowering effects for bitter melon, fenugreek, and cinnamon, though heterogeneity in study design and formulation persists (Kim et al., 2022; Kim et al., 2023). Policy efforts should therefore focus on standardisation and safety regulation of herbal nutraceuticals while promoting local cultivation and sustainable harvesting, particularly in regions where these botanicals are traditional dietary components.

Dietary Fibre, Whole Grains, and Omega-3 Sources

Large-scale reviews confirm that higher intake of dietary fibre and whole grains is associated with improved glycaemic control and reduced incidence of diabetes (Nitzke et al., 2024). Likewise, omega-3 fatty acids from fish or plant sources enhance lipid metabolism and insulin sensitivity (Bayram & Kızıltan, 2024). Translating these findings into public health action requires agriculture-nutrition collaboration—supporting local production of grains, pulses, and aquatic foods and ensuring they remain affordable and accessible for populations at risk of diabetes.

Implementation and Policy Considerations

While clinical evidence supports the metabolic benefits of functional foods and nutraceuticals, policy frameworks are essential to ensure equitable impact. Without coordinated action, market-driven nutraceutical trends may widen health disparities by privileging affluent consumers and urban markets. Integrating functional foods into public health strategies therefore requires: Regulatory clarity on labelling, safety, and health claims; Incentives for local food production and smallholder participation; Inclusion in national dietary guidelines to promote whole-food–based, culturally adaptable interventions. Community education to counter misinformation about supplements as substitutes for healthy diets. Such policy integration shifts the emphasis from individualised supplementation toward collective nutritional resilience, positioning functional foods as a cornerstone of sustainable diabetes prevention (Silpi, 2025; Sharma et al., 2024). However, translating these findings into policy should be approached cautiously, as much of the available evidence is derived from controlled settings that may not fully reflect real-world dietary behaviours or resource-constrained environments.

Equity and Sustainability in Research Translation

Finally, the global evidence base must evolve to reflect diverse populations and food environments. Most existing studies originate from high-income settings, leaving major gaps in low- and middle-income countries where T2DM prevalence is accelerating and where traditional diets could offer culturally congruent solutions. Strengthening research partnerships in these regions will help validate locally available functional foods and integrate indigenous knowledge with scientific innovation (Rashidinejad, 2024). By embedding clinical research within sustainable food systems and equity frameworks, functional food science can transition from laboratory innovation to a public health movement that simultaneously promotes metabolic health, environmental stewardship, and social justice.

Misconceptions, Misinformation, and Ethical Challenges in Functional Food Communication

Public interest in functional foods and nutraceuticals has grown rapidly, driven by the pursuit of "natural" solutions to chronic diseases such as Type 2 diabetes. However, this enthusiasm often outpaces the scientific evidence and regulatory oversight. Misconceptions surrounding these products are not merely matters of individual misunderstanding; they reflect deeper challenges in communication, policy, and commercial governance within global food and health systems.

Public interest in functional foods and nutraceuticals has grown rapidly, driven by the pursuit of "natural" solutions to chronic diseases such as Type 2 diabetes (Baker et al., 2022). However, this enthusiasm often outpaces the scientific evidence and regulatory oversight, with inconsistent regulatory frameworks and variable substantiation of health claims complicating effective governance (de Brito Alves & de Souza, 2023). Misconceptions surrounding these products are not merely matters of individual misunderstanding; they reflect deeper challenges in communication, policy, and commercial governance within global food and health systems (Shan et al., 2025; Hasler, 2002).

Misinformation and the "Natural Equals Safe" Narrative

Marketing practices frequently portray nutraceuticals and "superfoods" as harmless, universally beneficial, or capable of curing diabetes. Such messaging exploits the perception that natural products are inherently safe and effective. Yet many nutraceuticals can interact with medications, vary widely in composition, or lack rigorous safety assessment (Fong et al., 2022). Addressing this requires clear, science-based communication strategies led by public health authorities, alongside stricter regulation of health claims to protect consumers from misleading or exaggerated assertions.

Market Dynamics and Equity Concerns

The global nutraceutical market is largely driven by commercial interests and tends to target higher-income populations, raising concerns about equitable access (Chhabra et al., 2025). This dynamic reinforces the need to

prioritise affordable, food-based strategies within public health frameworks, particularly for populations most affected by T2DM.

Regulatory Fragmentation and the Need for Policy Coherence

The global regulatory landscape for nutraceuticals is fragmented, with wide disparities in labelling standards, safety testing, and marketing controls. Weak oversight allows unsubstantiated claims and variable product quality to persist across markets (Siddiqui & Moghadasian, 2020). To align with public health priorities, governments and international bodies should:

- Establish evidence-based approval processes for functional food claims;
- Integrate nutraceutical regulation into nutrition and food safety policy frameworks; and
- Promote transparency and accountability in research–industry partnerships.

Such policy coherence will safeguard consumer trust while supporting innovation grounded in scientific integrity.

Health Literacy and Responsible Public Communication

The public's ability to evaluate nutrition information is shaped by media literacy, education, and cultural beliefs (Bailey & Okoduwa, 2025). Low health literacy increases susceptibility to misinformation about quick dietary "fixes." Health professionals and communicators, therefore, play a pivotal role in translating complex research into accessible, culturally appropriate messages. Engagement through schools, community health programs, and digital platforms can help shift narratives away from miracle claims toward sustainable, evidence-based dietary habits. Ultimately, improving nutrition literacy and ethical communication is central to ensuring that functional foods and nutraceuticals contribute to informed, equitable, and sustainable public health outcomes rather than reinforcing consumer confusion or market dependency.

Challenges and Limitations

Despite growing scientific interest in functional foods and nutraceuticals, several challenges limit their effective translation into equitable and sustainable public health practice. These limitations span not only research design but also policy coherence, food system structures, and socioeconomic disparities that determine who benefits from innovation.

Methodological Heterogeneity and Evidence Quality

The scientific evidence base remains constrained by significant methodological variation. Many studies differ in design, participant characteristics, intervention duration, and measured outcomes, leading to heterogeneity that complicates synthesis and policy translation (Siddiqui & Moghadasian, 2020). Small sample sizes, lack of standardised formulations, and inconsistent reporting on dosage and bioavailability limit the generalizability of findings to real-world populations. Moreover, a disproportionate number of studies are conducted in controlled clinical or laboratory settings that fail to capture the complex dietary, cultural, and environmental contexts in which people actually consume these foods. This methodological gap impedes the development of pragmatic guidelines to inform national nutrition policies or public health programs. This variability underscores the need for cautious interpretation of pooled findings and limits the strength of causal inferences that can be drawn across heterogeneous study designs.

Translational Barriers and Implementation Gaps

Even when functional foods and nutraceuticals show measurable benefits in trials, their adoption into population-level strategies is often slow. Implementation barriers include limited integration between nutrition science, public health programming, and agricultural policy, as well as insufficient capacity for intersectoral coordination (Lam et al., 2025; Popkin & Ng, 2021; Roy et al., 2023).

In many low- and middle-income countries (LMICs), where T2DM prevalence is rising most rapidly, health systems are primarily structured around curative care rather than preventive nutrition interventions. As a result, functional food-based approaches remain underutilised in diabetes prevention frameworks. Bridging this gap requires cross-sectoral collaboration among ministries of health, agriculture, education, and trade to ensure that evidence translates into affordable, accessible, and culturally relevant dietary solutions (Fekete et al., 2025; Rashidinejad, 2024; Sharma et al., 2024).

Data Gaps and Structural Inequities in Research

Global research on functional foods and nutraceuticals is geographically skewed toward high-income countries, resulting in data gaps for LMIC populations where the nutritional and metabolic landscape differs substantially (Rashidinejad, 2024). Locally available and culturally specific functional foods remain underrepresented in peer-reviewed studies, which limits recognition of indigenous and traditional food systems that may already support metabolic resilience (Gyawali et al., 2024; Rashidinejad, 2024). Additionally, inequities in research funding and infrastructure constrain participation by LMIC institutions, perpetuating a cycle in which the most affected regions remain understudied and underrepresented in global dietary guidelines. Supporting South–South research collaborations and inclusive funding models is therefore essential to achieving global relevance and equity in functional food research (Fekete et al., 2025; Rashidinejad, 2024).

Regulatory and Policy Fragmentation

Regulatory inconsistencies across countries hinder product standardisation, consumer trust, and evidence-based decision-making (Siddiqui & Moghadasian, 2020). While some regions classify nutraceuticals as foods, others treat them as pharmaceuticals or dietary supplements, resulting in varied approval pathways and labelling standards (Lam et al., 2025). Such fragmentation enables unverified claims and inconsistent quality, eroding the credibility of functional

food science. Establishing harmonised global standards and embedding nutraceutical governance within broader nutrition and health policy frameworks are key steps toward ensuring safety, efficacy, and equitable market regulation (Lam et al., 2025; Shan et al., 2025; Silpi, 2025).

Equity, Affordability, and Access Constraints

A critical yet often overlooked limitation lies in the economic accessibility of functional foods and nutraceuticals. While functional foods such as legumes, grains, and fermented products can be affordable staples, many nutraceutical formulations are premium-priced, reinforcing health inequities. Populations at greatest risk for T2DM—often in low-income and marginalised groups—may have limited access to diverse foods, fortified products, or health-promoting ingredients. Without policy measures to subsidise, promote, or produce these foods locally, the potential of functional nutrition will remain inequitably distributed. Achieving public health impact thus depends not only on scientific validation but also on economic and policy frameworks that democratize access to nutritionally beneficial foods (Chhabra et al., 2025; Darmon & Drewnowski, 2015; Drewnowski, 2009).

Environmental and Sustainability Considerations

Finally, while functional foods are often framed as "health-promoting," their production and distribution systems can carry environmental costs. For example, intensive extraction of bioactive compounds or overharvesting of medicinal plants may threaten ecosystems. A sustainable approach must prioritise eco-friendly sourcing, local value chains, and circular food systems that minimise waste and support biodiversity. Integrating sustainability metrics into functional food research would align metabolic health objectives with the broader Sustainable Development Goals (SDGs) (Fekete et al., 2025; Popkin & Ng, 2021; Rashidinejad, 2024). Table 2 summarises key multilevel limitations associated with functional foods and nutraceuticals and their implications for equity and sustainability within public health nutrition systems.

Table 2. Systemic barriers to the equitable and sustainable use of functional foods and nutraceuticals in public health

Level	Limitation	Equity/Sustainability Implication
Research	Small trials, inconsistent outcomes, poor standardisation	Weak evidence base, limited applicability across populations
Implementation	Gaps between research and health systems	Low adoption in LMICs, underutilization in prevention strategies
Policy	Regulatory fragmentation, lack of coherence	Inconsistent standards, inequitable consumer protection
Equity	Economic barriers and limited access	Disproportionate benefit to high-income consumers
Sustainability	Unsustainable sourcing and manufacturing	Potential ecological harm, conflict with SDG principles

Toward Systemic Solutions

To overcome these limitations, future efforts must adopt a systems-based, equity-driven approach that integrates research, policy, and practice. Priorities include:

- Establishing multinational research collaborations focused on culturally relevant functional foods;
- Embedding functional food strategies in universal health coverage and primary care nutrition programs;
- Creating inclusive funding mechanisms for LMIC researchers;
- And ensuring that product innovation aligns with sustainability and social justice objectives.

Through this system's integration, the field can move beyond efficacy trials to transformative nutrition policy, ensuring that functional foods and nutraceuticals contribute meaningfully to diabetes prevention and health equity worldwide (Bailey & Okoduwa, 2025a; Fekete et al., 2025; Lam et al., 2025; Rashidinejad, 2024).

Limitations of the Review

This review has some limitations that should be considered when interpreting its conclusions. First, as a narrative synthesis, it does not employ formal systematic review or meta-analytic methods, which may introduce selection bias despite efforts to include a broad and representative evidence base. Second, the included studies exhibit substantial heterogeneity in design, population characteristics, intervention types, and outcome measures, limiting direct comparability and the strength of generalisable conclusions. Third, much of the available evidence, particularly for nutraceuticals and bioactive compounds, is derived from short-term clinical trials or controlled experimental settings, which may not reflect long-term effectiveness or real-world dietary behaviours. Fourth, publication bias may favour studies reporting positive metabolic outcomes, potentially leading to an overestimation of the benefits of certain interventions.

Finally, the global evidence base remains skewed toward high-income settings, with limited representation of low- and middle-income countries where the burden of Type 2 diabetes is rapidly increasing. This gap limits the contextual applicability of the findings across diverse cultural and food-system environments. These limitations highlight the need for more standardised, long-term, and context-specific research to strengthen the evidence base and inform equitable public health nutrition strategies.

Future Directions: Toward Equitable, Sustainable, and

Precision-Based Nutrition Systems

The evolving science of functional foods and nutraceuticals offers an unprecedented opportunity to reimagine diabetes prevention and management through integrated food-and-health systems. Yet, realising this potential requires a shift from narrow biomedical paradigms toward holistic, policy-driven approaches that prioritise equity, sustainability, and cultural relevance. Future work should focus on bridging the gap between laboratory innovation, local food systems, and population-level implementation.

Precision Nutrition with a Public Health Lens

Advances in genomics, metabolomics, and microbiome research have fueled optimism for *precision nutrition*—tailoring dietary interventions to individual metabolic profiles. While such innovations promise greater efficacy, they risk widening inequities if confined to high-resource settings. The next generation of research must therefore integrate precision approaches into public health practice, ensuring tools and data are accessible to all populations.

Developing context-appropriate precision nutrition models—for example, using simplified metabolic markers or diet–microbiome interactions relevant to regional diets—could help translate emerging science into *low-cost, population-scalable solutions*. Partnerships among academic, public health, and community sectors can ensure that advances in personalised nutrition contribute to collective well-being rather than commercial exclusivity (Fekete et al., 2025; Lam et al., 2025; Shan et al., 2025).

Embedding Functional Foods in Sustainable Food Systems

Sustainability must be a core principle guiding future development and deployment of functional foods and nutraceuticals. This entails: Promoting agroecological production of nutrient-rich crops and bioactive plant species. Encouraging short, transparent value chains that support local farmers and minimise carbon footprints. Integrating functional foods into climate-resilient food policies, aligning human and planetary health objectives. Research agendas should adopt a "nutrition–environment co-benefit" framework to quantify how functional food systems can simultaneously reduce the diabetes burden and environmental degradation. These efforts align with the Sustainable Development Goals (SDGs 2, 3, 12, and 13), advancing global priorities for healthy, sustainable diets (Fekete et al., 2025; Popkin & Ng, 2021; Rashidinejad, 2024).

Policy Integration and Governance Innovation

For functional foods and nutraceuticals to deliver equitable health outcomes, they must be embedded within national nutrition and non-communicable disease (NCD) strategies. Governments and international bodies should prioritise:

- **Regulatory coherence**, establishing transparent standards for safety, labelling, and efficacy.
- **Fiscal and agricultural policies** that incentivise production and consumption of nutrient-dense foods.
- **Cross-sectoral governance platforms** linking health, agriculture, trade, and education.

Such governance reforms can reposition functional foods as public goods within preventive health systems, rather than luxury commodities accessible only to privileged groups (Lam et al., 2025; Sharma et al., 2024; Silpi, 2025).

Strengthening Local Innovation and South–South Collaboration

Empowering local research and innovation ecosystems is essential for ensuring that functional food strategies are relevant, sustainable, and inclusive. Many of the world's traditional diets already embody the principles of functional nutrition; strengthening these indigenous food systems through South–South collaboration, equitable funding mechanisms, and community-based participatory research will enable LMICs to shape the global research agenda. This decentralised approach can facilitate the validation of regionally specific functional foods—from African grains and Indian spices to Latin American pulses—while preserving biodiversity and cultural identity (Gyawali et al., 2024; Rashidinejad, 2024).

Advancing Nutrition Literacy and Public Engagement

Effective translation of scientific knowledge into behaviour change depends on public trust and comprehension. Future strategies should invest in nutrition education, health literacy, and community engagement to ensure individuals can make informed dietary choices amid complex marketing landscapes. Digital platforms, school curricula, and healthcare systems should promote critical understanding of evidence-based nutrition, countering misinformation while celebrating culturally rooted functional foods. This participatory model not only empowers consumers but also strengthens accountability across the food industry and policy spectrum (Baker et al., 2022; Hasler, 2002).

A Vision for Systems Transformation

The future of functional foods and nutraceuticals lies in their integration into equitable and sustainable food systems. Achieving this requires alignment between scientific evidence, public policy, and community practices, ensuring that nutrition interventions are not only effective but also accessible and culturally relevant. Achieving this transformation requires convergence across science, policy, and social action:

- **Science** must prioritise translational, interdisciplinary research connecting molecular nutrition to community health outcomes.
- **Policy** must operationalise findings through equitable food, agriculture, and trade regulations.
- **Society** must sustain public dialogue that values food as both a cultural heritage and a health resource.

By embedding innovation within these interconnected domains, functional foods and nutraceuticals can evolve from niche markets into vehicles for metabolic health equity, advancing global efforts to reduce the burden of Type 2 diabetes while promoting sustainable development (Fekete

et al., 2025; Popkin & Ng, 2021; Rashidinejad, 2024).

Statement on Originality and Synthesis

This review represents an original synthesis of existing literature, integrating findings across nutritional science, public health, and food systems research. Rather than reproducing prior work, the manuscript critically interprets and contextualises evidence to highlight the intersection of metabolic health, equity, and sustainability in the prevention and management of Type 2 diabetes.

Conclusions

Functional foods and nutraceuticals offer promising, though modest, contributions to the prevention and management of Type 2 diabetes. Their greatest value lies not in isolated biochemical effects but in their integration into sustainable, culturally appropriate dietary patterns that support metabolic health at the population level.

At the same time, innovation in functional food science must align with sustainability principles—supporting biodiversity, environmentally responsible sourcing, and local agricultural livelihoods. Integrating these priorities will ensure that advances in functional food research contribute not only to diabetes prevention but also to global goals for planetary health and sustainable development. Ultimately, the path forward demands a shift from product-focused strategies to systems-based nutrition solutions—where scientific innovation, cultural knowledge, and public policy converge to create resilient, equitable, and health-promoting food environments. When guided by evidence, ethics, and sustainability, functional foods and nutraceuticals can become not just tools for glycaemic control, but cornerstones of a fairer and healthier global nutrition future (Fekete et al., 2025; Popkin & Ng, 2021; Rashidinejad, 2024).

Author Contributions

SP contributed to conceptualisation, literature search, collation, management and synthesis of the articles and drafted the original manuscript, and both authors contributed to writing, review, and editing. SIRO contributed to conceptualisation, methodology, and supervision. Both authors approved the final version of the manuscript and agree to be accountable for all aspects of the work.

Declaration of Generative AI and AI-Assisted Technologies in Scientific Writing

The authors confirm that no generative AI tools were used to produce the scientific content, ideas, analysis, or conclusions of this manuscript. AI-assisted tools, including QuillBot and Consensus AI, were used only for limited language editing and paraphrasing support to improve clarity and expression. All scientific content remains the original intellectual work of the authors, who take full responsibility for the accuracy and integrity of the manuscript.

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Conflict of Interest

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