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Food as Medicine? Understanding the Growing World of Functional Foods and Nutraceuticals

Pooja Singnale*, Debasis Sasmal, Soibam Peter, Naveen Khoisnam, Ugarsain Sangwan, Satveer Yadav, Keshab Gogoi and Inchen Namchoom
ICAR Krishi Vigyan Kendra Anjaw, Arunachal Pradesh
*Email: singnalepooja37@gmail.com

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Abstract

The concept of "food as medicine" has gained increasing scientific attention due to the presence of bioactive compounds in foods that offer potential health benefits beyond basic nutrition. Functional foods and nutraceuticals have emerged as important areas of research at the intersection of nutrition, food science and human health. This article explores the major categories of functional foods, including oats, barley, tomatoes, turmeric, amla, green tea, garlic, flaxseed, pulses and probiotic foods. It highlights their key bioactive components, potential physiological mechanisms and findings from human studies. Particular emphasis is placed on distinguishing the health effects of whole foods from those of concentrated extracts and supplements. Evidence suggests that certain functional foods may positively influence health indicators, including blood lipids, blood pressure and inflammatory markers. However, such effects should not be considered definitive evidence of disease prevention or treatment. Overall, functional foods may contribute to healthier dietary patterns, although their benefits require further validation through rigorous human clinical research.

Keywords: Functional foods; nutraceuticals; bioactive compounds; probiotics

Introduction

Can food really be medicine?

The idea is not new. For centuries, traditional food systems have recognized the close relationship between diet and health, long before modern nutrition science began to explain the biological mechanisms behind it. Today, this age-old concept is gaining renewed attention as researchers explore the health-promoting potential of functional foods and nutraceuticals foods or food-derived components that may offer benefits beyond basic nutrition. From dietary fiber and probiotics to omega-3 fatty acids, polyphenols, millets, spices and fermented foods, scientists are increasingly investigating how bioactive compounds in our everyday diet may influence the gut microbiome, metabolism, inflammation and long-term health. Yet, as the boundary between food and medicine attracts growing scientific and commercial interest, an important question deserves careful consideration: how much of the promise of "food as medicine" is supported by scientific evidence and how much is driven by popular claims and marketing?

Traditionally, food has been understood primarily as a source of energy and essential nutrients required for growth, development and normal physiological function. However, advances in nutritional biochemistry and food science have revealed that many foods contain bioactive compounds capable of interacting with biological pathways in the body. Dietary fiber, phytochemicals, carotenoids, polyphenols, phytosterols, bioactive peptides, probiotics and omega-3 fatty acids are among the diverse components being investigated for their potential physiological effects. This has led to a broader understanding of nutrition in which food is considered not merely as fuel, but as a complex combination of nutrients and bioactive constituents that may influence health and disease risk. Within this evolving field, functional foods are generally understood as foods that provide benefits beyond basic nutrition when consumed as part of the usual diet. Nutraceuticals, a term derived from "nutrition" and "pharmaceutical," generally refer to food or food-derived products or bioactive components that are used or studied for their potential health-promoting or disease-risk-reducing effects. Although the terms are often used interchangeably in popular discourse, they

are not synonymous: functional foods remain foods consumed as part of the diet, whereas nutraceuticals are more commonly associated with concentrated or specifically formulated food-derived products.

Food as Medicine?

Can food really be considered medicine? Although the question may appear modern, the relationship between diet and health has been recognised across traditional food cultures for centuries. Long before the biological mechanisms of nutrition were understood, particular foods and dietary practices were associated with health and well-being. Modern nutritional science is now providing a more detailed explanation of some of these observations by investigating the biological activities of compounds naturally present in foods. Dietary fibre, probiotics, omega-3 fatty acids, polyphenols, carotenoids, plant sterols and other bioactive constituents are being studied for their possible roles in processes involving metabolism, inflammation, cardiovascular function and the gut microbiome. This growing scientific interest has brought functional foods and nutraceuticals into the spotlight. At the same time, it raises an important question: where does scientifically demonstrated benefit end and popular health claims or commercial promotion begin?

Food has traditionally been viewed primarily as a source of energy, essential nutrients and the raw materials required for growth and normal physiological function. Research in nutritional biochemistry and food science, however, has demonstrated that foods are chemically complex systems containing numerous compounds that can interact with biological pathways. These include phytochemicals, dietary fibers, carotenoids, polyphenols, phytosterols, bioactive peptides, probiotics and omega-3 fatty acids. Such findings have broadened the conventional view of nutrition: food is not simply fuel, but a complex mixture of nutrients and biologically active constituents that may influence physiological function and disease risk. Functional foods are generally described as foods that may provide health benefits beyond their basic nutritional contribution when consumed as part of the normal diet. The term *nutraceutical*, derived from "nutrition" and "pharmaceutical," is generally applied to food-derived substances or preparations that are consumed or investigated for their potential health-promoting or disease-risk-reducing effects. Despite their overlapping concepts, the two terms should not be treated as interchangeable. A functional food remains part of the food supply and is normally consumed as a food, whereas a nutraceutical is more often presented in a concentrated, isolated or specially formulated form. The terminology itself remains subject to scientific debate, as there is no single universally accepted definition of a functional food.

Major Classification of Functional Foods

Functional foods can be broadly grouped according to whether their functional characteristics occur naturally or are introduced or enhanced through food processing and formulation.

1. Naturally Functional Foods

These are foods that naturally contain nutrients or bioactive compounds that may provide physiological effects beyond basic nutrition.

Examples: oats, barley, fruits, vegetables, pulses, nuts, seeds, green tea and fatty fish.

2. Modified or Fortified Functional Foods

These are conventional foods whose nutritional or bioactive composition has been deliberately enhanced through fortification, enrichment or other forms of modification.

Examples: calcium-fortified milk, vitamin D-fortified foods, omega-3-enriched products and phytosterol-enriched spreads.

3. Functional Foods with Added Bioactive Components

These foods are formulated with specific components intended to provide an additional physiological benefit.

Examples: probiotic-containing yogurt, prebiotic-enriched foods and products enriched with dietary fiber, plant sterols or omega-3 fatty acids.

This broad classification is useful because it distinguishes foods that are naturally functional from products in which a particular health-related component has been deliberately introduced or enhanced. In practice, the categories may overlap. A single product may, for example, be both fortified and probiotic.

Functional Foods: From Bioactive Compounds to Health Benefits

Functional foods have become an important area of research at the intersection of nutrition, food science and human health. Their scientific appeal comes from the presence of compounds that may influence biological processes in addition to supplying conventional nutrients. Dietary fiber, polyphenols, carotenoids, phytosterols, bioactive peptides, probiotics and omega-3 fatty acids are among the components

being investigated for their physiological effects (Temple, 2022).

However, the presence of a bioactive compound should not by itself be interpreted as proof of a health benefit. Its effect may depend on the amount consumed, chemical form, absorption and metabolism, as well as the characteristics of the individual consuming it. Most importantly, evidence from human studies is needed to determine whether a biological effect translates into a meaningful health outcome. Functional foods are therefore more appropriately considered as components of a health-supporting dietary pattern rather than as substitutes for medicines.

Oats and Barley: The Role of β-Glucan

Oats and barley are among the most extensively studied cereal-based functional foods. Their particular importance comes from β-glucan, a soluble dietary fiber that has been investigated for its effects on cholesterol metabolism and other cardiometabolic outcomes.

A systematic review and meta-analysis of randomized controlled trials published in 2022 examined the effects of oat β-glucan intake in hypercholesterolemic adults. The analysis included 13 trials involving 927 participants and found significant reductions in total cholesterol and LDL cholesterol following β-glucan intake, while significant effects were not observed for triglycerides or HDL cholesterol (Yo *et al.,* 2022). These findings provide evidence that regular consumption of β-glucan-rich foods may contribute to improvements in lipid profiles. However, the findings should not be interpreted to mean that oats function as a pharmaceutical treatment. The magnitude of the response may vary according to dose, duration of intake and individual characteristics. Oats and barley demonstrate how a naturally occurring food component such as β-glucan can influence an established cardiovascular risk factor.

Tomatoes: Lycopene and Cardiovascular Health

Tomatoes are an important dietary source of lycopene, a carotenoid responsible for their characteristic red colour. Lycopene has been investigated extensively because of its antioxidant properties and its possible involvement in biological pathways related to cardiovascular health.

A systematic review and meta-analysis of tomato and lycopene interventions reported improvements in several cardiovascular risk-related measures. The analysis found effects involving LDL cholesterol, inflammatory markers and endothelial function, while lycopene supplementation was associated with a reduction in systolic blood pressure (Cheng *et al.*, 2017). These findings require careful interpretation because research involving whole tomatoes, tomato products and isolated lycopene preparations does not necessarily provide equivalent evidence. A whole food contains a mixture of nutrients and phytochemicals, whereas a supplement may provide a much more concentrated amount of one compound. Tomatoes illustrate the potential importance of food-derived carotenoids such as lycopene, while also demonstrating why evidence from supplements should not automatically be applied to ordinary dietary intake.

Turmeric: Curcumin and Inflammation

Few culinary spices have attracted as much scientific attention as turmeric (*Curcuma longa*). Its principal bioactive compounds are curcuminoids, particularly curcumin. Experimental research has identified several biological activities associated with curcumin, including effects on pathways related to oxidative stress and inflammation.

Human clinical research has also examined whether these biological activities translate into measurable changes in inflammatory markers. An umbrella meta-analysis of randomized clinical trials published in 2023 included 10 studies involving 5,870 participants. The analysis found significant reductions in C-reactive protein (CRP), interleukin-6 (IL-6) and tumour necrosis factor-alpha (TNF-α) following curcumin supplementation (Naghsh *et al.*, 2023). Such findings are promising but require appropriate context. A reduction in an inflammatory biomarker does not by itself demonstrate that a food or supplement can prevent or cure an inflammatory disease. In addition, many clinical investigations use standardized curcumin preparations that provide substantially different exposures from the quantities normally consumed when turmeric is used as a culinary spice. Turmeric demonstrates how traditional foods can provide starting points for modern biomedical research, while also highlighting the difference between culinary consumption and concentrated supplementation.

Amla: The Indian Gooseberry

Amla (*Phyllanthus emblica* L.), commonly known as Indian gooseberry, is particularly relevant when considering functional foods from an Indian perspective. It has a long history of traditional use and contains vitamin C together with a diverse collection of polyphenolic

compounds, including tannins and other phytochemicals (Gul *et al.*, 2022).

A comprehensive review published in *Food Chemistry* describes amla as a source of phenolic acids, tannins, flavonoids, sterols, triterpenoids, lignans and other phytonutrients. The review also discusses evidence concerning several biological activities attributed to its constituents (Ma *et al.*, 2024). Despite this promising chemical profile, the available research is not uniform. Studies have used different forms of the fruit, extracts and preparations, with considerable variation in dosage and experimental conditions. More carefully controlled human studies are therefore required to establish which effects are reproducible and clinically meaningful (Ma *et al.*, 2024). Amla illustrates the potential of traditional Indian foods as sources of diverse bioactive compounds, while also showing why traditional use and laboratory evidence need to be distinguished from established clinical benefit.

Green Tea: Catechins and Cardiometabolic Effects

Green tea contains several polyphenolic compounds known as catechins, with epigallocatechin gallate (EGCG) being one of the most extensively studied. These compounds have been investigated for their possible effects on oxidative processes, metabolism and cardiovascular function.

A systematic review and meta-analysis published in *Frontiers in Nutrition* examined 55 randomized controlled trials involving 4,874 participants. The investigators reported modest improvements in several cardiometabolic risk factors following green tea supplementation (Zamani *et al.*, 2023). An important limitation, however, is that many of the studies involved green tea extracts or concentrated preparations rather than the beverage consumed in ordinary dietary quantities. Consequently, the results should not be interpreted as demonstrating that routine consumption of brewed green tea necessarily produces effects of the same magnitude. Green tea is a useful example of a polyphenol-rich food, but findings from concentrated extracts must be distinguished from evidence concerning normal dietary consumption.

Garlic: Organosulfur Compounds and Cardiovascular Risk Factors

Garlic has a long history of dietary and traditional use and has also been investigated extensively for possible cardiovascular effects. Its characteristic biological properties are associated with several organosulfur compounds, whose concentrations and chemical forms can change depending on processing and storage.

A meta-analysis of randomized controlled clinical trials focusing specifically on garlic powder reported significant reductions in total cholesterol and LDL cholesterol. The same analysis also found reductions in fasting blood glucose, systolic blood pressure and diastolic blood pressure (Kwak *et al.*, 2014). More recently, another meta-analysis of randomized controlled trials involving individuals with dyslipidemia reported reductions in total cholesterol, triglycerides and LDL cholesterol following garlic consumption (Du *et al.*, 2024). Although these results indicate potential cardiometabolic effects, garlic products are not chemically identical. Fresh garlic, aged preparations, powders and extracts may differ substantially in their composition and biological activity. Garlic demonstrates that a familiar culinary food may influence several cardiometabolic risk factors, but the form and amount consumed are important when interpreting the evidence.

Flaxseed: Omega-3 Fatty Acids, Fibre and Lignans

Flaxseed is notable because several potentially bioactive components occur together within the same food. These include the plant-derived omega-3 fatty acid alpha-linolenic acid (ALA), dietary fiber and lignans, a group of plant polyphenols.

Blood pressure has been one of the major outcomes investigated in human flaxseed studies. A systematic review and meta-analysis of controlled trials found that flaxseed intake was associated with modest reductions in both systolic and diastolic blood pressure. Some analyses indicated stronger effects with whole flaxseed and longer intervention periods (Khalesi *et al.*, 2015). A separate systematic review and meta-analysis of controlled clinical trials likewise reported modest blood-pressure reductions associated with flaxseed supplementation (Ursoniu *et al.*, 2016). These findings suggest that flaxseed may contribute to cardiovascular health when incorporated into an appropriate dietary pattern. Nevertheless, such evidence should not be interpreted as a justification for replacing prescribed treatment for hypertension. Flaxseed shows how several potentially active components ALA, fiber and lignans can work within the complex matrix of a single food.

Pulses and Legumes: Fiber, Resistant Starch and Plant Protein

Pulses such as lentils, chickpeas, beans and peas form an important part of traditional diets in many regions, particularly in South Asia. Their nutritional value extends beyond plant protein: they also provide dietary fiber, resistant starch and a range of phytochemicals.

A 2023 systematic review and meta-analysis investigated associations between legume consumption and cardiovascular disease and type 2 diabetes. The review included 47 studies comprising cohort studies and randomized trials. Although the observational evidence did not demonstrate a clear reduction in disease incidence, randomized trials indicated improvements in several risk factors, including total cholesterol, LDL cholesterol, fasting glucose and HOMA-IR (Thorisdottir *et al.*, 2023). These results support the inclusion of pulses within a varied and balanced diet but do not establish that legumes independently prevent cardiovascular disease or type 2 diabetes. The potential value of pulses lies in their overall nutritional composition rather than in a single "miracle" compound.

Probiotic Foods: Beneficial Microorganisms

Some functional foods differ from conventional examples because their potential effects are associated with living microorganisms rather than primarily with vitamins or phytochemicals. Certain fermented foods, including selected cultured dairy products, may contain microorganisms capable of interacting with the gastrointestinal environment.

The International Scientific Association for Probiotics and Prebiotics defines a probiotic as a live microorganism that, when administered in adequate amounts, provides a health benefit to the host (Hill *et al.*, 2014). This definition is important because fermentation alone does not make a food a probiotic. A particular microorganism must be present in an adequate amount and have evidence demonstrating a health benefit. Moreover, probiotic effects are often strain-specific, meaning that results obtained with one strain cannot automatically be applied to every microorganism marketed as a probiotic. Probiotics broaden the concept of functional foods by demonstrating that health-related food effects may involve living microorganisms as well as chemical compounds.

From Individual Foods to a Broader Dietary Perspective

The foods discussed above illustrate an important feature of functional-food science: their potential effects rarely depend on one isolated molecule. Oats and barley provide β-glucan, tomatoes contain lycopene, turmeric supplies curcuminoids, green tea contains catechins, amla provides vitamin C and diverse polyphenols, flaxseed combines ALA with fiber and lignans, while pulses offer protein, fiber, resistant starch and phytochemicals.

This complexity distinguishes food from conventional pharmaceutical products. Medicines are generally formulated to deliver a defined active substance at a controlled dose. Foods, in contrast, contain numerous compounds whose concentrations can vary according to plant variety, growing conditions, processing, storage, cooking and serving size. Consequently, functional-food research needs to move beyond simply identifying a compound in a food. Researchers must also consider how much of that compound is consumed, whether it is absorbed and metabolized, how it interacts with the food matrix and whether its consumption produces a meaningful outcome in humans.

The difference between laboratory evidence and real-world dietary effects is particularly important. A compound can produce a strong biological response in cultured cells or experimental animals while producing a much smaller effect or no clinically meaningful effect—when consumed through an ordinary diet. Another important consideration is the distinction between food and nutraceutical preparations. A food contains a complex mixture of nutrients and bioactive compounds in a particular matrix, whereas a nutraceutical may deliver a concentrated or isolated component. Therefore, evidence supporting a high-dose extract should not automatically be used to make claims about the corresponding whole food.

Ultimately, the scientific value of functional foods lies not in labelling particular foods as "superfoods," but in understanding how dietary components interact with human physiology. The strongest conclusions arise when plausible mechanisms are supported by well-designed human studies, systematic reviews and randomized controlled trials.

Where Does the Evidence End and Marketing Begin?

The rapid growth of the functional-food and nutraceutical market has created a difficult communication challenge. Scientific studies may identify promising biological effects, while commercial messages can sometimes convert these preliminary findings into much stronger claims.

For example, demonstrating that a compound reduces an inflammatory biomarker does not

establish that it prevents an inflammatory disease. Similarly, an improvement in LDL cholesterol does not automatically demonstrate a reduction in cardiovascular events. Evidence from cell cultures and animal models can help explain biological plausibility, but such findings cannot substitute for clinical evidence in humans. The same caution applies to traditional claims. Traditional knowledge can provide valuable clues about foods worthy of scientific investigation, but historical use alone cannot establish efficacy, optimal dosage or safety.

A scientifically responsible approach therefore requires asking several questions:

- Was the study performed in humans?
- Was it a randomized controlled trial or an observational study?
- Was the intervention a whole food, food extract or purified compound?
- What dose was used?
- Was the outcome a biomarker or a clinically meaningful health outcome?
- Were the findings reproduced in other studies?
- Does a systematic review or meta-analysis support the conclusion?

These questions help separate evidence-based nutritional information from exaggerated claims.

Can Food Replace Medicine?

The phrase "food as medicine" can be useful as a way of highlighting the importance of nutrition, but it can also be misleading if interpreted literally. Food and medicines operate within different scientific and clinical frameworks. A balanced diet can influence risk factors such as blood pressure, blood lipids, body weight and glucose regulation. Dietary patterns rich in whole grains, vegetables, fruits, legumes, nuts and other minimally processed foods are important components of overall health. Functional foods may contribute to these benefits by providing specific nutrients and bioactive compounds.

However, when an individual has a diagnosed medical condition requiring treatment, replacing prescribed medication with a food or nutraceutical without appropriate medical advice can be harmful. Even when a functional food has a measurable physiological effect, that effect may be relatively modest compared with the effect of a therapeutic drug. The more scientifically appropriate view is therefore one of complementarity rather than replacement. Functional foods may support health and, in some circumstances, contribute to the management of risk factors, but they should not automatically be considered alternatives to evidence-based medical treatment.

The Future of Functional Foods and Nutraceuticals

Research in this field is moving beyond the identification of individual "health-promoting" compounds. Increasing attention is being given to the food matrix, bioavailability, gut microbiome, metabolism and individual variation in response to diet.

The gut microbiome is particularly important because dietary components can influence the microorganisms living in the gastrointestinal tract, while microbial metabolism can in turn alter the biological activity of food-derived compounds. This creates a complex relationship between what people eat, their intestinal microorganisms and their physiological responses. Another emerging area is personalised nutrition, in which dietary recommendations may increasingly take account of genetics, metabolism, microbiome composition, lifestyle and other individual characteristics. Such approaches could eventually help determine why the same food produces different responses in different people. At the same time, advances in food processing and biotechnology are enabling researchers to develop foods with modified concentrations of particular nutrients or bioactive compounds. Fortified foods, functional beverages, probiotic products and other specially formulated foods are likely to remain important areas of research and commercial development.

However, technological innovation should be accompanied by rigorous evaluation. A new functional food should not be considered successful simply because it contains a high concentration of a biologically active compound. Its safety, bioavailability, efficacy, appropriate dosage and clinically meaningful outcomes must also be established.

Conclusion

The growing interest in functional foods reflects a broader change in our understanding of nutrition. Foods are not simply sources of calories, protein, vitamins and minerals; they also contain a diverse range of compounds that can interact with biological systems. β-glucan in oats and barley, lycopene in tomatoes, curcuminoids in turmeric, catechins in green tea, organosulfur compounds in garlic and ALA, fibre and lignans in flaxseed illustrate the range of components currently being investigated. At the same time, the evidence discussed in this article

demonstrates why the phrase "food as medicine" should be used with caution. Several foods and food-derived compounds have been associated with improvements in cardiovascular, metabolic or inflammatory biomarkers. However, a change in a biomarker is not necessarily equivalent to preventing or treating a disease. Similarly, results obtained using concentrated extracts or purified compounds cannot automatically be applied to the quantities consumed in ordinary foods.

Functional foods are therefore best understood as components of a broader health-promoting dietary pattern rather than replacements for medical treatment. Their potential benefits may arise from the combined action of multiple nutrients and bioactive compounds, the physical structure of the food, interactions with the gut microbiome and the overall dietary context. For consumers, the most useful question is not whether a particular food is a "miracle food," but whether credible human evidence supports including it as part of a balanced diet. For researchers, the challenge is to move beyond promising laboratory observations and establish which functional foods produce reproducible and clinically meaningful benefits in humans.

The future of functional foods and nutraceuticals is likely to involve increasingly sophisticated research into bioactive compounds, food matrices, the gut microbiome and individual responses to diet. Yet one principle should remain central: functional foods may complement healthy living and, where appropriate, medical care but they should not be confused with medicines simply because they contain biologically active compounds. The real promise of "food as medicine" lies not in replacing pharmacological treatment, but in understanding how scientifically supported dietary choices can contribute to better health across the lifespan.

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