Review Article

Role of Nutraceuticals in health and disease prevention: A Review Article

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Abstract

Nutraceuticals can offer health benefits beyond simple diet; they have become an important part of contemporary preventative healthcare. These bioactive substances, which come from natural food sources including plants, animals, and microbes, are crucial for controlling physiological processes and lowering the chance of developing chronic illnesses. According to current scientific knowledge, nutraceuticals affect health through a number of processes, such as immunological boosting, metabolic regulation, anti-inflammatory effects, antioxidant activity, and gut microbiome manipulation**.** Together, these efforts help prevent and treat serious illnesses like diabetes, metabolic syndrome, heart disease, gastrointestinal problems, cancer, obesity, and neurological disorders. All things considered, nutraceuticals are a promising and quickly developing sector that connects nutrition and medicine, providing fresh chances to advance tailored nutrition, prevent disease, and promote health.

Keywords: Nutraceutical, Plants, Prevention, Disease, Therapeutic effect.

Introduction

This evolving perspective has led to the emergence of *nutraceuticals*, a broad category of food-derived products that offer medical or health benefits, including the prevention and management of chronic diseases. Positioned between conventional foods and pharmaceuticals, nutraceuticals encompass functional foods, dietary supplements, and bioactive components that exert physiological effects capable of enhancing well-being and supporting disease prevention[1]. A central debate concerns whether nutraceuticals should be regarded as foods, supplements, or drug-like agents; however, their value lies in their ability to promote health, reduce disease risk, and complement standard therapeutic interventions. With increasing global recognition of lifestyle-related diseases, nutraceuticals have gained prominence as adjunctive strategies that integrate nutritional therapy into modern healthcare.

Nutraceuticals play a key role in maintaining metabolic balance, supporting immune function, and protecting against oxidative and inflammatory damage. Herbal-based nutraceuticals, in particular, have demonstrated beneficial effects in conditions such as obesity, diabetes mellitus, cardiovascular disorders, cancer, allergies, neurodegenerative diseases like Alzheimer's disease, and various inflammatory pathologies. These effects arise from diverse mechanisms, including antioxidant activity, modulation of gut microbiota, regulation of lipid and glucose metabolism, and enhancement of cellular defence pathways. Based on their chemical nature, biological action, and natural origin, nutraceuticals can be broadly classified into categories such as dietary fibres, probiotics and prebiotics, polyunsaturated fatty acids (PUFAs), antioxidant vitamins, minerals, polyphenols, and other plant-derived phytonutrients. Together, these components contribute to a comprehensive, preventive approach to long-term health maintenance[2].

HISTORY OF NUTRACEUTICALS

The concept of nutraceuticals appears modern, yet its roots lie in ancient medical traditions that used food for healing. For instance, since antiquity many medical texts (Western as well as Eastern) assumed a "food-as-medicine" continuum. In the classical Western tradition, the legacy of Hippocrates is often evoked, including the alleged maxim "Let food be thy medicine." Similarly, in ancient Indian medicine such as Ayurveda, foods, herbs and botanicals have been described for therapeutic purposes and health maintenance (as "āhāra").

A major milestone in the systematic use of food for disease-prevention is credited to James Lind — in 1747 he conducted one of the first controlled dietary experiments showing that citrus fruits significantly reduced occurrence of scurvy among sailors. This experiment is widely considered an early example of "clinical nutrition" long before the discovery of vitamins.

The modern term Nutraceuticals was coined in 1989 by Stephen L. DeFelice — combining "nutrition" and "pharmaceutical". He defined nutraceuticals as "any food or part of a food that provides medical or health benefits, including prevention and/or treatment of disease." Meanwhile, in Japan in the early 1980s the concept of Functional Foods gained traction — and by 1991 the Japanese government instituted a regulatory framework known as FOSHU (Foods for Specified Health Use), thereby formalizing health-claim labelling for foods with scientifically assessed beneficial properties. Today, nutraceuticals form a global, evidence-based (though often debated) field at the intersection of nutrition, preventive health, and functional medicine[3].

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Table 1: Historical Development of Nutraceuticals

Time Period / Era	Key Developments	Details
Ancient Civilizations	Early recognition of food as medicine	Ayurveda used herbs, spices, and plant-based remedies; Traditional Chinese Medicine used ginseng, green tea, fermented foods for vitality; Egyptian & Greek physicians used botanicals.
400 BC	Hippocrates' principle	Famous quote: *"Let food be thy medicine and medicine be thy food."* Highlighted food–health connection.
1747 (18th Century)	First clinical nutrition study	Dr. James Lind discovered citrus fruits prevent scurvy, proving food can cure diseases.
Late 19th to Early 20th Century	Discovery of essential vitamins & minerals	Extraction of Vitamin C, Vitamin D, B-complex etc. Led to large-scale fortification programs: iodized salt, Vitamin D milk, iron-fortified flour.
Mid-20th Century	Rapid growth of nutrition science	Studies linked diet to heart disease, cancer, obesity, diabetes. Discovery of bioactive compounds like omega-3, probiotics, antioxidants, fiber, carotenoids, polyphenols. Beginning of functional foods.
1989	Concept of *nutraceutical* introduced	Dr. Stephen DeFelice coined the term combining *nutrition* + *pharmaceutical*. Defined nutraceuticals as foods/components with therapeutic or preventive health benefits.
1991 (Japan)	First global functional food regulatory system	Japan established **FOSHU** (Foods for Specific Health Use). Allowed foods with scientifically proven health claims. Recognized probiotics, fiber, plant sterols, bioactive compounds.
Early 2000s – Present	Global expansion of nutraceutical industry	Driven by aging populations, lifestyle diseases, and health awareness. Regulatory bodies (FDA, EFSA, FSSAI) monitor safety, labeling, and health claims.
Present Research Trends	Advanced scientific exploration	Studies on effects on immunity, metabolism, inflammation, gut microbiota, and chronic disease prevention. Nutraceuticals now blend traditional wisdom with evidence-based science.

CLASSIFICATION OF NUTRACEUTICALS

Nutraceuticals are non-specific biological treatments that are intended to prevent pathological processes, improve overall health, and reduce symptoms associated with illness.

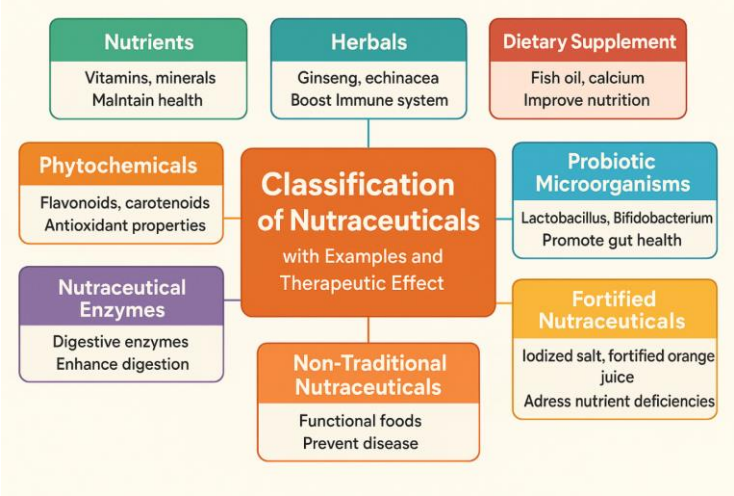

Figure No.1 Classification of Nutraceuticals

Nutraceuticals can be generally categorized into the following groups based on their source and functional attributes:

(a) Nutrients

Nutrients — the vitamins, minerals, fatty acids, amino acids and other biochemical compounds essential for normal physiological functioning — form the core building blocks of human health. When, in addition to fulfilling basic dietary needs, these nutrients or nutrient-rich foods exhibit health-protective, disease-preventive or therapeutic properties, they are often categorized under the broader umbrella of "nutraceuticals"[2].

The term Nutraceuticals — a blend of "nutrition" and "pharmaceuticals" — was coined in 1989. According to scientific reviews, nutraceuticals encompass not only isolated nutrients but also dietary supplements, functional foods, and bioactive food-derived compounds such as antioxidants, omega-3 fatty acids, fibres, and phytochemicals. When used appropriately, nutrient-based nutraceuticals may offer several health advantages beyond mere nutrition: they can help in disease prevention, promote general wellness, support metabolic and cardiovascular health, and even contribute to lifespan and quality-of-life improvements.

Table. 2 Nutrients and Bioactive Compounds Herbals

Nutrient / Bioactive (as Nutraceutical)	Source / Examples of Food / Food-derived source	Reported Therapeutic / Health Benefits
Omega-3 fatty acids (EPA, DHA)	Fatty fish; microalgae; omega-3 rich eggs, etc. (16)	Anti-inflammatory; cardiovascular protection; support in metabolic disorders; reduction of chemotherapy-related toxicities in some studies (17)
Curcumin (from turmeric)	Turmeric spice / curry / turmeric-supplements. (18)	Antioxidant, anti-inflammatory; anti-cancer (induces apoptosis in cancer cell lines); may aid in chronic diseases (cancer,

		cardiovascular, neurological) according to reviews. (19)
Epigallocatechin gallate (EGCG) (a tea polyphenol)	Green tea (and related products) (18)	Antioxidant; reduces free radical formation; anti-inflammatory; may protect against UV-induced skin damage; anticarcinogenic potential. (18)
Quercetin (flavonoid)	Fruits, vegetables, tea, red wine, etc. (20)	Antioxidant, anti-inflammatory; may reduce blood pressure and oxidized-LDL (atherosclerosis risk); potential protection against cardiovascular disease. (20)
Vitamins (e.g. Vitamin C, Vitamin E, Vitamin D, others)	Citrus fruits, leafy vegetables, nuts/seeds, dairy/fortified foods, sunlight-exposed foods (for Vitamin D) (17)	Vitamin C/E — antioxidant, supports skin health, oxidative stress reduction, supports immunity. Vitamin D & minerals (like calcium) — bone health (bone & teeth formation), prevention of osteoporosis. (10)
Proteins / Peptides (e.g. from milk: casein / whey-derived peptides)	Dairy / milk proteins (2)	Some milk-derived peptides may exhibit antihypertensive (blood pressure lowering) effects — acting similarly to ACE-inhibitors but naturally. (2)

Herbal medicines and nutraceuticals have long supported traditional healthcare and are now widely studied for their therapeutic potential and safety. Many herbs contain phytochemicals with anti-inflammatory, antioxidant, antimicrobial, metabolic, hepatoprotective and immunomodulatory effects[3]. Key bioactive such as polyphenols, flavonoids, terpenoids, alkaloids and organosulfur compounds act through antioxidant, anti-inflammatory, metabolic and immune pathways. Common herbs like turmeric, ginger, garlic and green tea offer broad systemic benefits, while ashwagandha, ginseng and holy basil function as adaptogens. Others, including milk thistle, cranberry and bitter melon, provide targeted organ-specific effects.

Table No. 3: Herbals as Nutraceuticals and its Therapeutics Effect.

S.N	Herb (common) — Scientific name	Main therapeutic / nutraceutical effects	Main bioactive(s) / mechanism / notes
1	Ginger — *Zingiber officinale*	Antiemetic (nausea in pregnancy/chemotherapy), anti-inflammatory, digestive aid, analgesic potential.	Gingerols, shogaols, zingerone — anti-inflammatory and antiemetic actions.
2	Garlic — *Allium sativum*	Cardiovascular benefits (BP, lipids – variable evidence), antiplatelet/antimicrobial, immune support.	Organosulfur compounds (allicin, diallyl sulfides) — antioxidant, vasodilatory, antimicrobial.
3	Green tea — *Camellia sinensis*	Cardiovascular protection, metabolic benefits, possible cancer-risk reduction signals; antioxidant and vascular benefits.	Catechins (EGCG) — antioxidant, anti-inflammatory, endothelial effects.
4	Cinnamon — *Cinnamomum* spp.	Glycemic control support (type 2 DM) and lipid modulation (evidence mixed/modest).	Cinnamaldehyde and polyphenols — insulin sensitizing, AMPK related effects.
5	Milk thistle — *Silybum marianum*	Hepatoprotective / antioxidant (used as adjunct for liver injury, NAFLD investigations).	Silymarin (flavonolignans) — free-radical scavenging, membrane stabilization, ↑glutathione.
6	Fenugreek — *Trigonella foenum-graecum*	Antidiabetic effects (improved glycaemic indices), lipid improvements in some trials.	Galactomannans, 4-hydroxyisoleucine — slow carb absorption, insulin-sensitizing actions.
7	Ashwagandha — *Withania somnifera*	Adaptogen: reduces stress/cortisol, anxiolytic effects; some metabolic and cognition benefits reported.	Withanolides and steroidal lactones — HPA axis modulation, antioxidant.
8	Holy basil / Tulsi — *Ocimum sanctum*	Anti-stress, antioxidant, metabolic support (glucose/lipids); antimicrobial and anti-inflammatory.	Eugenol, ursolic acid, other phenolics — multiple pathways (anti-inflammatory, antioxidant).
9	Neem — *Azadirachta indica*	Broad antimicrobial, anti-inflammatory, antidiabetic and dental uses (traditional + experimental evidence).	Azadirachtin and limonoids, flavonoids — antimicrobial, immunomodulatory.
10	Aloe vera — *Aloe barbadensis*	Topical wound healing, skin soothing; some oral uses for GI (mixed evidence).	Polysaccharides, anthraquinones, vitamins — wound healing, anti-inflammatory.

(b) Dietary Supplements

Nutraceuticals, encompassing vitamins, minerals, bioactive plant compounds, and functional supplements, play a significant role in promoting health and preventing disease. Their use has expanded globally due to growing awareness of preventive healthcare, lifestyle disorders, and evidence-based benefits of targeted supplementation. Essential micronutrients such as vitamin D, calcium, vitamin C, zinc, iron, folate, and vitamin B12 are widely utilized to correct deficiencies, support immune function, and maintain metabolic balance[3,4]. Bioactive compounds including omega-3 fatty acids, probiotics, curcumin, green tea catechins, berberine, resveratrol, and garlic contribute to anti-inflammatory, cardiometabolic, and antioxidant effects, although evidence varies across clinical studies. Functional supplements like glucosamine, coenzyme Q10, psyllium, melatonin, creatine, and L-arginine are also used for joint health, cardiovascular support, digestive regulation, sleep improvement, and physical performance. While many nutraceuticals show meaningful therapeutic potential, their efficacy often depends on dosage, formulation, and individual patient context, highlighting the need for evidence-based and judicious use.

Table no. 4 Nutraceutical and their health effects

S.N	Nutraceutical (common form)	Reported therapeutic / health effects
1	**Vitamin D (cholecalciferol D3)**	Bone health, prevents rickets/osteomalacia, supports calcium absorption; mixed/limited benefit for CV outcomes.
2	**Calcium (carbonate, citrate)**	Bone health, osteoporosis prevention (with vitamin D).
3	**Vitamin C (ascorbic acid)**	Antioxidant; prevents scurvy; modest/uncertain effect for common cold (some benefit in specific contexts).
4	**Zinc (zinc gluconate/acetate)**	Immune function; may shorten duration of common cold when used as lozenges early.
5	**Iron (ferrous sulfate/fumarate)**	Treats iron-deficiency anemia; improves hemoglobin and symptoms.
6	**Folate / Folic acid**	Prevents neural tube defects (pregnancy); treats folate deficiency; supports RBC synthesis.
7	**Vitamin B12 (cyanocobalamin / methylcobalamin)**	Treats B12 deficiency (neuropathy, megaloblastic anemia); essential for neurological function.
9	**Probiotics (Lactobacillus, Bifidobacterium strains)**	Improves some forms of antibiotic-associated diarrhea, IBS symptoms, and certain pediatric conditions; supports gut microbiota.
11	**Glucosamine sulfate (± chondroitin)**	Symptomatic relief of osteoarthritis pain / function in some studies; mixed results across trials.
12	**Coenzyme Q10 (ubiquinone / ubiquinol)**	May reduce statin-associated myalgia; evidence for symptomatic improvement in heart failure and some CV endpoints (adjunctive).
13	**Psyllium (soluble fiber)**	Lowers LDL cholesterol; helps glycemic control and bowel regularity.
14	**Berberine**	Lowers fasting glucose and modestly improves lipids; compares in some studies with metformin for glycemic control.
15	**Melatonin**	Improves sleep onset and some circadian disorders; adjunct in jet lag and shift-work sleep issues.
16	**Creatine monohydrate**	Improves short-term high-intensity exercise performance; increases muscle mass when combined with resistance training.
17	**Green tea catechins / EGCG**	Modest effects on weight management, antioxidant markers; cardiovascular/metabolic signals but mixed results.
18	**Resveratrol**	Proposed antioxidant, metabolic and cardiovascular benefits in preclinical studies; human evidence inconsistent and generally weak.
19	**Garlic (aged extract / allicin)**	Small reductions in blood pressure and LDL cholesterol in some studies.
20	**Selenium**	Antioxidant role (selenoproteins); some studies suggest benefits for thyroid health and cancer prevention in select contexts; excess risk if over-supplemented.
21	**Magnesium (oxide, citrate)**	Helps muscle/nerve function; may modestly help migraine prophylaxis, blood pressure, glycemic control in some studies.
22	**Vitamin E (alpha-tocopherol)**	Antioxidant role; trials for CV disease and cognitive decline largely negative or mixed; possible harm at high doses.
23	**L-arginine / nitric oxide precursors**	Short-term vasodilatory effects; used experimentally for vascular/endothelial function and exercise performance with mixed results.
24	**Proanthocyanidins / anthocyanins (berry extracts)**	Antioxidant, potential vascular and metabolic benefits in small trials.

Table No.5 Dietary Supplements as Nutraceutical and Therapeutic Effects

(c) Phytochemicals

Phytochemicals are naturally occurring bioactive compounds found in plants that provide significant health-promoting benefits beyond basic nutrition. As nutraceuticals, phytochemicals play a crucial role in disease prevention, modulation of biochemical pathways, and enhancement of physiological functions. They are widely present in fruits, vegetables, herbs, spices, cereals, legumes, and plant-derived beverages. Numerous scientific studies highlight their therapeutic potential, making them valuable components in preventive healthcare.

One major class of phytochemicals is polyphenols, which include flavonoids, phenolic acids, tannins, and lignans. Flavonoids such as quercetin (found in onions, apples, berries) exhibit potent antioxidant, anti-inflammatory, and cardioprotective effects. They scavenge free radicals and modulate inflammatory pathways, thereby reducing oxidative stress linked to chronic diseases. Resveratrol, a polyphenol found in grapes and red wine, is widely studied for its cardioprotective, anti-aging, and anti-cancer effects. It activates sirtuin pathways and improves endothelial function, contributing to vascular health[3,4].

Alkaloids also hold therapeutic relevance. Caffeine, from coffee and tea, is known for its neurostimulator and antioxidant properties. Capsaicin, the major active compound in chili peppers, shows analgesic and anti-inflammatory effects by modulating pain pathways, making it useful in topical treatments for neuropathic pain. Berberine, an isoquinoline alkaloid found in Berberis species, demonstrates hypoglycaemic, antimicrobial, and lipid-lowering properties[4,5].

Terpenoids, including monoterpenes, diterpenes, and triterpenes, contribute significantly to human health. Curcumin, a curcuminoid from turmeric, is among the most extensively studied nutraceuticals. It exhibits antioxidant, anti-inflammatory, anti-cancer, and neuroprotective effects. Curcumin modulates cellular signalling pathways, including NF-κB and cytokine expression, which explains its broad therapeutic potential. Gingerols from ginger are known for their anti-emetic, anti-inflammatory, and digestive benefits.

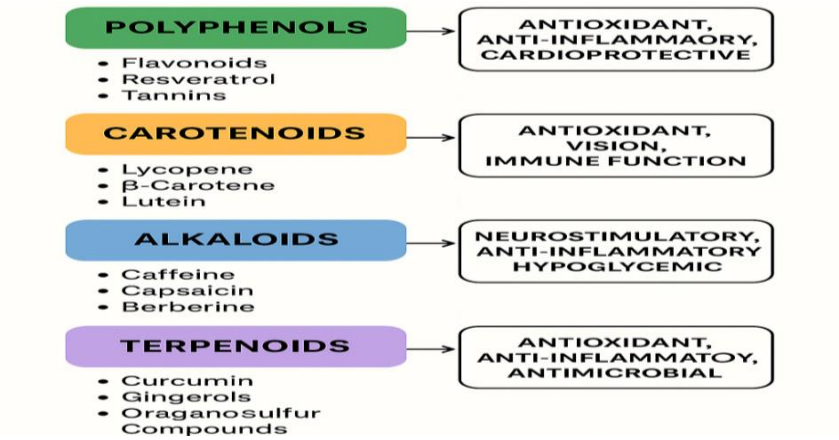

Figure No.2 Phytochemicals as Nutraceuticals

(d) Probiotic Microorganisms

Probiotics are live microorganisms which, when administered in adequate amounts, confer a health benefit on the host. This definition, established by FAO/WHO and reinforced by later expert reviews, is the working standard for probiotics used as nutraceuticals. Common probiotic genera used in nutraceutical products include Lactobacillus (now split into several related genera in recent taxonomies), Bifidobacterium, and the yeast Saccharomyces. These organisms are delivered via fermented foods (yogurt, kefir, kimchi), fortified foods, and dietary supplements; strains and dose (colony-forming units, CFU) determine clinical effects[7].

Gastrointestinal benefits are the most consistently supported therapeutic effects. Specific probiotic strains reduce the duration of acute infectious diarrhoea in children and adults, lower the risk of antibiotic-associated diarrhoea (including C. difficile in some settings), and can improve symptoms in certain subgroups of irritable bowel syndrome (IBS). Mechanisms include competitive inhibition of pathogens, production of antimicrobial substances, modulation of gut barrier function, and interaction with local immune cells.

(e) Nutraceutical Enzymes

Enzymes are biological catalysts that accelerate biochemical reactions within the human body. As nutraceuticals, enzymes play a pivotal role in improving digestion, reducing inflammation, enhancing nutrient absorption, and supporting various metabolic functions. Enzyme-based nutraceuticals are widely derived from plants, animals, and microbial sources and are increasingly used to promote health and prevent disease. Their therapeutic applications include management of gastrointestinal disorders, systemic inflammation, cardiovascular diseases, and immune dysfunctions[7,8].

1. **Digestive Enzymes as Nutraceuticals:** Digestive enzymes are among the most commonly used enzyme-based nutraceuticals. They assist in the breakdown of macronutrients—carbohydrates, proteins, and fats—thereby enhancing digestion and nutrient absorption.

Amylases: Break down complex carbohydrates into simple sugars. They help manage indigestion, bloating, and carbohydrate malabsorption[9,10].

Proteases (e.g., bromelain from pineapple, papain from papaya): Aid in the digestion of proteins and are used to reduce inflammation, swelling, and post-operative pain.

Lipases: Promote fat digestion and support pancreatic insufficiency and fat-malabsorption disorders[11,12].

Lactase: Helps individuals with lactose intolerance by breaking down lactose into glucose and galactose[13,14].

2. **Anti-Inflammatory Enzymes:**

Serratiopeptidase (serrapeptase): A proteolytic enzyme that reduces inflammation by breaking down inflammatory mediators such as bradykinin. Commonly used for sinusitis, arthritis, and postoperative swelling[15,16].

Nattokinase: A fibrinolytic enzyme derived from fermented soybeans (natto). It helps dissolve blood clots, reduces blood viscosity, and supports cardiovascular health.

Bromelain: Exhibits anti-inflammatory, anticancer, and immunomodulatory effects. It is used in sports injuries, osteoarthritis, and gastrointestinal disorders[17,18].

3. **Enzymes for Cardiovascular Health:** Fibrinolytic enzymes, especially nattokinase and lumbrokinase, play crucial cardioprotective roles. They support blood flow, prevent clot formation, and reduce the risk of thrombosis. Nattokinase has been studied for its ability to lower blood pressure, improve lipid profile, and enhance endothelial function[19,20].

4. Antioxidant and Detoxification Enzymes: Enzymes such as superoxide dismutase (SOD), glutathione peroxidase, and catalase help neutralize free radicals and oxidative stress. As nutraceuticals, these enzymes contribute to healthy aging, immune enhancement, and protection against chronic diseases like cancer, diabetes, and neurodegenerative disorders[21].

5. Enzymes in Metabolic and Immune Support : Alpha-galactosidase: Used for reducing gas and bloating by breaking down complex carbohydrates, Pancreatic enzyme blends: Helpful in pancreatic disorders, cystic fibrosis, and malabsorption syndromes, Lysozyme: Exhibits antibacterial and antiviral activities and is used in immune-support formulations[22,23].

f) Fortified Nutraceuticals

Fortified nutraceuticals are foods whose nutritional value has been enhanced by adding vitamins, minerals or other micronutrients that were not originally present (or present in insufficient amounts), to improve health and prevent nutrient-deficiency disorders. Unlike naturally occurring “traditional” nutraceuticals (e.g. antioxidants in fruits), fortified nutraceuticals represent a form of non-traditional or “engineered” functional foods — for example, cereals with added iron or vitamins, milk enriched with vitamin D, or orange juice fortified with calcium[23,24].

Milk fortified with vitamin D (cholecalciferol): Such fortified dairy supports calcium absorption and bone health, helping to prevent conditions like rickets, osteomalacia, and age-related bone weakening.

Iron-fortified cereals or flour supplemented with folic acid: These help address iron-deficiency anaemia — a common problem especially among children and women of reproductive age[25,26].

g) Recombinant Nutraceuticals:

Recombinant nutraceuticals are a subset of non-traditional or biotechnology-derived nutraceuticals. They are foods or food products created via genetic recombination, biotechnology, or fermentation/enzyme processes — often resulting in enhanced nutritional properties or novel bioactive compounds not present (or present in lower amounts) in the original food[27,28].

Typical examples of recombinant nutraceuticals include genetically modified crops such as Golden Rice, recombinant or bio-engineered Golden Kiwifruit, iron-enriched or "iron rice", multivitamin corn, and other modified cereals or plants. Additionally, certain foodstuffs produced using biotechnology — such as cheese or yogurt made using recombinant enzymes like Recombinant Chymosin — are also classified under recombinant nutraceuticals[29,30].

Role of Nutraceuticals in the Treatment of Chronic Diseases — Mechanisms of Action with Examples

Nutraceuticals — bioactive compounds or food-derived products that provide health benefits beyond basic nutrition — have attracted growing interest as complementary strategies for preventing and managing chronic diseases (cardiovascular disease, type 2 diabetes, neurodegenerative disorders, cancer, metabolic syndrome and chronic inflammatory conditions). They act through multiple, often overlapping mechanisms: lowering oxidative stress, modulating inflammation and immune responses, altering lipid and glucose metabolism, reshaping gut microbiota, and influencing cell signalling and gene expression. Evidence from mechanistic studies and clinical trials supports beneficial effects for certain nutraceuticals, although efficacy varies by compound, dose, formulation and patient population[31,32].

Mechanisms of action

1. Antioxidant activity (direct and indirect)

Many nutraceuticals (polyphenols, vitamins C and E, carotenoids, coenzyme Q10, anthocyanins) neutralize reactive oxygen species (ROS) directly and/or up-regulate endogenous antioxidant defences (e.g., activation of Nrf2 pathway, increased expression of superoxide dismutase, catalase, glutathione peroxidase). By reducing oxidative damage to lipids, proteins and DNA they mitigate a central driver of chronic disease progression such as atherogenesis and neurodegeneration. Mechanistic and cellular studies show both radical scavenging and gene-regulatory antioxidant effects for these compounds[32].

2. Anti-inflammatory modulation (cytokines & signalling pathways)

Chronic low-grade inflammation underpins many noncommunicable diseases. Nutraceuticals like curcumin, resveratrol, omega-3 fatty acids and certain flavonoids inhibit pro-inflammatory transcription factors (notably NF-κB), reduce production of cytokines (TNF-α, IL-6, IL-1β) and modulate cyclooxygenase and lipoxygenase pathways. These effects translate into improved biomarkers and, in some trials, reduced disease activity or slower progression[33].

3. Lipid and cardiovascular effects (lipid metabolism & endothelial function)

Compounds such as omega-3 fatty acids, phytosterols, soluble fibres (psyllium, beta-glucan) and niacin influence lipid metabolism and vascular health. Mechanisms include reduced hepatic triglyceride synthesis, enhanced LDL clearance, inhibition of intestinal cholesterol absorption (phytosterols), and improved endothelial function via increased nitric oxide bioavailability and lowered oxidative stress. Clinical meta-analyses support triglyceride lowering by omega-3s and modest LDL-lowering by phytosterols and soluble fibre.

4. Glycaemic control and insulin sensitivity

Several nutraceuticals (e.g., berberine, alpha-lipoic acid, chromium, fenugreek, cinnamon, polyphenols) improve glucose metabolism by enhancing insulin signalling (AMPK activation, improved GLUT4 translocation), reducing insulin resistance, and slowing carbohydrate digestion/absorption. Mechanistic studies show AMPK and PPAR activation as recurring targets; clinical trials have reported modest reductions in fasting glucose and HbA1c for some agents.

5. Gut-microbiota modulation

Probiotics, prebiotics and certain polyphenols act by reshaping gut microbial communities and metabolite profiles (short-chain fatty acids such as butyrate), which influence host metabolism, immune regulation and intestinal barrier function. This microbiome-mediated route is key for metabolic syndrome, inflammatory bowel disease and even neuroinflammation via the gut–brain axis[34].

6. Modulation of cell signalling, apoptosis and epigenetics

Phytochemicals (resveratrol, curcumin, green tea catechins) target signalling cascades (SIRT1, AMPK, MAPKs), affect mitochondrial function and can modulate epigenetic marks (DNA methylation, histone acetylation) influencing gene expression involved in cell survival, inflammation and metabolism. These pleiotropic actions help explain observed benefits in models of ageing, neurodegeneration and cancer prevention research[35].

Conclusion

Nutraceuticals represent a dynamic and evolving interface between nutrition and medicine, reflecting a paradigm shift from disease-centered treatment toward prevention and holistic health promotion. Rooted in ancient traditions that viewed food as a therapeutic agent, nutraceuticals have gained renewed scientific relevance through advances in nutrition science, biotechnology, and clinical research. The growing burden of lifestyle-related and chronic diseases such as cardiovascular disorders, diabetes, obesity, cancer, and neurodegenerative conditions has amplified interest in nutraceuticals as adjuncts to conventional therapy. Herbal and plant-derived nutraceuticals, rich in bioactive phytochemicals, exemplify how traditional knowledge and modern science can converge to support metabolic balance, immune resilience, and protection against oxidative stress.Overall, nutraceuticals hold significant potential as complementary tools in preventive and personalized medicine, bridging dietary practices with therapeutic goals and contributing to a more integrated, sustainable approach to long-term health and well-being.

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