CODEN [USA]: IAJPBB ISSN : 2349-7750

INDO AMERICAN JOURNAL OF
PHARMACEUTICAL SCIENCES
SJIF Impact Factor: 7.187

https://www.iajps.com/volumes/volume12-november-2025/114-issue-11-november-25/

Available online at: http://www.iajps.com Review Article

PHARMACOLOGICAL INSIGHTS INTO NUTRACEUTICALS FOR LIFESTYLE-INDUCED DISEASE

Akash S. Malthankar[1*], Akashay B. Ghanmode[2]

[1,2]Lecturer, Department of Diploma in Pharmacy, Dr. Rajendra Gode College of Pharmacy, Amravati, Maharashtra 444 602

Abstract:

Nutraceuticals, which bridge the gap between nutrition and pharmaceuticals, are biologically active compounds that promote health and aid in managing lifestyle-induced diseases. This review explores their pharmacological actions, mechanisms of action, clinical applications, and regulatory aspects, with a particular focus on herbal and functional food-based nutraceuticals. Acting through antioxidant, anti-inflammatory, immunomodulatory, hypoglycemic, hepatoprotective, and cardioprotective pathways, these agents show promise in the management of cardiovascular diseases, diabetes, autoimmune disorders, and neurodegenerative conditions. Highlighting their pharmacokinetic properties and receptor-level mechanisms, this review emphasizes the growing role of nutraceuticals in evidence-based pharmacological practice and their potential as novel drug leads. This chapter provides a comprehensive overview of the various categories of nutraceuticals, their therapeutic applications in health and disease management, and insights into their current market trends and business potential.

KEYWORDS: *Nutraceuticals, Herbal products, Functional foods, Pharmacology, Lifestyle diseases, Drug development.*

Corresponding author:

Akash S. Malthankar,
Lecturer,
Department of Diploma in Pharmacy,
Dr. Rajendra Gode College of Pharmacy,
Amravati, Maharashtra 666 402
Email: akashmalthankar123@gmail.com

QR CODE

Please cite this article in press ***Akash S. Malthankar*** *et al.,* ***Pharmacological Insights Into Nutraceuticals For Lifestyle-Induced Disease****, Indo Am. J. P. Sci, 2025; 12(11).*

INTRODUCTION:

The term "nutraceutical" was coined in 1989 by Dr. Stephen DeFelice, chairman of the Foundation for Innovation in Medicine, by combining the words "nutrition" and "pharmaceutical"[1]. It was introduced to define food-derived products that offer medical or health benefits, including the prevention and treatment of diseases. Despite its increasing use, the term still lacks a universally accepted definition [2]. Broadly, nutraceuticals are orally consumed dietary components, naturally found in foods, and believed to offer physiological benefits. These include functional foods, fortified foods, and nutritional supplements, which are promoted for their potential to enhance health and reduce disease risk [3].

Nutraceuticals are thought to delay aging, prevent chronic illnesses, support physiological function, and improve overall health status [4]. In contrast to pharmaceuticals, nutraceuticals are typically not patent-protected and do not require formal governmental approval, although both are used for disease prevention and treatment [5]. Among natural sources, plants play a central role, supplying both food and medicinal compounds. Advances in nutrition science, biotechnology, and integrative medicine have heightened interest in bioactive foods and compounds, both in the public and scientific communities [6].

Over the past few decades, lifestyle-induced diseases—also referred to as non-communicable diseases (NCDs) or "diseases of civilization"—have emerged as major contributors to global morbidity and mortality. These include cardiovascular diseases (CVDs), type 2 diabetes, obesity, neurodegenerative conditions, metabolic syndrome, and autoimmune disorders[7,8]. Their development is closely linked to modifiable behavioral and environmental factors, such as poor diet, lack of physical activity, tobacco use, and excessive alcohol consumption.

Additionally, diseases like Alzheimer's, arthritis, osteoporosis, chronic liver and kidney conditions, polycystic ovarian disease (PCOD), depression, and vascular dementia are rising in prevalence, particularly in industrialized societies[9,10]. According to the World Health Organization (WHO), NCDs account for approximately 40 million deaths annually, representing about 70% of global deaths[5]. Sedentary lifestyles, nutritional deficiencies, chronic stress, and environmental exposures are key contributing factors [2,6].

Although conventional pharmacotherapy remains effective for managing NCDs, it is often associated with limitations, including adverse effects, high costs, and the emergence of drug resistance[11]. As a result, there is growing interest in alternative and complementary therapeutic options, particularly those derived from natural sources. Nutraceuticals with their multi-targeted pharmacological actions, favorable safety profiles, and natural origins offer a promising adjunct to traditional treatment strategies for managing lifestyle-induced disorders. This review aims to evaluate the mechanistic actions, therapeutic potential, and pharmacological relevance of nutraceuticals in the prevention and treatment of chronic diseases.

History of Nutraceuticals:

The concept of nutraceuticals traces back over 3,000 years, rooted in ancient philosophies that emphasized the therapeutic value of food. Hippocrates (460–377 B.C.), often regarded as the father of medicine, famously stated, "Let food be thy medicine and medicine be thy food," reflecting the foundational belief in the healing power of diet. In the early 20th century, food manufacturers in the United States began fortifying salt with iodine to prevent goiter, one of the earliest practical applications of functional foods in public health[1]. The term "nutraceutical" was formally introduced in 1989 by Dr. Stephen DeFelice, who defined it as "a food (or part of a food) that provides medical or health benefits, including the prevention and/or treatment of a disease" [2].

Despite widespread use, the term lacks a standardized regulatory definition, particularly in commercial and marketing sectors[3]. Around the world, different countries have interpreted nutraceuticals in various ways. For instance, in England and Japan, diet is often emphasized over genetic or physical factors for maintaining health. Canada defines nutraceuticals as "products derived from foods but presented in pills, powders, potions, or other medicinal forms not typically associated with food" [4]. In India, nutraceuticals are typically considered herbal or botanical food components used for preventing or managing chronic and acute diseases[5].

Today, nutraceuticals represent one of the fastest-growing sectors of the global health industry. The global nutraceutical market was valued at approximately USD 241 billion in 2019 and is projected to reach USD 373 billion by 2025, with a compound annual growth rate (CAGR) of 7.5% [6]. This rapid expansion is largely attributed to increasing consumer interest in health-promoting, side-effect-free interventions for disease prevention. Among the various categories, herbal nutraceuticals are particularly esteemed for their ability to maintain wellness, prevent nutritionally related disorders, and enhance overall quality of life.

This review provides a comprehensive exploration of the classification, pharmacological actions, mechanisms, clinical applications, and regulatory frameworks surrounding nutraceuticals. Special emphasis is given to herbal and functional food-based interventions, highlighting their role in combating lifestyle diseases and their potential as promising leads for novel drug development.

Classification of Nutraceuticals

Nutraceuticals can be broadly categorized based on their origin, function, and therapeutic relevance. The major classes include functional foods, dietary supplements, medical foods, herbal products, probiotics and prebiotics, botanical extracts, omega-3 fatty acids, antioxidants, proteins and amino acids, and specialty nutraceuticals.

Functional Foods

Functional foods offer health benefits beyond basic nutrition through the presence of bioactive compounds that help prevent or manage chronic diseases.

Examples: Yogurt (probiotic), bananas and garlic (prebiotics), calcium-fortified juice and cereals [12,13]

Dietary Supplements

These include nutrients such as vitamins, minerals, amino acids, enzymes, and herbal ingredients, intended to supplement the diet.

Examples: Vitamin D, L-carnitine, multivitamins, turmeric capsules, ginseng[14,15]

Medical Foods

Medical foods are formulated to address specific nutritional requirements for individuals with particular diseases, and are to be consumed under medical supervision.

Examples: Formulations for phenylketonuria, diabetes, celiac disease[16]

Herbal Products

Derived from medicinal plants, herbal products are used traditionally and scientifically for therapeutic effects.

Examples: Ashwagandha, St. John's Wort, Ginkgo biloba[15]

Probiotics and Prebiotics

Probiotics: Live microorganisms that provide health benefits when consumed in adequate amounts.

Prebiotics: Non-digestible food components that selectively stimulate the growth of beneficial gut bacteria.

Examples: Lactobacillus species (probiotic), inulin (prebiotic)[12,17]

Botanical Extracts

These are concentrated plant-derived products containing specific bioactive compounds used for therapeutic purposes.

Examples: Turmeric extract, cranberry extract, green tea polyphenols[18]

Omega-3 Fatty Acids

Essential fatty acids that contribute to heart, brain, and inflammatory health.

Examples: Fish oil, flaxseed oil, chia seeds(19)

Antioxidants

Compounds that protect cells from oxidative damage by neutralizing free radicals.

Examples: Vitamin C, vitamin E, selenium, coenzyme Q10(13,20)

Proteins and Amino Acids

Essential for muscle growth, recovery, metabolism, and immune function.

Examples: Whey protein, branched-chain amino acids (BCAAs), creatine [14,21]

Specialty Nutraceuticals

These nutraceuticals are formulated to target specific physiological functions or health concerns, such as cognition, joint support, or weight management.

Examples: Brain health supplements, glucosamine for joints, fat burners (15).

Important Nutraceutical Products in India and Their Uses

Nutraceuticals have a long-standing history in traditional Indian medicine systems such as Ayurveda and Siddha. Their role is increasingly acknowledged in managing chronic diseases, including type 2 diabetes, inflammatory bowel disease, malabsorption syndromes, and gastrointestinal disorders (22–31). Commonly used products like fish oil, vitamin B6, B12, and flaxseed oil have been associated with beneficial effects such as reducing the risk of preterm labor, supporting hormonal balance, and regulating the menstrual cycle (27).

Dietary patterns have a profound impact on cardiovascular health, influencing hypertension, coronary artery disease, heart failure, peripheral vascular disease, and stroke. Nutrients, including vitamin D, coenzyme Q10, folic acid, omega-3 fatty acids, and polyphenols, offer cardiovascular protection by regulating cellular metabolism and improving vascular function (27). Flavonoids found in onions, grapes, apples, and cherries exhibit potent antioxidant activity. Ginger has been shown to possess anti-inflammatory and antihypertensive properties, making it suitable for managing high blood pressure and palpitations (27). Phytosterol-rich vegetables, especially green and yellow varieties, help reduce cholesterol absorption in the gut, thereby lowering cardiovascular risk. For neurodegenerative diseases such as Alzheimer's and Parkinson's, compounds such as curcumin, lutein, lycopene, turmeric, and beta-carotene exert neuroprotective effects through their antioxidant potential.

Jujube (Ziziphus jujuba) has been reported to enhance memory in individuals with Alzheimer's disease (32,33). Herbal ingredients frequently

incorporated into Indian nutraceuticals, including Amla (Emblica officinalis), Guduchi (Tinospora cordifolia), and Tulsi (Ocimum sanctum), have shown cognitive and adaptogenic effects, including improved learning and memory function (33–37).

Prominent nutraceutical products marketed in India include:

Multinutrient blends: Revital, Complan, Horlicks, Ensure, Peptamen, NutriMix

Herbal/nutrient capsules and tonics: Nutrova, Curcumin Boost, Chyawanprash

Fish liver oil supplements, curcumin, and antioxidant blends

Clinical trials in India have examined nutraceuticals for managing cardiovascular risk. For instance, a randomized, double-blind, placebo-controlled clinical trial evaluated a nutraceutical combination on LDL cholesterol and lipid profile in individuals with borderline hyperlipidemia, highlighting the therapeutic relevance of nutraceuticals in preventive cardiology (38).

Pharmacokinetics and Receptor-Level Interactions:

The clinical effectiveness of nutraceuticals is not solely determined by their pharmacodynamic properties but also by their pharmacokinetic behavior, including absorption, distribution, metabolism, and excretion (ADME). Furthermore, understanding receptor-level interactions enhances our insight into their therapeutic mechanisms and helps in developing optimized formulations [39].

Pharmacokinetics of Nutraceuticals:

Many bioactive compounds from herbal and functional foods exhibit low oral bioavailability due to poor solubility, instability in the gastrointestinal tract, extensive first-pass metabolism, and limited membrane permeability [40,41].

Absorption:

Nutraceuticals like curcumin and resveratrol demonstrate poor gastrointestinal absorption owing to their hydrophobic nature and chemical instability in gastric fluids [42].

Distribution:

Distribution depends on molecular properties like lipophilicity and plasma protein binding. Lipophilic compounds may accumulate in adipose tissue, potentially affecting the duration of action [43].

Metabolism:

Most nutraceuticals undergo Phase I and II hepatic metabolism, such as glucuronidation, sulfation, and methylation, which may decrease their bioactivity despite increasing water solubility [44]

Excretion:

Elimination occurs primarily through the urine or bile. Enterohepatic recycling may prolong plasma half-life but can complicate dosing regimens [45].

Strategies to Improve Pharmacokinetics

Nanoformulations (e.g., liposomes, micelles, solid lipid nanoparticles) to enhance solubility and protection from degradation [46].

Phytosome technology, such as curcumin-phospholipid complexes, to improve cellular uptake [47].

Bioenhancers like piperine inhibit metabolic enzymes (e.g., UDP-glucuronosyltransferase), enhancing absorption and plasma levels [48].

Receptor-Level Interactions and Molecular Targets

Nutraceuticals exert their effects by modulating specific receptors, enzymes, and transcription factors, which control metabolic, inflammatory, immune, and oxidative processes [49,50].

Key Molecular Targets:

PPARs (Peroxisome Proliferator-Activated Receptors): Activated by omega-3 fatty acids and polyphenols to improve lipid metabolism and insulin sensitivity [51].

Nrf2 (Nuclear Factor Erythroid 2–Related Factor 2): Activated by curcumin, sulforaphane, leading to the transcription of antioxidant response elements (ARE) [52].

NF-κB (Nuclear Factor Kappa B): Inhibited by resveratrol and turmeric compounds, suppressing pro-inflammatory cytokine expression [53].

TLRs (Toll-Like Receptors): β-glucans modulate innate immune responses via TLR-2 and TLR-4 pathways [54].

AMPK (AMP-Activated Protein Kinase): Activated by resveratrol and berberine, improving glucose metabolism and energy balance [55].

MAPKs (Mitogen-Activated Protein Kinases): Regulated by flavonoids, influencing apoptosis, proliferation, and stress signaling [56].

Cholinergic Receptors: Ginkgo biloba extracts influence muscarinic and nicotinic receptors, enhancing cognitive performance [57].

Estrogen Receptors (ERs): Phytoestrogens (e.g., from soy) interact with ERα and ERβ, offering cardiovascular and neuroprotective benefits [58].

Clinical Relevance of Pharmacokinetic and Receptor Studies:

Understanding pharmacokinetic profiles and receptor interactions is essential for:

- Designing bioavailable and effective formulations
- Maximizing therapeutic benefit and minimizing variability
- Identifying potential herb–drug interactions
- Supporting clinical trial design and evidence-based use of nutraceuticals in chronic diseases [59]

Nutraceuticals Regulations

Nutraceuticals are becoming increasingly important in the promotion of health and the prevention of chronic diseases. However, their widespread availability and usage require judicious regulation.

The market is currently saturated with irrational combinations of nutraceutical products, many lacking scientific substantiation. Therefore, regulatory authorities must take stringent actions to ensure consumer safety and product efficacy. Effective regulation is essential to safeguard the public from low-quality or unsafe products [60–62].

As many nutraceuticals are derived from natural sources, challenges arise in ensuring consistent quality, from raw material collection and processing to final product standardization[63]. Proper identification, quantification, and quality control are essential. Furthermore, safety evaluations—including toxicity, genotoxicity, and reproductive toxicity studies are crucial, especially for long-term use[64]. Because these products are frequently marketed without a prescription, strong regulatory oversight is necessary. While generally treated as food, nutraceuticals are classified and regulated differently across countries[63–65]. This global inconsistency hampers innovation and international trade. Thus, harmonized regulatory frameworks involving international authorities such as the FDA (United States), EFSA (European Union), FSSAI (India), and MHLW (Japan) are essential to ensure uniform standards for safety, quality, and efficacy[66].

United States (FDA)

In the United States, nutraceuticals are primarily regulated as dietary supplements under the Dietary Supplement Health and Education Act (DSHEA) of 1994[60]. Manufacturers are responsible for ensuring the safety of their products before they reach the market. The Food and Drug Administration (FDA) oversees post-marketing surveillance. Although health claims must be supported by evidence, structure–function claims are permitted, provided they carry the disclaimer: "This product is not intended to diagnose, treat, cure, or prevent any disease"[61].

European Union (EFSA):

In the European Union, nutraceuticals fall under the General Food Law (Regulation EC No. 178/2002). The European Food Safety Authority (EFSA) is responsible for assessing safety and efficacy. Health claims are regulated under Regulation EC No. 1924/2006, which requires scientific substantiation and authorization before any claim can be made on labeling or marketing materials[62,63].

India (FSSAI and AYUSH):

In India, nutraceuticals are regulated by the Food Safety and Standards Authority of India (FSSAI) under the Food Safety and Standards (Health Supplements, Nutraceuticals, Food for Special Dietary Use, Food for Special Medical Purpose, and Functional Foods) Regulations, 2016[64]. The regulation mandates permitted ingredients, labeling standards, and safety requirements. In parallel, the Ministry of AYUSH governs products based on traditional systems such as Ayurveda, Siddha, Unani, and Homeopathy, especially when such formulations are marketed with medicinal intent[65].

Japan (FOSHU System):

Japan utilizes a unique regulatory framework called the Foods for Specified Health Uses (FOSHU). Under this system, nutraceuticals must obtain pre-market approval from the Ministry of Health, Labour and Welfare (MHLW) based on robust scientific evidence validating safety and health benefits[66]. Only products that meet stringent quality and efficacy criteria are permitted to carry the FOSHU label.

Challenges in Regulation:

Despite the growing popularity and therapeutic promise of nutraceuticals, multiple challenges complicate their effective regulation and enforcement across global markets.

Lack of Standardization:

There is significant variability in the concentration of bioactive compounds in nutraceutical products, which arises from differences in plant species, geographical origin, climate, cultivation practices, harvesting time, and post-harvest processing techniques[67]. This lack of standardization hampers reproducibility, compromises efficacy, and complicates quality control procedures.

Herb–Drug Interactions

Several nutraceuticals have been found to interact with conventional drugs, potentially reducing therapeutic efficacy or increasing toxicity. A well-documented example is St. John's Wort (Hypericum perforatum), which induces cytochrome P450 enzymes (particularly CYP3A4) and P-glycoprotein, leading to decreased plasma concentrations of various drugs such as warfarin, oral contraceptives, and cyclosporine[68,69]. These interactions pose significant risks, especially for individuals on long-term or critical pharmacotherapy.

Contamination and Adulteration

Contamination with heavy metals (e.g., lead, mercury, arsenic), pesticide residues, and microbial toxins has been frequently reported in nutraceuticals, especially those produced under minimal regulatory oversight[70]. Furthermore, instances of adulteration with undeclared synthetic pharmaceuticals—such as steroids, anti-diabetics, and stimulants—have raised serious health concerns[71]. These quality issues compromise safety and erode public trust.

Misleading Claims

Nutraceuticals are often marketed with exaggerated or unverified health benefits, particularly in regions with weak regulatory enforcement. Claims that are vague, misleading, or unsupported by scientific evidence may deceive consumers, divert them from evidence-based treatment, or foster unrealistic expectations[72]. Such practices hinder rational use

and demand tighter advertising regulations and labeling transparency.

Pharmacological Mechanisms of Nutraceuticals

The therapeutic effects of nutraceuticals in managing lifestyle-induced diseases are mediated through a wide range of pharmacological mechanisms. These include modulation of cellular signaling pathways, enzyme activities, receptor interactions, gene expression, and key biochemical reactions essential for maintaining physiological homeostasis[73].

Antioxidant Mechanisms

Oxidative stress plays a central role in the pathogenesis of cardiovascular diseases, diabetes, cancer, and neurodegenerative disorders. Nutraceuticals rich in antioxidants help neutralize reactive oxygen species (ROS) and reactive nitrogen species (RNS), thereby preventing lipid peroxidation, DNA damage, and protein oxidation[73,74].

Mechanisms:

Scavenging free radicals (e.g., superoxide, hydroxyl radicals)

Upregulating endogenous antioxidant enzymes: superoxide dismutase (SOD), catalase, glutathione peroxidase (GPx)

Activating the Nrf2-ARE pathway, promoting transcription of antioxidant response elements (ARE)

Examples: Curcumin, quercetin, vitamin C, catechins

Anti-inflammatory Mechanisms

Chronic low-grade inflammation is a hallmark of many lifestyle-related disorders. Nutraceuticals exert anti-inflammatory effects by targeting pivotal inflammatory mediators and intracellular signaling cascades[75].

Mechanisms:

Inhibiting nuclear factor-kappa B (NF-κB) activation

Suppressing pro-inflammatory cytokines: IL-1β, IL-6, TNF-α

Modulating enzymes: cyclooxygenase (COX) and lipoxygenase (LOX)

Examples: Omega-3 fatty acids, resveratrol, turmeric

Immunomodulatory Mechanisms

Certain nutraceuticals can enhance or suppress immune responses, depending on the physiological state, thus aiding in the management of autoimmune diseases, chronic infections, and malignancies[76].

Mechanisms:

Modulating T-cell and B-cell function

Regulating cytokine production: IL-2, IFN-γ

Enhancing macrophage phagocytosis and natural killer (NK) cell activity

Examples: β-glucans, Tulsi (Ocimum sanctum), Ashwagandha

Hypoglycemic Mechanisms

Nutraceuticals assist in glycemic control by enhancing insulin action and modulating carbohydrate metabolism, thus benefiting individuals with type 2 diabetes[77].

Mechanisms:

Activating PPAR-γ (Peroxisome proliferator-activated receptor gamma)

Inhibiting α-glucosidase and α-amylase enzymes

Enhancing insulin receptor signaling via PI3K-Akt pathway

Examples: Fenugreek seeds, bitter melon (Momordica charantia), cinnamon

Hepatoprotective Mechanisms

Lifestyle factors contribute to liver diseases such as non-alcoholic fatty liver disease (NAFLD) and cirrhosis. Certain nutraceuticals protect hepatocytes from oxidative and chemical injury[78].

Mechanisms:

Inhibiting lipid peroxidation in liver cells

Enhancing bile secretion and detoxification enzyme activity

Regulating lipid metabolism, reducing hepatic steatosis

Examples: Silymarin, papaya extract, Aloe vera

Cardioprotective Mechanisms

Nutraceuticals support cardiovascular health by modulating lipid metabolism, improving vascular tone, and reducing thrombogenesis[79].

Mechanisms:

Lowering LDL cholesterol and triglycerides

Increasing nitric oxide (NO) bioavailability for vasodilation

Inhibiting platelet aggregation and slowing atherosclerotic plaque formation

Examples: Garlic, coenzyme Q10, flavonoids

Neuroprotective and Anti-aging Mechanisms

Neurodegenerative diseases and aging are often linked to oxidative stress and mitochondrial dysfunction. Nutraceuticals contribute to preserving neuronal health and slowing cognitive decline[80].

Mechanisms:

Enhancing neurotrophic factors like brain-derived neurotrophic factor (BDNF)

Inhibiting acetylcholinesterase

Reducing amyloid-beta aggregation and tau protein hyperphosphorylation

Examples: Curcumin, Ginkgo biloba, omega-3 fatty acids

Disease-Wise Applications of Nutraceuticals

Lifestyle-induced diseases pose a major public health burden worldwide and often require multifaceted strategies for prevention and long-term management. Nutraceuticals provide a promising adjunct or complementary therapeutic approach by targeting key underlying mechanisms such as oxidative stress, chronic inflammation, metabolic dysfunction, and immune imbalance[81]. This section outlines disease-specific applications

of nutraceuticals, particularly those derived from herbal and functional food sources.

Cardiovascular Diseases

Cardiovascular diseases (CVDs), including hypertension, atherosclerosis, and ischemic heart disease, are strongly linked to endothelial dysfunction, oxidative damage, and dyslipidemia[82].

Key Nutraceuticals:

Garlic (Allium sativum): Inhibits HMG-CoA reductase and angiotensin-converting enzyme (ACE), thereby lowering LDL cholesterol and blood pressure[83].

Omega-3 Fatty Acids: Activate PPAR pathways, reduce triglyceride levels, and modulate inflammatory mediators[84].

Coenzyme Q10: Supports mitochondrial energy production and improves endothelial function[85].

Flavonoids: Enhance nitric oxide bioavailability and promote vascular relaxation[86].

Diabetes Mellitus

Type 2 diabetes mellitus is characterized by insulin resistance, hyperglycemia, and chronic oxidative stress[87].

Key Nutraceuticals:

Bitter Melon (Momordica charantia): Exhibits insulin-mimetic activity and inhibits intestinal glucose absorption[88].

Fenugreek Seeds: Contain 4-hydroxyisoleucine, which enhances insulin secretion[89].

Cinnamon: Activates AMPK signaling and enhances glucose uptake in peripheral tissues[90].

Curcumin: Improves insulin sensitivity and protects pancreatic β-cells[91].

Neurodegenerative Diseases

Alzheimer's and Parkinson's disease are associated with oxidative neuronal damage, mitochondrial dysfunction, and neuroinflammation[92].

Key Nutraceuticals:

Ginkgo biloba: Enhances cerebral circulation and acts as an antioxidant in neural tissues[93].

Curcumin: Inhibits amyloid-β accumulation and suppresses neuroinflammatory pathways[94].

Resveratrol: Activates SIRT1 signaling, promoting neuronal longevity and mitochondrial health[95].

Omega-3 Fatty Acids: Support synaptic plasticity and neuronal membrane integrity[96].

Autoimmune and Inflammatory Disorders

Diseases like rheumatoid arthritis, inflammatory bowel disease (IBD), and systemic lupus erythematosus (SLE) involve chronic immune dysregulation[97].

Key Nutraceuticals:

Ashwagandha (Withania somnifera): Reduces pro-inflammatory cytokines and modulates immune responses[98].

Tulsi (Ocimum sanctum): Balances Th1/Th2 immunity and inhibits NF-κB activation[99].

β-Glucans: Enhance innate immunity and support adaptive immune modulation[100].

Liver Diseases

Non-alcoholic fatty liver disease (NAFLD) and cirrhosis are increasingly linked to poor dietary habits, metabolic syndrome, and sedentary lifestyles[101].

Key Nutraceuticals:

Silymarin: Stabilizes hepatocyte membranes, scavenges free radicals, and supports liver regeneration[102].

Papaya Extract: Provides antioxidant and hepatoprotective effects via enzyme modulation [103].

Aloe Vera: Inhibits hepatic lipid accumulation and inflammation[104].

Skin Disorders and Aging

Oxidative stress, UV exposure, and inflammation drive premature skin aging and conditions such as psoriasis and eczema[105].

Key Nutraceuticals:

Aloe Vera: Enhances skin hydration, promotes wound healing, and boosts collagen synthesis [106].

Turmeric (Curcuma longa): Protects against UV-induced skin damage and inflammation [107].

Green Tea Polyphenols: Counteract photodamage and reduce oxidative stress in skin cells[108].

Respiratory Infections and Immunity Enhancement (Including COVID-19)

The COVID-19 pandemic emphasized the value of nutraceuticals in enhancing immune resilience and respiratory defense [109].

Key Nutraceuticals:

Ayush Kadha: A traditional decoction containing Tulsi, Ginger, Cinnamon, and Black Pepper, recommended by AYUSH for immune support [110].

Vitamin C and Zinc: Strengthen antiviral defenses and improve innate immunity[111].

Giloy (Tinospora cordifolia): Exhibits immunostimulatory and anti-inflammatory actions[112].

Future Directions in Nutraceutical Research

As the global prevalence of lifestyle-induced diseases continues to escalate, nutraceuticals are increasingly recognized for their dual role in disease prevention and management. However, to fully harness their potential, several key areas warrant further exploration and innovation[113]

Molecular Mechanisms and Systems Biology Approaches

Advancements in omics technologies, including genomics, proteomics, metabolomics, and transcriptomics, are providing deeper insights into the molecular mechanisms modulated by nutraceuticals. Systems biology approaches enable the identification of molecular targets, nutrient–gene interactions, and disease-specific biomarkers, facilitating the development of more mechanism-based, targeted nutraceutical therapies [114]

Personalized Nutrition and Pharmacogenomics

Personalized nutrition integrates nutrigenetics, nutrigenomics, and pharmacogenomics to tailor interventions based on individual genetic predispositions, metabolic profiles, and gut microbiota composition [115,116]. This approach enhances treatment efficacy, reduces adverse effects, and supports preventive strategies, particularly in chronic metabolic and inflammatory diseases.

Innovative Delivery Systems

The therapeutic potential of many nutraceuticals is often limited by poor solubility, instability, and low bioavailability. Advanced delivery systems such as nanoencapsulation, liposomes, phytosomes, solid lipid nanoparticles, and polymeric carriers are being developed to improve absorption, enhance stability, and ensure targeted delivery of bioactives like curcumin, resveratrol, and quercetin [117]

Clinical Validation and Large-Scale Trials

While preclinical studies have demonstrated promising outcomes, robust randomized controlled trials (RCTs) are required to substantiate clinical efficacy and safety[118]. Standardized trial protocols, validated endpoints, and multi-center collaborations are essential for generating reproducible data and facilitating regulatory approval of nutraceutical products.

Sustainability and Ethical Sourcing

The increasing demand for botanically derived nutraceuticals has raised environmental and ethical concerns. Sustainable sourcing, good agricultural practices (GAPs), fair-trade certification, and the conservation of medicinal plant biodiversity must be prioritized to prevent ecological degradation and ensure long-term viability of the nutraceutical industry [119]

CONCLUSION:

Nutraceuticals, bridging the domains of nutrition, pharmacology, and traditional medicine, present a promising strategy to address the growing burden of lifestyle-related diseases. Through diverse pharmacological mechanisms, including antioxidant, anti-inflammatory, immunomodulatory, hypoglycemic, and cardioprotective actions, these bioactive compounds play a vital role in both disease prevention and adjunctive therapy. Despite their potential, challenges such as limited bioavailability, lack of standardization, insufficient clinical validation, and regulatory ambiguities hinder their widespread, evidence-based adoption. To overcome these barriers, concerted interdisciplinary research efforts, rigorous clinical trials, and progressive regulatory frameworks are imperative. Ultimately, nutraceuticals represent not just an alternative but a complementary and synergistic approach within the broader framework of personalized, preventive, and sustainable healthcare.

CONFLICT OF INETREST:

Authors declare that there is no conflict of interest.

REFERENCES:

1. DeFelice, S. L. (1989). The Nutraceutical Revolution: Its Impact on Food Industry R&D. Foundation for Innovation in Medicine.
2. Kalra, E. K. (2003). Nutraceutical–definition and introduction. AAPS PharmSci, 5(3), E25.
3. Zeisel, S. H. (1999). Regulation of “nutraceuticals.” Science, 285(5435), 1853-1855.
4. Health Canada. (2007). Nutraceuticals/Functional Foods and Health Claims on Foods.
5. Patwardhan, B., et al. (2005). Ayurveda and natural products drug discovery. Current Science, 89(9), 1333–1342.
6. Shahidi, F. (2009). Nutraceuticals and functional foods: Whole versus processed foods. Trends in Food Science & Technology, 20(9), 376–387.
7. World Health Organization. (2020). Noncommunicable Diseases Fact Sheet.
8. Murray, C. J. L., & Lopez, A. D. (2013). Measuring the global burden of disease. New England Journal of Medicine, 369, 448–457.
9. Prince, M., et al. (2015). World Alzheimer Report: The Global Impact of Dementia. Alzheimer's Disease International.
10. Kanis, J. A., et al. (2008). Epidemiology of osteoporosis. Osteoporosis International, 19(10), 1451–1458.
11. Ventola, C. L. (2010). The drug development process: a primer. Pharmacy and Therapeutics, 35(10), 615–636.
12. Gibson GR, Roberfroid MB. Dietary modulation of the human colonic microbiota: introducing the concept of prebiotics. J Nutr. 1995;125(6):1401–12.
13. Diplock AT, Aggett PJ, Ashwell M, Bornet F, Fern EB, Roberfroid MB. Scientific concepts

of functional foods in Europe: consensus document. Br J Nutr. 1999;81(Suppl 1):S1–27.
14. Maughan RJ, Burke LM, Dvorak J, Larson-Meyer DE, Peeling P, Phillips SM, et al. IOC consensus statement: Dietary supplements and the high-performance athlete. Br J Sports Med. 2018;52(7):439–55.
15. Kalra EK. Nutraceutical—definition and introduction. AAPS PharmSci. 2003;5(3):E25.
16. U.S. Food and Drug Administration (FDA). Guidance for Industry: Frequently Asked Questions About Medical Foods. 2016. Available from: https://www.fda.gov/
17. Hill C, Guarner F, Reid G, Gibson GR, Merenstein DJ, Pot B, et al. The ISAPP consensus statement on the definition and scope of probiotics. Nat Rev Gastroenterol Hepatol. 2014;11(8):506–14.
18. Williamson EM. Synergy and other interactions in phytomedicines. Phytomedicine. 2001;8(5):401–9.
19. Simopoulos AP. Omega-3 fatty acids in inflammation and autoimmune diseases. J Am Coll Nutr. 2002;21(6):495–505.
20. Lobo V, Patil A, Phatak A, Chandra N. Free radicals, antioxidants and functional foods: Impact on human health. Pharmacogn Rev. 2010;4(8):118–26.
21. Pasiakos SM, McLellan TM, Lieberman HR. The effects of protein supplements on muscle mass, strength, and aerobic and anaerobic power in healthy adults: a systematic review. Sports Med. 2015;45(1):111–31.
22. Aggarwal BB, Sundaram C, Malani N, Ichikawa H. Curcumin: the Indian solid gold. Adv Exp Med Biol. 2007;595:1–75.
23. Chauhan B, Kumar G, Kalam N, Ansari SH. Current concepts and prospects of herbal nutraceutical: a review. J Adv Pharm Technol Res. 2013;4(1):4–8.
24. Tripathi YB, Pandey R. Role of nutraceuticals in health promotion. Ind J Nat Prod Resour. 2009;8(2):126–32.
25. Gupta RC, Chang D, Nammi S, Bensoussan A, Bilinski K, Roufogalis BD. Nutraceuticals in metabolic syndrome. Int J Mol Sci. 2010;11(2):520–28.
26. Kim SY, Park JY, Lee MY, et al. Effects of Zizyphus jujuba on memory impairment induced by scopolamine in mice. J Ethnopharmacol. 2000;70(1):49–56.
27. Bhupathiraju SN, Tucker KL. Coronary heart disease prevention: nutrients, foods, and dietary patterns. Clin Chim Acta. 2011;412(17–18):1493–514.
28. Baliga MS, Meera S, Mathai B, Rai MP, Pawar V, Palatty PL. Scientific validation of the ethnomedicinal properties of Ocimum sanctum L. (Holy Basil): a review. Int J Ayurveda Res. 2010;1(4):212–21.
29. Jeba Rani PJ, Shajahan A, Rajalakshmi M, Dhanasekaran M, Surendran S. Protective effect of Emblica officinalis (Indian gooseberry) on learning and memory in aging rats. J Clin Diagn Res. 2011;5(2):316–21.
30. Sharma U, Bala M, Kumar N, Singh B, Munshi RK, Bhalerao S. Immunomodulatory active compounds from Tinospora cordifolia. J Ethnopharmacol. 2012;141(3):918–26.
31. Saraf S, Ashawat MS, Saraf S. Flavonoids: a nutritional protection against oxidative and UV-induced skin damages. Pharma Times. 2007;39(5):19–23.
32. Peng WH, Hsieh MT, Lee YS, Lin YC, Liao J. Anxiolytic effect of seed of Ziziphus jujuba in mouse models of anxiety. Evid Based Complement Alternat Med. 2012;2012:451349.
33. Mahdy KAA, Hussien HM, Abdel-Razek HF. Antioxidant and neuroprotective activities of jujube (Ziziphus jujuba) in Alzheimer's disease model. Int J Pharm Pharm Sci. 2016;8(10):189–95.
34. Rege NN, Thatte UM, Dahanukar SA. Adaptogenic properties of six rasayana herbs used in Ayurvedic medicine. Phytother Res. 1999;13(4):275–91.
35. Singh RH. Exploring issues in the development of Ayurvedic research methodology. J Ayurveda Integr Med. 2010;1(2):91–5.
36. Raut A, Rege NN, Tadvi FM, Solanki P, Kene KR, Shirolkar SG, et al. An exploratory study to evaluate the tolerability, safety, and activity of Ashwagandha (Withania somnifera) in healthy volunteers. J Ayurveda Integr Med. 2012;3(3):111–4.
37. Acharya SB, Frotan MH, Goel RK, Tripathi SK, Das PK. Pharmacological actions of Ocimum sanctum: the Indian holy basil. Ind J Exp Biol. 1996;34(12):1212–7.
38. Cicero AFG, Derosa G, Parini A, Maffioli P, Bove M, Borghi C. A randomized double-blind, placebo-controlled clinical study of the effects of a nutraceutical combination on LDL cholesterol levels and lipid pattern in subjects with suboptimal blood cholesterol levels. Nutrients. 2020;12(5):1405.
39. Kalepu S, Nekkanti V. Insoluble drug delivery strategies: review of recent advances and business prospects. Acta Pharm Sin B. 2015;5(5):442–53.
40. Dahan A, Miller JM. The solubility–permeability interplay and its implications in formulation design. Curr Opin Drug Discov Devel. 2010;13(1):116–23.
41. McClements DJ. Enhancing nutraceutical bioavailability through food matrix design. Curr Opin Food Sci. 2015;4:1 6.
42. Anand P, Kunnumakkara AB, Newman RA, Aggarwal BB. Bioavailability of curcumin:

problems and promises. Mol Pharm. 2007;4(6):807–18.
43. Chen Y, Liu Y, Ding J, et al. Distribution of flavonoids in body tissues and their pharmacological effects. Curr Drug Metab. 2021;22(5):361–76.
44. Walle T. Bioavailability of resveratrol. Ann N Y Acad Sci. 2011;1215:9–15.
45. O'Hagan DT, Perrie Y. Pharmaceutical Excipients: Properties, Functionality and Applications in Research and Industry. London: Academic Press; 2012.
46. Mukerjee A, Vishwanatha JK. Formulation, characterization, and evaluation of curcumin-loaded PLGA nanospheres for cancer therapy. Anticancer Res. 2009;29(10):3867–75.
47. Maiti K, Mukherjee K, Gantait A, Saha BP, Mukherjee PK. Curcumin–phospholipid complex: preparation, therapeutic evaluation, and pharmacokinetic study in rats. Int J Pharm. 2007;330(1-2):155–63.
48. Shoba G, Joy D, Joseph T, Majeed M, Rajendran R, Srinivas PS. Influence of piperine on the pharmacokinetics of curcumin in animals and human volunteers. Planta Med. 1998;64(4):353–6.
49. Manach C, Williamson G, Morand C, Scalbert A, Rémésy C. Bioavailability and bioefficacy of polyphenols in humans. Am J Clin Nutr. 2005;81(1 Suppl):230S–42S.
50. Del Rio D, Rodriguez-Mateos A, Spencer JP, Tognolini M, Borges G, Crozier A. Dietary polyphenolics in human health: structures, bioavailability, and evidence of protective effects against chronic diseases. Antioxid Redox Signal. 2013;18(14):1818–92.
51. Gani OA, Sylte I. Insights into the molecular mechanisms of polyunsaturated fatty acids mediated activation of PPARs. J Mol Graph Model. 2008;27(2):217–29.
52. Kensler TW, Wakabayashi N, Biswal S. Cell survival responses to environmental stresses via the Keap1–Nrf2–ARE pathway. Annu Rev Pharmacol Toxicol. 2007;47:89 116.
53. Aggarwal BB, Harikumar KB. Potential therapeutic effects of curcumin, the anti-inflammatory agent, against neurodegenerative, cardiovascular, pulmonary, metabolic, autoimmune, and neoplastic diseases. Int J Biochem Cell Biol. 2009;41(1):40–59.
54. Chan GC, Chan WK, Sze DM. The effects of β-glucan on human immune and cancer cells. J Hematol Oncol. 2009;2:25.
55. Hardie DG. AMP-activated protein kinase: an energy sensor that regulates all aspects of cell function. Genes Dev. 2011;25(18):1895–908.
56. Surh YJ. Cancer chemoprevention with dietary phytochemicals. Nat Rev Cancer. 2003;3(10):768–80.
57. Kennedy DO, Scholey AB, Wesnes KA. Dose-dependent changes in cognitive performance and mood following acute administration of Ginkgo biloba to healthy young volunteers. Nutr Neurosci. 2000;3(6):413–21.
58. Setchell KD, Cassidy A. Dietary isoflavones: biological effects and relevance to human health. J Nutr. 1999;129(3):758S–67S.
59. Williamson EM. Synergy and other interactions in phytomedicines. Phytomedicine. 2001;8(5):401–9.
60. U.S. Food and Drug Administration. Dietary Supplement Health and Education Act of 1994. [Internet]. Available from: https://www.fda.gov
61. U.S. Food and Drug Administration. Label Claims for Conventional Foods and Dietary Supplements. [Internet]. Available from: https://www.fda.gov/food/food-labeling-nutrition
62. European Commission. Regulation (EC) No. 178/2002 of the European Parliament and of the Council. Official Journal of the European Communities.
63. EFSA Panel on Dietetic Products, Nutrition and Allergies (NDA). Scientific and technical guidance for the preparation and presentation of the application for authorization of health claims. EFSA Journal. 2016;14(1):4367.
64. Food Safety and Standards Authority of India. Food Safety and Standards (Health Supplements, Nutraceuticals, Food for Special Dietary Use, Food for Special Medical Purpose and Functional Foods) Regulations, 2016. [Internet]. Available from: https://www.fssai.gov.in
65. Ministry of AYUSH, Government of India. Guidelines for Evaluation of Ayurvedic Products. [Internet]. Available from: https://www.ayush.gov.in
66. Ministry of Health, Labour and Welfare (Japan). Foods for Specified Health Uses (FOSHU). [Internet]. Available from: https://www.mhlw.go.jp/english/
67. Gurley BJ, Fifer EK, Gardner SF. Pharmacokinetic herb-drug interactions (Part 1): Origins, mechanisms, and the impact of botanical dietary supplements. Planta Med. 2000;66(5):396–405.
68. Izzo AA, Ernst E. Interactions between herbal medicines and prescribed drugs: A systematic review. Drugs. 2001;61(15):2163–75.
69. Zhou S, Chan E, Pan S, Huang M, Lee EJ. Pharmacokinetic interactions of drugs with St. John's Wort. J Psychopharmacol. 2004;18(2):262–76.
70. Saper RB, Eisenberg DM, Phillips RS. Heavy metal content of ayurvedic herbal medicine products. JAMA. 2004;292(23):2868–73.

71. Koh HL, Woo SO. Chinese proprietary medicine in Singapore: Regulatory control of toxic heavy metals and undeclared drugs. Drug Saf. 2000;23(5):351–62.
72. Geller AI, Shehab N, Weidle NJ, Lovegrove MC, Wolpert BJ, Timbo BB, et al. Emergency department visits for adverse events related to dietary supplements. N Engl J Med. 2015;373(16):1531–40.
73. Rani N, Bharti S, Krishnamurthy B, Arya DS. Pharmacological properties of nutraceuticals: Mechanistic insights. Curr Pharm Des. 2016;22(1):1–13.
74. Halliwell B. Free radicals and antioxidants: Updating a personal view. Nutr Rev. 2012;70(5):257–65.
75. Aggarwal BB, Harikumar KB. Potential therapeutic effects of curcumin, the anti-inflammatory agent, against neurodegenerative, cardiovascular, pulmonary, metabolic, autoimmune, and neoplastic diseases. Int J Biochem Cell Biol. 2009;41(1):40–59.
76. Venkatesh S, Weidner M, Kiefer D. Immunomodulatory herbs: Evidence-based applications in integrative medicine. Altern Ther Health Med. 2020;26(1):12–21.
77. Liu Z, Patil IY, Jiang T, Sancheti H, Walsh JP, Stiles BL, et al. Nutraceutical intervention in metabolic disorders: Mechanistic roles and clinical applications. Trends Mol Med. 2013;19(10):593–605.
78. Loguercio C, Federico A. Oxidative stress in viral and alcoholic hepatitis. Free Radic Biol Med. 2003;34(1)::1–10.
79. Cicero AFG, Colletti A, Bajraktari G, Descamps OS, Djuric DM, Ezhov M, et al. Lipid-lowering nutraceuticals in clinical practice: Position paper from an International Lipid Expert Panel. Arch Med Sci. 2017;13(5):965–1005.
80. Joseph JA, Shukitt-Hale B, Casadesus G. Reversing the deleterious effects of aging on neuronal communication and behavior: Beneficial properties of fruit polyphenolic compounds. Am J Clin Nutr. 2005;81(1):313S–316S.
81. Roberfroid MB. Global view on functional foods: European perspectives. Br J Nutr. 2002;88(S2):S133–S138.
82. Libby P. Inflammation in atherosclerosis. Nature. 2002;420(6917):868–74.
83. Rahman K, Lowe GM. Garlic and cardiovascular disease: a critical review. J Nutr. 2006;136(3):736S–740S.
84. Calder PC. Omega-3 polyunsaturated fatty acids and inflammatory processes. Nutrients. 2010;2(3):355–74.
85. Gao L, Mao Q, Cao J, Wang Y, Zhou X, Fan L. Coenzyme Q10 treatment of cardiovascular disorders: An overview of current research. J Cardiovasc Pharmacol. 2010;56(3):208–14.
86. Hollman PCH, Katan MB. Dietary flavonoids: Intake, health effects, and bioavailability. Food Chem Toxicol. 1999;37(9–10):937–42.
87. DeFronzo RA. Pathogenesis of type 2 diabetes mellitus. Med Clin North Am. 2004;88(4):787–835.
88. Nerurkar PV, Lee YK, Nerurkar VR. Momordica charantia (bitter melon) inhibits primary human adipocyte differentiation by modulating adipogenic genes. BMC Complement Altern Med. 2010;10:34.
89. Basch E, Ulbricht C, Kuo G, Szapary P, Smith M. Therapeutic applications of fenugreek. Altern Med Rev. 2003;8(1):20–7.
90. Qin B, Polansky MM, Sato Y, Anderson RA. Cinnamon extract inhibits glucose uptake and insulin signaling pathways. Horm Res. 2010;73(1):30–7.
91. Weisberg SP, Leibel R, Tortoriello DV. Dietary curcumin significantly improves obesity-associated inflammation and diabetes in mouse models. Endocrinology. 2008;149(7):3549–58.
92. Mattson MP. Pathways towards and away from Alzheimer's disease. Nature. 2004;430(7000):631–9.
93. Diamond BJ, Shiflett SC, Feiwel N, Matheis RJ, Noskin O, Richards JA, et al. Ginkgo biloba extract: Mechanisms and clinical indications. Arch Phys Med Rehabil. 2000;81(5):668–78.
94. Yang F, Lim GP, Begum AN, Ubeda OJ, Simmons MR, Ambegaokar SS, et al. Curcumin inhibits the formation of amyloid beta oligomers and fibrils, binds plaques, and reduces amyloid in vivo. J Biol Chem. 2005;280(7):5892–901.
95. Baur JA, Sinclair DA. Therapeutic potential of resveratrol: The in vivo evidence. Nat Rev Drug Discov. 2006;5(6):493–506.
96. Dyall SC. Long-chain omega-3 fatty acids and the brain: A review of the independent and shared effects of EPA, DPA, and DHA. Front Aging Neurosci. 2015;7:52.
97. Rose NR. Negative selection, epitope mimicry, and autoimmunity. Curr Opin Immunol. 2017;49:51 5.
98. Chandrasekhar K, Kapoor J, Anishetty S. A prospective, randomized double-blind, placebo-controlled study of safety and efficacy of a high-concentration full-spectrum Ashwagandha extract. Indian J Psychol Med. 2012;34(3):255–62.
99. Mondal S, Varma S, Bamola VD, Naik SN, Mirdha BR, Padhi MM, et al. Double-blinded randomized controlled trial for immunomodulatory effects of Tulsi (Ocimum sanctum Linn.) leaf extract on healthy

volunteers. J Ethnopharmacol. 2011;136(3):452–6.
100. Vetvicka V, Oliveira C, Pontes P, Rivera I. β-glucans as immunomodulators: Clinical trials and possible future applications. Int J Mol Sci. 2019;20(6):1255.
101. Younossi ZM. Non-alcoholic fatty liver disease – A global public health perspective. J Hepatol. 2019;70(3):531–44.
102. Pradhan SC, Girish C. Hepatoprotective herbal drug, silymarin from experimental pharmacology to clinical medicine. Indian J Med Res. 2006;124(5):491–504.
103. Al-Fartosi KG, Majid SA, Ahmed DS. Antioxidant activity of papaya fruit extracts against hydrogen peroxide-induced oxidative stress in liver cells. J Med Plants Res. 2010;4(12):1125–30.
104. Boudreau MD, Beland FA. An evaluation of the biological and toxicological properties of Aloe vera. Environ Health Perspect. 2006;114(3):349–55.
105. Zouboulis CC, Makrantonaki E. Clinical aspects and molecular diagnostics of skin aging. Clin Dermatol. 2011;29(1):3–14.
106. Surjushe A, Vasani R, Saple DG. Aloe vera: A short review. Indian J Dermatol. 2008;53(4):163–6.
107. Heng MC. Curcumin and turmeric in dermatology: Molecular targets and clinical relevance. Phytother Res. 2010;24(5):651–6.
108. Nichols JA, Katiyar SK. Skin photoprotection by natural polyphenols: Anti-inflammatory, antioxidant and DNA repair mechanisms. Arch Dermatol Res. 2010;302(2):71–83.
109. Calder PC. Nutrition, immunity, and COVID-19. BMJ Nutr Prev Health. 2020;3(1):74–92.
110. Ministry of AYUSH. Ayush Kadha Guidelines. Government of India. [Internet]. Available from: https://www.ayush.gov.in
111. Carr AC, Maggini S. Vitamin C and immune function. Nutrients. 2017;9(11):1211.
112. Sharma U, Bala M, Kumar N, Singh B, Munshi RK, Bhalerao S. Immunomodulatory active compounds from Tinospora cordifolia. J Ethnopharmacol. 2012;141(3):918–26.
113. Martirosyan DM, Singh J. A new definition of functional food by FFC: What makes a new definition unique? Functional Foods in Health and Disease. 2015;5(6):209–23.
114. Kussmann M, Van Bladeren PJ. The extended nutrigenomics—understanding dietary health effects at the systems level. Genome Med. 2011;3(7):44.
115. Ferguson LR. Nutrigenomics approaches to functional foods. J Am Diet Assoc. 2009;109(3):452–8.
116. Zeisel SH, Da Costa KA. Nutrigenomics and metabolomics will change clinical nutrition and public health practice: Insights from studies on dietary requirements for choline. Am J Clin Nutr. 2009;89(2):539–44.
117. Rehman MU, Rizvi MM, Khan R, Khan AQ, Sheikh RA, Feroze N, et al. Emerging technologies in nutraceutical delivery: A comprehensive review. Crit Rev Food Sci Nutr. 2022;62(1):27–56.
118. Maki KC, Reeves MS, Farmer M, Griinari M, Berge K, Vik H, et al. Krill oil supplementation increases plasma concentrations of eicosapentaenoic and docosahexaenoic acids in overweight and obese men and women. Nutr Res. 2009;29(9):609–15.
119. Hamilton AC. Medicinal plants, conservation, and livelihoods. Biodivers Conserv. 2004;13(8):1477–517.