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Therapeutic and Preventive Potential of Nutraceuticals and Functional Foods in Modern Healthcare

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Abstract: Nutraceuticals and functional foods have increasingly emerged as supportive strategies alongside conventional medical treatments because of their contribution to health enhancement and disease risk reduction. These naturally derived food-based bioactive substances offer advantages that extend beyond basic nutritional value, exhibiting antioxidant, anti-inflammatory, cardioprotective, antidiabetic, anticancer, and immune-regulating properties. This review provides a detailed examination of nutraceuticals and functional foods, encompassing their definitions, categories, therapeutic benefits, safety and quality aspects, regulatory considerations, global market developments, and future directions. Particular attention is given to their potential role in the prevention and management of chronic conditions such as cancer, diabetes, cardiovascular diseases, obesity, migraine, dry eye syndrome, and oral health disorders. The review also underscores the importance of robust scientific evidence, harmonized regulatory frameworks, and innovative delivery technologies to improve bioavailability and maintain product safety. Collectively, nutraceuticals and functional foods represent a rapidly advancing domain that integrates nutritional science with pharmacological approaches to support comprehensive healthcare.

Keywords: *Nutraceuticals; Functional Foods; Bioactive Compounds; Disease Prevention; Regulatory Aspects; Global Market.*

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I. INTRODUCTION

➢ *Nutraceuticals*

The term nutraceutical was first coined in 1989 by Dr. Stephen L. DeFelice, the founder and chairman of the Foundation for Innovation in Medicine (FIM) in Crawford, New Jersey. The word was created by merging the terms “nutrition” and “pharmaceutical.” [1] A nutraceutical is defined as a bioactive compound that is derived or purified from food sources and marketed in medicinal forms that are not typically associated with regular foods. These substances are recognized for providing health benefits beyond basic nutrition, including the prevention or management of various diseases such as cancer, cardiovascular disorders, gastrointestinal conditions, and inflammatory bowel diseases. [2] Common examples of nutraceuticals include beta-carotene, lycopene, omega-3 fatty acids, probiotics, and phenolic or polyphenolic compounds known for their antioxidant properties. Nutraceuticals are not always classified as essential nutrients; however, they exert beneficial physiological effects on the human body. [3] They are widely believed to offer multiple therapeutic advantages. Medicinal plants play a significant role in traditional systems of medicine across the world and form an important component of many nutraceutical preparations. Their bioactive constituents contribute substantially to the health-promoting properties associated with nutraceutical products. [4]

➢ *Functional Foods*

Functional foods are those foods or food components that are consumed as part of a normal daily diet and provide additional health advantages beyond their fundamental nutritional content. In addition to supplying essential nutrients required for growth and maintenance, these foods contribute to improved overall well-being and may help reduce the risk of certain diseases. [5] Examples of functional foods include nuts, garlic, and green tea. Such foods provide

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important macronutrients like carbohydrates, proteins, and fats, along with necessary vitamins and other bioactive compounds that support optimal health. Many functional foods are naturally occurring whole foods. [6,7] As scientific research continues to uncover their beneficial properties, these foods are increasingly recognized and promoted for their positive effects on health. [8]

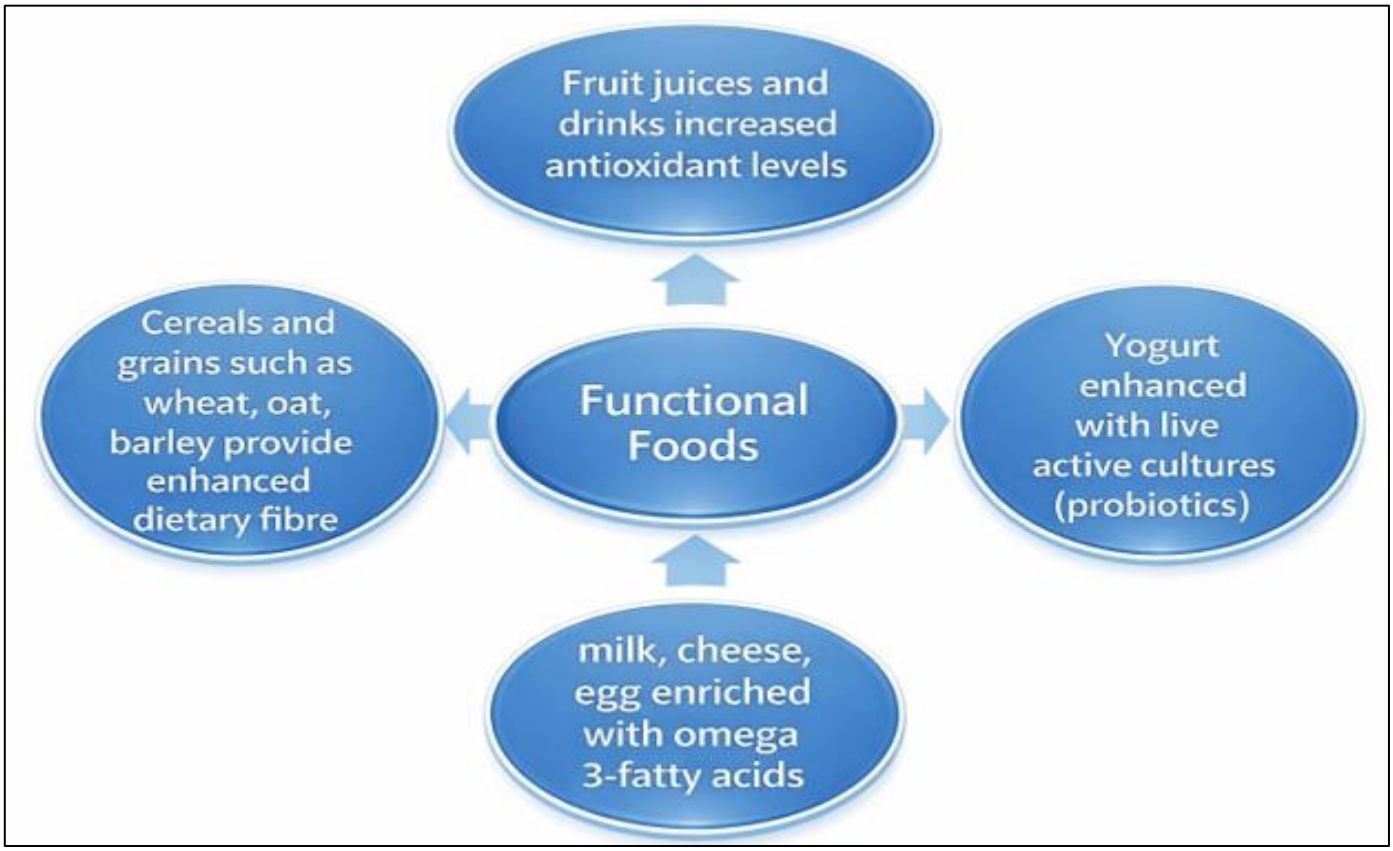

Fig 1 Some Examples of Functional Food Products Exerting the Biological Activities

➢ *Importance in Modern Healthcare:*

The nutraceutical and functional food sector presents significant opportunities for developing innovative strategies to address modern health challenges. These products are often regarded as cost-effective, relatively safe, and capable of delivering meaningful health benefits. [9] Nevertheless, maximizing the potential of functional foods requires comprehensive scientific investigation to confirm their safety, effectiveness, and long-term impact. Establishing clear scientific criteria and standardized measures for evaluating efficacy remains a major research priority, which in turn requires substantial financial and institutional support. [10] Advancing the field of nutraceuticals will depend on coordinated efforts among researchers, industry stakeholders, healthcare professionals, policymakers, and consumers to promote evidence-based practices and encourage continued innovation. [11]

In the United States, a large proportion of the population estimated at nearly two-thirds regularly uses nutraceutical or health-related products. [12] The American health and wellness market has been valued at approximately $91 billion, though some estimates suggest that the figure may approach $250 billion. Variations in reported market size are largely due to differences in how nutraceuticals and related products are defined and categorized. [13]

➢ *Classification of Nutraceutical*

Nutraceuticals are commonly categorized into two main groups based on their method of preparation: traditional and non-traditional. Due to the vast number and diversity of bioactive compounds available, it is challenging to develop a single, comprehensive classification system that includes every type of nutraceutical. Therefore, a practical classification approach is often adopted based on the types of nutraceutical products currently available in the marketplace. Plant-based foods play a significant role in reducing the risk of chronic diseases. [14] This protective effect is largely attributed to the presence of phytochemicals naturally occurring bioactive compounds found in plants. Although these compounds generally exhibit lower potency compared to synthetic pharmaceutical drugs, their regular consumption as part of the daily diet may positively influence various physiological and pathological processes within the body.

Examples of bioactive constituents naturally present in food matrices include lipids, proteins, vitamins, glycosides, and several other phytochemical components. These compounds contribute to the overall health-promoting properties associated with nutraceutical products. [15]

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Table 1 Classification of Nutraceuticals [16,17]

Main Category	Sub-category	Description / Examples
Traditional Nutraceuticals	Chemical Constituents	a) Nutrients: Vitamins, amino acids with nutritional functions b) Herbals: Willow bark (Salix nigra), Lavender (Lavandula angustifolia) c) Phytochemicals: Carotenoids, flavonoids, non-flavonoid polyphenols, phenolic acids
Traditional Nutraceuticals	Probiotic Microorganisms	Converts toxic intestinal flora into beneficial microorganisms such as Bacillus bulgaricus; helps prevent lactose intolerance through β-galactosidase enzyme
Traditional Nutraceuticals	Nutraceutical Enzymes	a) Hemicellulase enzyme (derived from microorganisms and mushrooms) b) Pancreolipase (from pancreatic juice)
Non-Traditional Nutraceuticals	Fortified Nutraceuticals	Foods fortified through agricultural breeding or by adding nutrients/ingredients, e.g., orange juice fortified with calcium, cereals with added vitamins or folic acid
Non-Traditional Nutraceuticals	Recombinant Nutraceuticals	Foods produced using biotechnology or genetic engineering, such as bread, alcohol, vinegar, etc.

II. NUTRACEUTICALS HEALTH BENEFITS

Numerous naturally occurring bioactive compounds have demonstrated significant health-promoting properties. Research findings indicate that nutraceuticals may offer therapeutic potential and are increasingly being explored for their role in the prevention and management of various diseases, including diabetes, bone disorders, and cancer. The following section provides a summary of selected nutraceuticals and highlights their potential benefits in combating different disease conditions. [18,19]

➢ *Cancer*

Extensive research indicates that chronic inflammation and several long-term diseases can be reduced through the use of nutraceutical compounds obtained from fruits, vegetables, vitamins, spices, and legumes [19]. These bioactive metabolites have demonstrated potential in modulating tumour metabolism and inhibiting cancer cell growth. Vitamins, in particular, contribute significantly to cancer prevention and management by supporting DNA methylation processes and facilitating proper DNA synthesis. Despite their therapeutic promise, many nutraceuticals exhibit limited clinical effectiveness due to poor bioavailability in vivo. To overcome this challenge, nanotechnology-based delivery systems have been developed to enhance absorption and stability. Compounds such as catechins, curcumin, green tea polyphenols, and quercetin are now being explored in nanopreventive and nanochemotherapeutic approaches, leading to improved bioavailability and therapeutic efficacy [20]. For example, ursolic acid, a naturally occurring compound with poor water solubility, shows enhanced stability and absorption when formulated as ursolic acid–phospholipid nanopowders, thereby increasing its potential effectiveness in cancer therapy [21].

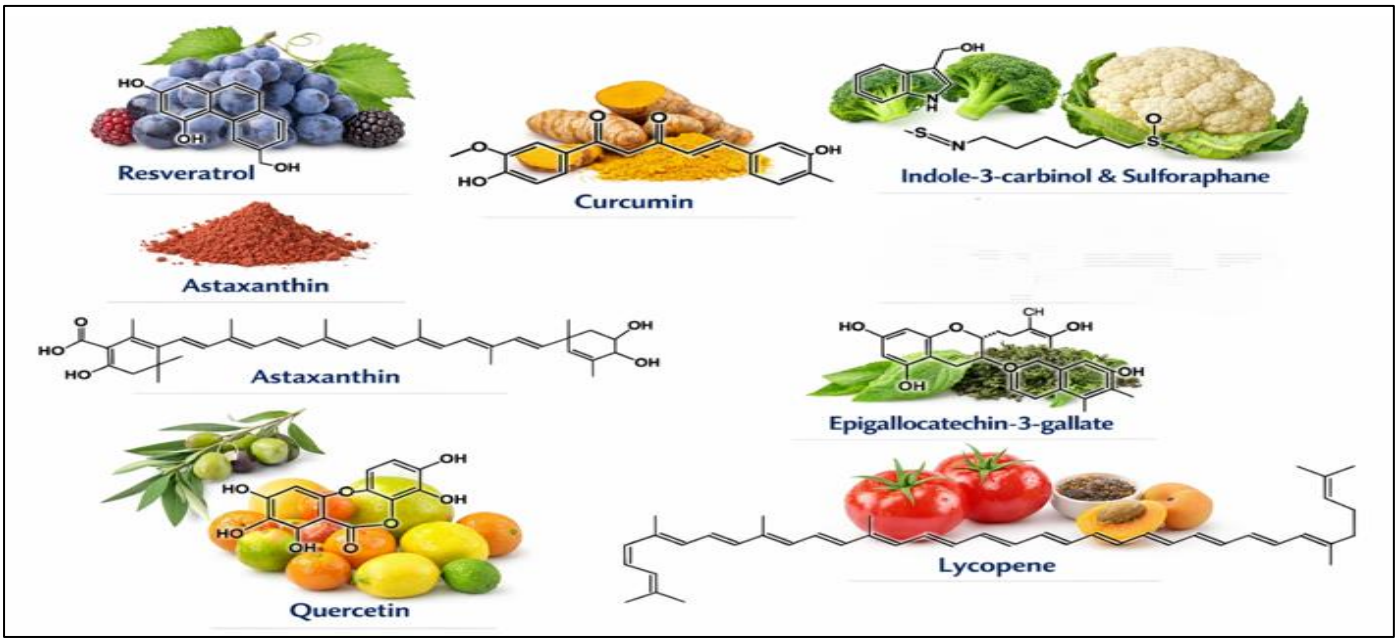

Fig 2 Food Having Anti-Cancer Property

➢ *Dry Eye Disease*

Elevated blood lipid levels and insufficient intake of omega-3 fatty acids are widely regarded as important contributors to the development of dry eye disease. [22] Evidence from multiple clinical investigations indicates that oral supplementation with antioxidants and omega-3 fatty acids particularly from sources such as fish oil and flaxseed (linseed) oil can alleviate the symptoms of dry eye. Omega-6 fatty acids, including those derived from evening primrose oil, have also shown benefits, although their effects appear to

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be comparatively modest. Furthermore, randomized controlled trials assessing the use of omega fatty acids and antioxidant supplements, whether administered individually or in combination, have documented measurable improvements in ocular comfort and surface health. Nutraceutical formulations enriched with omega lipids have additionally been associated with increased tear production, better tear film stability, and enhanced tear turnover, thereby supporting overall tear function in individuals affected by dry eye disease. [23]

➢ *Diabetes*

Scientific investigations have increasingly examined the role of citrus fruits in supporting the management of diabetes. Beyond supplying essential nutrients such as vitamins, minerals, pectin, and dietary fiber, citrus fruits are rich in bioactive phytochemicals, including phenolic acids, flavonoids, flavones, and flavones. [24] These compounds are valued for their biological activities, particularly their antioxidant and anti-inflammatory properties, as well as their ability to reduce platelet aggregation and improve vascular health. In addition to citrus-derived compounds, other nutraceutical constituents such as phenolic acids, flavonoids, stilbenes, lignans, and polymeric lignans have demonstrated promising effects in the prevention and management of metabolic disorders and diabetes-related complications. Collectively, these bioactive substances present meaningful opportunities for improving glycemic control and reducing the overall risk associated with diabetes. [25]

➢ *Cardiovascular Diseases*

Flavonoids exhibit significant nutraceutical potential in the management of cardiovascular diseases. Their cardioprotective effects are largely attributed to their strong antioxidant properties, which arise from the presence of polyphenolic compounds. These bioactive molecules enhance the body's antioxidant defence system by neutralizing free radicals, donating electrons, and chelating metal ions such as ferrous ions. [26] Through these mechanisms, flavonoids help reduce oxidative stress and protect cardiac tissues from damage. Moreover, they have been recognized for their protective role against cardiotoxicity induced by certain antitumor agents. By scavenging reactive oxygen species and minimizing oxidative injury, flavonoids contribute to both the prevention and supportive treatment of cardiovascular complications associated with anticancer therapy. [27,28]

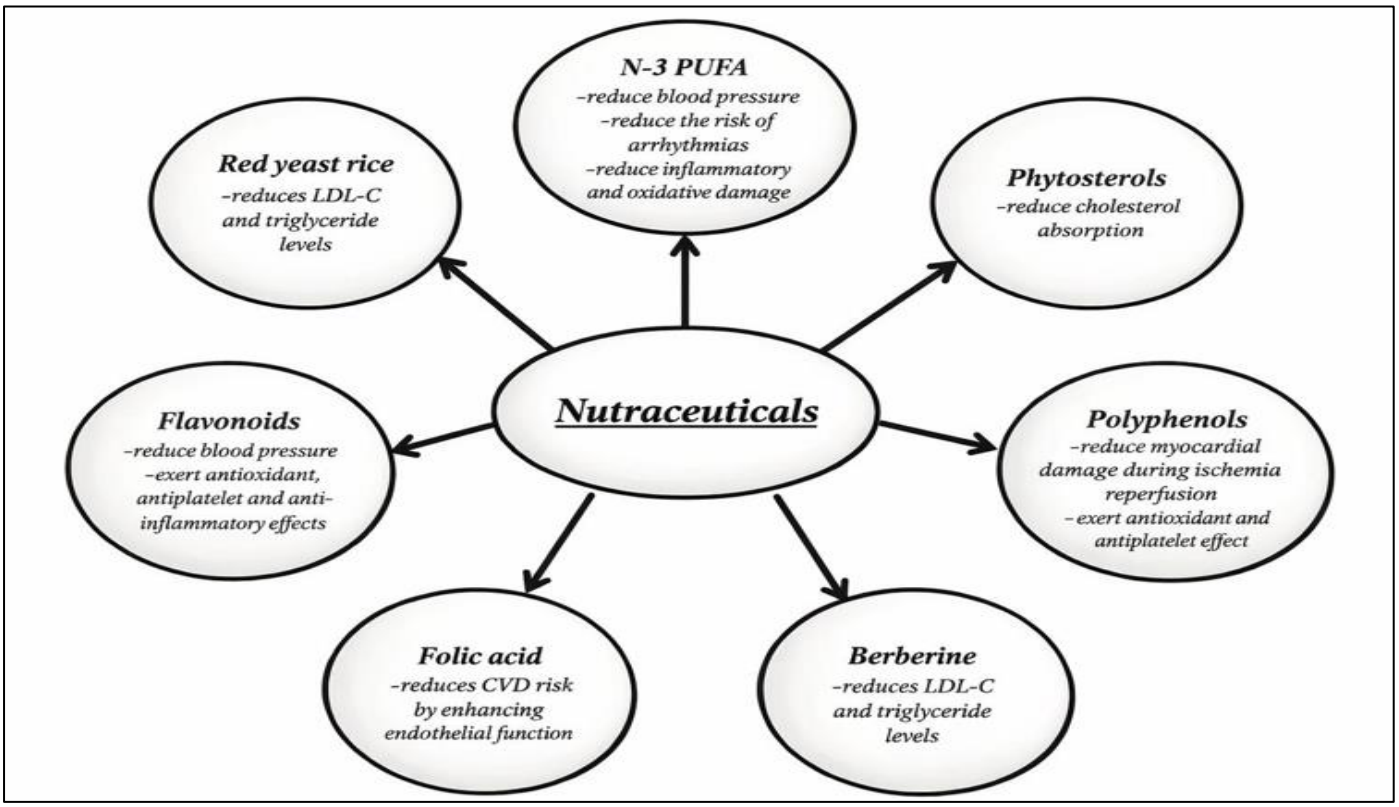

Fig 3 Nutraceuticals in Cardiovascular Disease

➢ *Oral Health*

Oral infections, including dental caries, tooth loss, and periodontal disorders, have a significant impact on overall health and quality of life. Dental caries commonly develops as a result of microbial activity in the oral cavity, along with contributing factors such as poor nutrition and inadequate oral hygiene. Emerging research indicates that green tea and its bioactive polyphenols may offer protective benefits for oral health. [29] These compounds exhibit antimicrobial and antioxidant properties, which can help limit bacterial growth and reduce oxidative stress in oral tissues. Regular consumption of green tea has also been associated with a decreased risk of abnormal cellular changes and may assist in controlling bad breath by neutralizing volatile sulphur compounds responsible for unpleasant odors. Overall, incorporating green tea into the diet may contribute to the prevention and management of various oral diseases. [30,31]

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➢ *Obesity*

Obesity is defined by an abnormal or excessive build-up of body fat that poses a risk to health. It is closely linked to a range of metabolic and physiological complications, including high blood pressure, type 2 diabetes, and impaired fertility. A major factor contributing to obesity is the long-term intake of calorie-rich, energy-dense foods combined with reduced physical activity. [32] With the global increase in obesity rates, there has been growing interest in the use of nutraceuticals as complementary approaches for weight control. Certain nutraceutical agents, such as glucomannan, chitosan, fenugreek, and vitamin C, have shown promising results in supporting fat reduction and lowering overall body weight. These substances may aid in appetite regulation, fat metabolism, and improved metabolic balance, highlighting their potential role as supportive tools in obesity management. [33]

➢ *Migraine*

A number of nutraceuticals have been proposed as supportive options for preventing and managing migraine episodes, such as feverfew, Parasites, and coenzyme Q10. Feverfew (Tanacetum parthenium), obtained from the dried leaves of a chrysanthemum-like plant, contains active constituents including melatonin and the essential oil chrysanthenyl acetate. These bioactive components are thought to help lower the intensity and frequency of migraine attacks. [34] Although large-scale, definitive clinical trials are still limited, the European Scientific Cooperative on Phytotherapy (ESCOP) recognizes feverfew as a potential prophylactic agent for migraine. Similarly, Petasites hybridus, commonly known as butterbur, has been documented in clinical reports as a generally safe and effective option when used over extended periods for migraine prevention. [35,36]

III. BIOACTIVE COMPOUND BASED NUTRACEUTICALS POSSESSING HEALTH BENEFITS

Nutraceuticals represent a unique interface between nutrition and healthcare, as they are derived from foods and provide benefits that go beyond simple nourishment. Their health-promoting and disease-preventing properties are largely attributed to bioactive constituents naturally occurring substances found in plants and food sources that influence biological functions. Important examples include polyphenols, carotenoids, and omega-3 fatty acids, which are known to support the body through antioxidant activity, reduction of inflammation, and regulation of immune responses. [37,38]

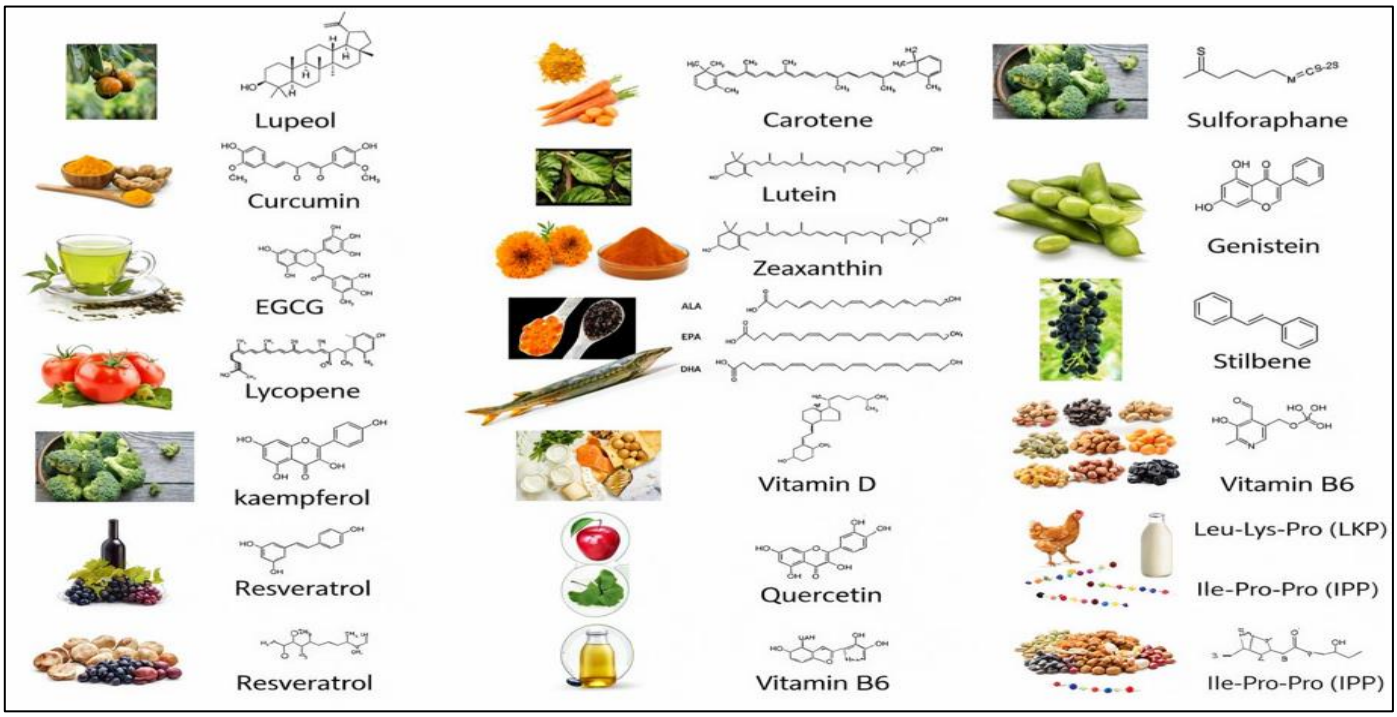

Fig 4 Bioactive Compounds Possessing Health Benefits

➢ *Safety and Quality Aspects*

Nutraceuticals provide significant health benefits and are increasingly consumed worldwide; however, their rapid market growth has raised concerns regarding product safety and quality. Despite the common perception that these products are inherently safe, certain phytochemicals, including digitalis and some anticancer plant-derived alkaloids, may cause toxic effects. Therefore, thorough evaluation through preclinical studies and well-designed, double-blind clinical trials is essential to ensure their safety. Regulatory requirements for dietary supplements vary among countries. [39] Under the Dietary Supplement and Health Education Act (DSHEA) of 1994, manufacturers are responsible for ensuring product safety before marketing. Although prior FDA approval is not required, manufacturers must ensure that labelling is accurate and not misleading, and that health claims are supported by scientific evidence. In

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addition, post-marketing surveillance and adverse-event reporting are mandatory to monitor product safety. [40,41]

➢ *Regulations*

The term nutraceutical does not have a legally defined status and does not represent a separate category of food products. Essentially, these products originate from natural sources, many of which have been consumed by humans for centuries as part of a regular diet. Consequently, regulatory agencies such as the FDA treat nutraceuticals under the same legal framework as conventional foods, requiring that ingredients be proven safe prior to marketing and that all product claims be accurate, scientifically supported, and not misleading. [42,43]

Regulatory authorities in regions including the United States, Canada, the European Union, China, and India enforce strict controls over food and drug production, distribution, and promotion. However, a comprehensive and uniform regulatory system specifically designed for nutraceuticals is still lacking. [44] To address this gap, many countries are developing new laws, issuing supplementary regulations, or providing updated regulatory interpretations. More detailed regulatory approaches for nutraceuticals, phytonutrients, phytotherapy, and nutritional therapy are being formulated through expert committee consultations. These efforts focus on Good Manufacturing Practices (GMP), Generally Recognized as Safe (GRAS) status, product testing, and analytical validation procedures. [45]

In India, the regulatory framework governing nutraceuticals requires substantial modernization. While global regulatory agencies have revised existing legislation to accommodate evolving consumer needs, India continues to rely heavily on older laws, such as the Prevention of Food Adulteration Act of 1954, for the control of packaged foods. Manufacturers must also comply with several additional regulatory instruments, including standards for weights and measures, infant nutrition laws, packaging requirements for edible oils, fruit and meat product regulations, milk and dairy controls, vegetable oil regulations, atomic energy and food irradiation rules, consumer protection laws, and environmental protection legislation. [46]

➢ *Global Nutraceutical Market*

Over the past several decades, the nutraceutical industry has experienced rapid global expansion. A market analysis estimated that the global nutraceutical sector was worth approximately US $160.6 billion in 2013 and was projected to grow to about US $241.1 billion by 2019. [47] This growth is driven by increasing health awareness, easy access to nutraceutical products, rising middle-class incomes, higher disposable earnings, and escalating healthcare expenses. In developing countries, the availability of low-cost raw materials further supports the manufacturing of these products. The market continues to show strong growth potential, particularly because nutraceuticals are viewed as modern lifestyle products that appeal strongly to younger consumers. Popular product categories include green tea, vitamin supplements, protein formulations, and energy drinks. [48]

In countries such as Brazil, Japan, and India, most nutraceutical companies operate mainly within domestic markets, with only a limited number expanding internationally. This is largely due to differences in regulatory requirements across nations, which create challenges for companies attempting to enter multiple global markets. Several multinational corporations play key roles in the global nutraceutical industry, including Monsanto, BASF, Archer Daniels Midland, Cargill, DuPont, GlaxoSmithKline, Abbott Laboratories, Ajinomoto, Nestlé, Yakult Danone, FMC Corporation, and Herbalife. [49,50]

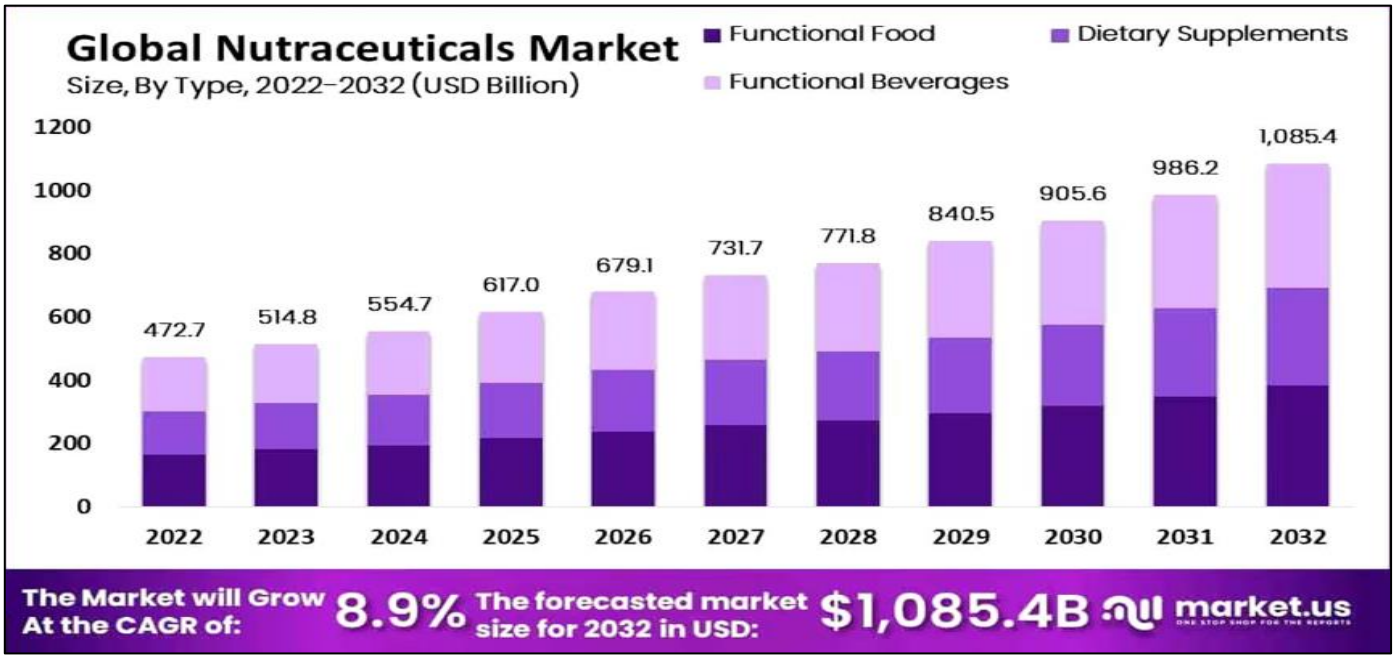

Fig 5 Global Market of Nutraceuticals

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➢ *Some Marketed Products Available as Nutraceuticals*

Many pharmaceutical companies are attempting to Manufacture nutraceuticals in therapeutic areas. Some of the commercially available nutraceuticals are Discussed in Table 2

Table 2 Commercially Available Nutritional Products [51,52,53,54]

S. No.	Product Name	Source	Category	Key Ingredients	Reported Benefits	Manufacturer
1	Glucon-D	Fortified glucose	Energy supplement	Glucose	Provides rapid energy and refreshment	Heinz
2	Glucose-D	Fortified glucose	Energy supplement	Dextrose monohydrate, calcium phosphates, vitamin D	Quickly restores energy levels	Dabur
3	Proteinex	-	Protein & nutritional supplement	Protein hydrolysate, essential vitamins and minerals, sugar, malt extract	Promotes physical and cognitive development	Pfizer Ltd.
4	GRD	-	Nutritional supplement	Vitamins, carbohydrates, protein	Supports tissue growth and repair	Zydus
5	B-Protein	-	Nutritional supplement	Soy protein, whey, casein, essential vitamins and minerals	Aids nutritional support and hemoglobin formation	British Biologicals
6	Tropicana	Vitamin C	Energy drink	B-vitamins, thiamine, folate	Nutrient-rich beverage beneficial for heart health	Tropicana Products Inc.
7	Frooti	Mango	Energy drink	Water, mango pulp, sugar, antioxidants	Refreshing fruit beverage	Parle Agro Pvt. Ltd.
8	Abcor	-	Heart supplement	-	Helps reduce cholesterol levels	Nutri Pharma
9	Cod Liver Oil	Fish	Vitamin & mineral supplement	Omega fatty acids, vitamins A and D	Enhances immune function	Sanofi
10	Fish Oil Plus	Salmon	Brain supplement	Omega-3 fatty acids	Supports heart health and maintains cholesterol and blood pressure	Pacific Health Inc.
11	Calcium Plus Milk	Fortified milk	Energy supplement	Carbohydrates, vitamin D, calcium	May reduce risk of osteoporosis	Shamrock Farms
12	Cognisure	Protein-rich polypeptide complex	Protein supplement	Proline-rich polypeptide complex (from colostrum), fructose, sorbitol	Supports healthy brain aging and cognitive function	Metagenics Inc.
13	Phenorex	Orange	Health supplement	CarniPure, falcate extract, caffeine, Advantra Z (Citrus aurantium extract)	Assists in fat metabolism	Gaspari Nutrition

IV. THE FUTURE ASPECTS OF NUTRACEUTICALS

The rapid growth of the nutraceutical sector reflects a clear shift in consumer preferences toward minimally processed foods that provide added nutritional value along with appealing taste and sensory qualities. This rising demand is driving significant global expansion of the nutraceutical industry. As the new millennium advances, the sector is expected to play an increasingly influential role across the food, pharmaceutical, healthcare, and agricultural domains. Researchers suggest that enzymes may represent a promising and relatively untapped area within nutraceutical development. Their broader application could open new possibilities for enhancing health outcomes. Similarly, microbial fermentation technologies offer strong potential for creating innovative functional foods with improved nutritional profiles. The global movement toward healthier products are unlikely to decline, and companies that invest strategically in scientific research, product innovation, marketing initiatives, and consumer awareness are likely to gain substantial long-term benefits. In addition, nutraceuticals delivered through advanced systems such as oral and transdermal routes may improve targeted therapeutic effects while optimizing bioavailability. The concept of "smart nutraceuticals" is also emerging, envisioning a future in which personalized nutrition is guided by individual genetic information. Such an approach could significantly

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enhance the effectiveness of dietary recommendations, which are currently broad and may only benefit a portion of the population.

V. CONCLUSION

Nutraceuticals are biologically active substances that provide health benefits beyond basic nutritional value. They are commonly derived from natural food sources, fortified foods, genetically modified crops, or processed dietary products. Compared to conventional pharmaceuticals, nutraceuticals are often more affordable and relatively easier to develop, manufacture, and distribute.

The growing interest in preventive healthcare has increased the appeal of nutraceuticals not only for food industries but also for pharmaceutical and biotechnology companies. Numerous studies have reported their potential role in managing and preventing various health conditions, including cancer, diabetes, dry eye syndrome, and joint-related disorders. Several pharmaceutical organizations, such as Ranbaxy and Abbott Healthcare, offer a broad range of nutraceutical products designed for diverse therapeutic applications.

Despite their expanding market and promising health benefits, further scientific research is necessary to establish their long-term safety, effectiveness, and standardized guidelines for use. The pharmaceutical sector faces the ongoing challenge of integrating nutrition-focused strategies into mainstream healthcare. Greater awareness among consumers and healthcare professionals about the role of nutrition in disease prevention and health promotion is essential for supporting longer, healthier lives.

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