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REVIEW

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An overview of nutraceuticals and their role in health applications

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ABSTRACT

Nutraceuticals, a term coined from the fusion of "nutrition" and "pharmaceutical," represent a burgeoning sector that bridges the gap between food and medicine. Essentially, these are food components or whole foods that provide nourishment and have a positive impact on the maintenance and modification of normal physiological functions, fostering overall health in individuals. Driven by current demographic trends and an increased focus on health and wellbeing, the global nutraceutical market is experiencing substantial growth. These functional foods encompass a range of categories including dietary fibres, prebiotics, probiotics, polyunsaturated fatty acids, antioxidants, and various types of natural or herbal foods. These serves as a potent beneficial tool in fighting against the commonly prevalent health issues such as obesity, cardiovascular diseases, diabetes, arthritis, cancer, osteoporosis, high cholesterol and neurological disorder. Consequently, nutraceuticals are ushering in a revolutionary phase in the spheres of medicine and health, transforming the food industry into a sector marked by intensive research and innovation. This review offers an insightful analysis of various bioactive elements that function as nutraceuticals, including carotenoids, flavonoids, prebiotics, probiotics edible flowers, alkaloids, and medicinal plants, and discusses their role in promoting health advantages. It underscores the importance of adopting appropriate dietary habits and sheds light on the health complications that may arise from neglecting established patterns of healthy eating. Additionally, this review explores the burgeoning development of new nutraceutical products, functional foods, and food supplements that promise unprecedented health benefits. It aims to elucidate the operative mechanisms of nutraceuticals and ventures to clarify and grasp both the analytical and formulation facets, as well as their regulatory dimensions. Furthermore, the review addresses the potential role of nutraceuticals in forestalling certain diseases, emphasizing their preventative capabilities in healthcare.

KEYWORDS

Nutraceutical; Herbal bioactive compounds; Disease prevention; Health promotion; Nutrition

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Introduction

In 1989, Stephen L. Defelice, the founder and chairman of the Foundation of Innovation Medicine, coined the term 'nutraceutical,' merging 'nutrition' and 'pharmaceutical.' Nutraceuticals refer to substances derived from food sources that offer health benefits beyond the basic nutritional value found in regular foods [1]. These products, whose claims vary based on the jurisdiction, may purport to mitigate chronic illnesses, enhance health, decelerate the aging process, prolong life span, or bolster the body's structure or functionality [2-5]. Nutraceuticals, essentially biologically active compounds discovered in food, encompass attributes of both nourishment and medication. These naturally occurring bioactive or chemical compounds function not only as nutritional supplements but also showcase properties that promote health, cure diseases, or possess preventive capabilities [6,7]. Constituted of essential components such as lipids, vitamins, carbohydrates, proteins, and minerals, nutraceuticals have demonstrated potential efficacy in treating a range of diseases including cardiovascular diseases, diabetes, atherosclerosis, cancer, and problems associated neurological conditions [8-10].

The inclination towards nutraceuticals can be attributed to several factors [11-15]:

i. An increasing number of consumers are alarmed by the escalating costs of healthcare.
ii. Individuals dissatisfied with the results of pharmaceutical products for enhancing health are gravitating towards nutraceuticals as a means to improve their health and thwart chronic diseases.
iii. Healthcare practitioners realize that our highly processed food supply, which is cultivated using chemical fertilizers, pesticides, herbicides, and often genetically modified seeds, lacks adequate nutrient content for optimal health.
iv. A populace that is leaning towards prevention as opposed to treatment of ailments.
v. Individuals afflicted with chronic diseases who haven't found respite through allopathic treatments.
vi. Patients who are constrained by limited financial resources, seeking more affordable health solutions.

Nutraceuticals Derived from Bioactive Compounds

Bioactive substances, present in minute quantities in various foods such as fruits, vegetables, and whole grains, harbor

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extensive therapeutic potential. They offer myriad health benefits beyond the fundamental nutritional contributions. These bioactive compounds can be categorized into two groups according to their sources: those derived from herbal origins, and those found in dietary supplements (Table 1).

Table 1. Bioactive ingredients.

Herbal bioactive ingredients	Dietary supplements
Anthraquinones	Carbohydrates
Alkaloids	Proteins
Tannins	Lipids
Carotenoids	Vitamins
Flavonoids	Probiotics
Bitters	Prebiotics
Essential oil	Mushroom

Herbal bioactive ingredients

Herbal bioactive ingredients refer to the naturally occurring compounds found in herbs and plant-based products that possess potential health benefits. These components are known to exhibit therapeutic properties and can play a significant role in preventing and treating various diseases. Therapeutic plants and herbs have garnered considerable interest over time due to their rich variety of aromas and tastes, making them valuable additions in both medical and culinary fields. Herbal bioactive compounds, encompassing substances like carotenoids, coumarins, flavonoids, lignans, phthalides, plant sterols, polyphenols, saponins, sulphides, and terpenoids, constitute a vital segment within the nutraceutical sector. These components not only enrich our food preparations but also serve as potent agents in enhancing health and preventing diseases, thereby highlighting their dual role in improving quality of life. These elements often have antioxidative, anti-inflammatory, and antimicrobial properties, making them powerful agents in promoting overall health and well-being [16]. Utilized in various traditional medicine systems for centuries, herbal bioactive ingredients are now being studied intensively for their potential applications in modern medicine. They are often used in the formulation of nutraceuticals, which are products that combine the benefits of nutrition and pharmaceuticals to promote health and prevent disease. Moreover, these herbal ingredients are a focal point in the ongoing research for the development of new drugs and therapies, particularly as the interest in natural and holistic approaches to health care continues to grow globally [17].

Alkaloids

Alkaloids constitute a distinct group of compounds that are pivotal in the biological mechanisms of various entities including plants, animals, and microorganisms. These compounds, characterized as heterocyclic chemical molecules containing nitrogen, find extensive applications in fields such as pharmacology, medicine, and ecology [18]. Their profound physiological impacts at cellular and molecular levels render them as effective healing agents, widely embraced by the pharmaceutical sector [19]. Despite their benefits, alkaloids can sometimes be extremely toxic, even in minuscule amounts, and are known to be soluble in organic solvents [20]. Plant-derived alkaloids have secured a firm place in the pharmaceutical industry, prominently featuring in drugs that serve anti-malarial (such as quinine and chloroquine), anti-cancer (like vinblastine, vincristine, and taxol), and cerebral blood circulation enhancing functions (vincamine) [21,22]. Furthermore, these compounds have seamlessly integrated into our daily diets, notably in the forms of beloved beverages like black tea and coffee, which contain the active alkaloids theophylline and caffeine, respectively [23]. They also enrich various culinary experiences, being prominent components in spices like long pepper (*Piper longum* L.) and black pepper (*Piper nigrum* L.), both rich in the alkaloid piperine, a popular ingredient in Indian and numerous other cuisines [24]. Adding to the list are capsicum peppers which comprise a range of varieties including chili and red pepper (*Capsicum annuum* L.), bird pepper or tabasco (*Capsicum frutescens* L.), Peruvian pepper (*Capsicum baccatum* L.), aji pepper (*Capsicum chinense* Jacq.), and rocoto pepper (*Capsicum pubescens* Ruiz & Pav.), all of which are substantial sources of alkaloids. Research underscores the considerable physiological potency of piperine, attesting to its safety for consumption [25].

Carotenoids

Carotenoids, organic pigments that confer orange, yellow, and red hues, are synthesized by organisms such as bacteria, fungi, algae, and plants, finding vivid expressions in fruits, vegetables, and seafood [26]. Unfortunately, animals are incapable of generating these compounds autonomously, necessitating dietary assimilation and subsequent metabolism to facilitate their involvement in vital physiological operations [27]. Playing multifaceted roles in biological systems, carotenoids function as antioxidants, agents modulating membrane fluidity, and ancillary constituents aiding in the light absorption process of photosynthetic assemblies [28]. Certain foods serve as abundant reservoirs of specific types of carotenoids: apricots and broccoli are rich in β-carotene and lutein; carrots and tomatoes are laden with β-carotene and lycopene; pumpkin offers a generous supply of β-carotene, β-cryptoxanthin, lutein, and zeaxanthin, while green leafy vegetables are a source of both lutein and β-carotene [29]. Notably, a small fraction of the identified carotenoids, approximately 50 out of the known 600, exhibit provitamin A activity, with β-carotene, α-carotene, and β-cryptoxanthin being the most pivotal [30]. Incorporating these carotenoids in our diet can be a preventive strategy against severe eye ailments. Beyond their role in eye health, carotenoids enhance resistance to oxidative stress across species, alongside showcasing potential anti-cancer attributes [31]. Their inclusion in daily diet thus not only adds color but also a plethora of health benefits, acting as a shield against various ailments [32].

Saponins

Steroid saponins are diverse, naturally occurring organic compounds that can be extracted from an extensive assortment of sources including various plants, microorganisms, and certain animal species [33]. Notable plant sources that are rich in these special compounds include aubergines (*Solanum aethiopicum* L.), capsicum peppers (*Capsicum annuum*), ginseng (*Panax ginseng*), and yucca (*Yucca schidigera*), amongst others. In the realm of pharmacology, saponins have proven to be invaluable due to

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their extensive range of medicinal properties [34]. Their versatility in potential health applications is quite remarkable, spanning from metabolic benefits such as hypoglycemic activity, which is vital in the regulation of blood sugar levels, to their ability to reduce LDL (Low-Density Lipoprotein) cholesterol and overall serum cholesterol. These attributes hint at their potential role in mitigating cardiovascular diseases, which are prevalent in today's society, characterized by lifestyles that often involve high cholesterol diets and limited physical activity. Furthermore, saponins have been noted for their potential anti-cancer properties, particularly in inhibiting the growth of cancer cells. This is a focal point in ongoing research, as scientists seek to unlock new, natural avenues for cancer treatment and possibly prevention. Saponins might offer a promising pathway in the development of novel strategies in the fight against this dreaded disease, which affects millions of people worldwide. In addition to their potential role in cancer inhibition, saponins are also known for their stimulation of the cell-mediated immune system. This function is essential in bolstering the body's defense mechanisms, enhancing its ability to ward off infections and diseases. Their antioxidant activity further amplifies this defensive role, helping in neutralizing harmful free radicals in the body, thereby potentially slowing down the aging process and protecting the body's cells from damage. Their antifungal properties mark them as potent agents in the fight against various fungal infections, which can sometimes be notoriously difficult to treat. Moreover, saponins have exhibited neurotrophic and neuroprotective activities, potentially playing a significant role in the protection of neural cells and fostering the growth and development of nervous tissue. This aspect is particularly important given the increasing prevalence of neurodegenerative diseases such as Alzheimer's and Parkinson's in the aging global population. Lastly, the viricidal effects of saponins illustrate their potential in combating viral infections, which is particularly pertinent in a world that has seen the devastating effects of viral pandemics. As we move forward, understanding and harnessing the viricidal capabilities of saponins could be vital in developing new strategies to combat viral diseases [35].

Tannins

Tannins are complex compounds characterized primarily by their phenolic and polyphenolic structures. These chemical constituents grant them the unique ability to act as astringents within the human body, instigating tissue contraction and causing the structural proteins in mucosa and skin to constrict. Their role, however, extends beyond this astringent property. They play a pivotal role in the proactive protection of the body against various types of oxidative damage. They proficiently prevent lipid peroxidation, a process that can lead to cell damage, and facilitate the neutralization of super-oxides and other free radicals, thus serving as potent antioxidants that help maintain the body's healthy state [36,37]. Moreover, tannins have found therapeutic application in the management of ulcerative colitis, owing to their array of health-promoting attributes [38]. These include their anti-inflammatory properties that can help soothe inflamed tissues, and antibacterial qualities that protect against infections. In addition, their antileishmanial properties make them potent agents in the fight against Leishmania parasites, which cause the disease leishmaniasis. Furthermore, they exhibit immunomodulatory actions, having the ability to modulate the immune system responses, and analgesic properties which assist in alleviating pain. Their anti-lymphocytic properties further hint at their potential role in managing conditions involving the lymphocytes, while their neuroprotective actions help safeguard the nervous system from potential damage. Tannins also have antidiarrheal qualities, providing relief in cases of diarrheal diseases, and exhibit antihypertensive effects, which may assist in managing high blood pressure conditions [39,40]. Interestingly, the benefits of tannins are not restricted to humans alone; those found to be useful in the agricultural sector as well, notably in the livestock industry. For instance, leguminous feeds rich in tannins have been utilized to safeguard livestock against various parasites, including gastrointestinal worms, thus promoting the overall health and well-being of these animals [41]. Tannins are versatile bioactive compounds with a wide range of beneficial health properties, showcasing potential in both medical and agricultural applications. Their multifaceted roles in health and disease prevention make them subjects of interest in ongoing and future research aimed at harnessing their full potential in promoting health and wellness.

Bitters

These compounds, renowned for their distinctive bitter taste, are found abundantly in a variety of herbs. Common herbs housing these bitter substances include yarrow (*Achilles millefolium*), chamomile (*Matricaria chamomilla*), horehound (*Marrubium vulgare*), peppermint (*Mentha piperita*), rue (*Ruta* Sp.), milk thistle (*Silybum marianum*), and dandelion (*Taraxacum*). These bitter components exert a significant influence on the digestive system, acting as catalysts for the secretion of digestive enzymes and aiding in the smooth flow of bile from the liver, which not only enhances appetite but also optimizes nutrient absorption from ingested food [42]. In medical practice, bitters are often recommended for individuals grappling with a range of ailments including gallbladder and liver dysfunctions, diminished appetite, gastritis, constipated bowels, and post-flu symptoms [43]. Aside from their pivotal role in digestive health, these bitter compounds are recognized for their multifaceted pharmacological properties. They have been noted to possess potential anticancer properties and have a calming effect on the nervous system. Moreover, their antibacterial, antioxidant, anti-inflammatory, and anti-diabetic attributes add to their therapeutic value, making them potent agents in the management of a spectrum of health conditions [44]. Despite their somewhat unpalatable taste, the efficacy of bitters is most prominent when they are consumed orally, as their beneficial impact initiates right in the oral cavity, making oral consumption a requisite for realizing their full health benefits. In the rich tapestry of Indian Ayurveda, several bitters have been delineated, such as guduchi (*Tinospora cordifolia*), manjista (*Rubia cordifolia*), and neem (*Azadirachta indica*), alongside others like turmeric (*Curcuma longa*) and *Rubia cordifolia*. These are frequently employed in the treatment of various ailments, primarily due to their favorable effects on the liver and spleen, solidifying their prominent place in holistic health practices [45].

Flavonoids

Flavonoids, naturally occurring compounds with antioxidant properties, are primarily found in the form of glycosides in various plants and foods. Significant sources of flavonoids encompass a variety of vegetables like broccoli, green pepper,

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kale, onion, spinach, and tomato, as well as fruits including oranges, grapefruits, apples, and grapes. Moreover, herbs such as *Citrus grandis, Hypericum perforatum, and Sophora japonica*, along with soybeans, serve as rich reservoirs of these beneficial compounds [46]. Aside from their roles as antioxidants, flavonoids are renowned for their multifaceted health benefits including their protective shield against coronary heart diseases. Furthermore, they possess a spectrum of promising properties such as antiviral, antiallergic, anticholinesterase, and anticancer effects, broadening their scope in the health sector [47]. The current market sees an influx of various products fortified with flavonoids, being actively researched and developed, or already available as functional foods and dietary supplements, fostering a healthier lifestyle. However, it is pertinent to note that the study of the ADME (Absorption, Distribution, Metabolism, and Excretion) characteristics of flavonoids in animal systems is somewhat underexplored in existing literature. This gap in research makes it challenging to fully predict the biological implications of flavonoids, consequently limiting their potential incorporation as viable food sources. Enhancing the understanding of these properties could potentially pave the way for a more comprehensive utilization of flavonoids in dietary practices [48].

Essential oils

Essential oils can be derived from a diverse array of plant components including buds, bark, fruits, flowers, herbs, leaves, roots, seeds, twigs, and wood [49]. These oils are a complex concoction of aromatic compounds that can be obtained through various extraction methods such as solvent extraction or steam distillation. Additionally, the subcritical water extraction technique has proven to be effective in extracting essential oils, for instance, from the leaves of *Thymbra spicata* [50]. These volatile essences are characterized by their unique fragrances, primarily composed of a mix of terpenes, aldehydes, esters, ketones, and phenolic compounds. One of the standout features of essential oils is their significant concentration of terpenoids, which are known to possess antiseptic and antibacterial properties [51]. These qualities enable them to bolster the body's natural defenses against a myriad of infectious diseases. Moreover, essential oils are known to confer several health benefits, including anticancer, anti-inflammatory, and antispasmodic properties. They also positively influence the heart and circulatory system, offering potential therapeutic effects. Certain oils like those derived from yarrow and chamomile have antispasmodic properties, while others like rosemary, ginger, and thyme have a beneficial impact on the circulatory system [52]. These diverse attributes make essential oils a valuable addition to various health and wellness applications.

Anthraquinones

Anthraquinones encompass a diverse range of molecules characterized by distinct biological properties [53]. One of the notable effects of these compounds is their ability to stimulate muscle contraction, often resulting in a laxative effect. Plants rich in anthraquinones include Aloe vera (*Aloe barbadensis Miller*), cascara (*Rhamnus purshianus*), dock (*Rumex crispus*), rhubarb (*Rheum palmatum*), and senna (*Senna alexandrina*). A significant body of research has pointed to the potential health benefits of these compounds, particularly in the realm of cancer treatment. For instance, the hydroxyanthraquinone present in aloe vera, known as aloe-emodin, has demonstrated potential in inhibiting the growth of various tumor cell lines, including those of lung cancer [54], hepatoma, and leukemia [55]. Furthermore, other constituents of the rhubarb plant, emodin and rhein, have also exhibited anticancer properties [56].

Additionally, aloe-emodin has been singled out for its specific anti-neuroectodermal tumor properties, manifesting in both *in-vitro* and *in-vivo* studies [57]. Apart from its anticancer effects, the latex of the aloe plant is a rich source of anthraquinones with anti-inflammatory properties, well-regarded for their healing and pain-relieving capabilities. Interestingly, the production of anthraquinones is not confined to plant species; these compounds have also been discovered in marine life. Recent studies have identified the presence of two such anthraquinones, Lupinacidin A and Galvaquinone B, in sea anemones found around Easter Island. These molecules have shown promising anti-tumor effects, positioning them as potential candidates for development as nutraceuticals, as highlighted in recent research conducted in Germany [19]. This opens up new avenues for the utilization of anthraquinones as valuable components in the development of health supplements and therapeutic agents.

Advantages of nutraceuticals

For over two decades, the scientific community has been diligently exploring the connection between phytochemicals and prospective health benefits. Various studies corroborate that the consumption of fruits and vegetables significantly reduces the risk of several diseases including those affecting the oesophagus, stomach, lungs, endometrium, oral cavity, pancreas, pharynx, and colon [58]. Key phytochemicals instrumental in staving off diseases encompass substances such as allium compounds, beta-carotene, dietary fibers, flavonoids, folic acid, D-limonene, dithiolthiones, indole-3-carbinol, inositol hexaphosphate (IHP), isoflavones, isothiocyanates, lutein, lycopene, phytosterols, selenium, and saponins. Cardiovascular diseases (CVDs), ailments affecting the heart and blood vessels, have been linked to a diminished intake of fruits and vegetables, thus elevating the risk factors [59]. A plethora of research underscores the positive repercussions of a diet rich in fruits and vegetables in averting CVDs. As a potent tool in combating and managing CVDs, nutraceuticals—encompassing minerals, vitamins, dietary fibers, antioxidants, and omega-3 polyunsaturated fatty acids—are often recommended in tandem with regular physical activity. Polyphenols, which facilitate alterations in cellular communication and metabolism, are known to mitigate the risks associated with vascular ailments [60]. Furthermore, flavonoids play a pivotal role in preventing CVDs, chiefly by hindering platelet aggregation through the inhibition of enzymes like angiotensin-converting enzyme and cyclooxygenase [61].

In the contemporary era, cancer stands as a predominant public health concern. The antioxidant properties of carotenoids render them potent agents in cancer prevention. Specifically, lycopene and its counterparts serve as a protective shield against cancer [62], significantly reducing oxidative stress and DNA damage, thus exhibiting anticancer properties [63]. This beneficial component can be found in an array of fruits such as tomatoes, pink grapefruits, guavas, watermelons, and papayas. Apples, enriched with pectin, a soluble fiber, offer protection against prostate cancer by preventing the adhesion of cancer cells to healthy cells within the organism.

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Additionally, certain natural phenolic compounds, including gallic acids, curcumin, ferulic acid, and caffeic acid, showcase anticancer attributes. Curcumin, a derivative of Curcuma longa, is renowned for its anti-inflammatory, antioxidative, and anticarcinogenic characteristics. Presently, the global community is grappling with the pressing issue of obesity, a condition that serves as a precursor to numerous severe ailments such as cancer, heart failure, hypertension, angina pectoris, hyperlipidemia, osteoarthritis, respiratory disorders, and renal vein thrombosis. The proliferation of obesity can be attributed predominantly to the consumption of high-fat diets. The realm of research is now pivoting towards understanding the efficacy of nutraceuticals in aiding obesity management. Several nutraceuticals, including capsaicin conjugated linoleic acid, Bitter melon, Bitter orange, and psyllium fiber, are believed to harbor potential anti-obesity properties [64]. In the context of weight management, various herbal stimulants such as ephedrine, caffeine, chitosan, and green tea have emerged as promising agents in fostering weight loss.

Conclusions

Nutraceuticals present a distinct alternative for all-natural remedies that extend beyond treatment, offering prevention against numerous serious diseases. These products are garnering increasing popularity owing to their affordability and easier accessibility compared to prescribed medicines. To fully grasp their role in health maintenance and disease management, extensive research over the long term is imperative. Further studies are warranted to analyze the influence of nutraceuticals on disease progression and pathogenesis, with a particular focus on understanding the interactions between bioactive compounds and other food constituents, and how this synergy impacts their medicinal efficacy. Additionally, consideration must be given to how the incorporation of varying types and quantities of bioactive compounds into food items might influence sensory attributes such as appearance, consistency, flavor, color, and texture, which, in turn, might affect the overall functionality of the product. Moreover, tackling the microbial instability of these functional ingredients when integrated into the food matrix stands as a significant challenge that needs addressing. To enhance the global market acceptance of these products, it is critical to expedite clinical trials and conduct them in a more precise and standardized manner.

Disclosure statement

No potential conflict of interest was reported by the authors.

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