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DIETARY SUPPLEMENTS AND FUNCTIONAL FOODS

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REVIEW BASED BOOK CHAPTER

NATURAL PRODUCTS AND EXTRACTS

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Abstract

As consumer demand for natural and sustainable health products continues to rise, natural products and extracts have garnered significant attention for their potential health benefits. This review offers a comprehensive overview of natural products, focusing on their sources, extraction methods, bioactive compounds, health benefits, applications, regulatory considerations, and future prospects. Natural products from a variety of sources provide a broad spectrum of bioactive compounds that support key health areas, including immune function, inflammation reduction, cardiovascular health, cognitive function, and gut health. Both traditional and modern extraction techniques are crucial for obtaining high-quality extracts, while challenges related to safety, efficacy, and sustainability remain paramount. Future developments include the integration of emerging technologies, exploration of novel sources, and the advancement of personalized nutrition strategies, which promise to enhance the efficacy, sustainability, and personalization of natural products. Harmonizing global regulatory frameworks will be essential for the development and marketing of high-quality natural products, ultimately promoting consumer health and well-being.

Keywords

Natural Products, Bioactive Compounds, Extraction Methods, Health Benefits, Personalized Nutrition

1. Introduction

1.1. Overview of Natural Products and Extracts

Natural products and extracts are substances derived from plants, animals, microorganisms, or marine sources that contain bioactive compounds with therapeutic or nutritional value [1]. These include whole herbs, essential oils, phytochemicals (e.g., polyphenols, alkaloids), and animal-derived compounds such as collagen or omega-3

fatty acids. Extracts, on the other hand, are concentrated forms of these natural products, obtained through methods such as solvent extraction, supercritical CO_2 extraction, or enzymatic processes [2].

Historically, natural products have been central to traditional medicine systems, including Ayurveda and Traditional Chinese Medicine, where plants like turmeric (*Curcuma longa*) and ginseng (*Panax ginseng*) were used for their anti-inflammatory and adaptogenic properties [3]. In modern applications, these substances have expanded into pharmaceuticals, nutraceuticals, and functional foods, driven by advancements in extraction technologies and scientific validation of their efficacy [4]. For instance, curcumin from turmeric is now standardized for use in anti-inflammatory supplements, while green tea polyphenols are incorporated into antioxidant-rich beverages [5].

Consumer demand for natural, plant-based, and sustainable ingredients has surged in recent years, driven by increased health awareness and environmental concerns [6]. A 2022 survey revealed that 68% of global consumers prioritize "clean-label" products, favoring ingredients like spirulina, chia seeds, and elderberry extracts [7]. Sustainability certifications, such as Fair Wild and USDA Organic, play a significant role in building consumer trust in ethically sourced natural products [8].

1.2. Role in Dietary Supplements and Functional Foods

Dietary supplements and functional foods, while distinct, play complementary roles. Supplements, such as capsules or powders, provide concentrated doses of bioactive compounds (e.g., vitamin D, omega-3s) to address nutrient deficiencies or meet specific health needs [9]. Functional foods, on the other hand, are everyday foods fortified with bioactive ingredients—such as probiotic yogurts or omega-3-enriched eggs—designed to promote health beyond basic nutrition [10].

Bioavailability is a crucial factor in both product categories. For example, combining turmeric with black pepper (Piper nigrum) enhances curcumin absorption by 2000% due to piperine's inhibition of metabolic enzymes [11]. Standardization is also key to ensuring consistent concentrations of bioactive compounds, as demonstrated by

Ginkgo biloba extracts standardized to 24% flavonoids and 6% terpenoids for cognitive support [12].

Safety remains a top priority, with regulatory agencies such as the FDA and EFSA requiring rigorous testing for contaminants like heavy metals and pesticide residues [13]. Emerging technologies, such as Nano emulsions, further optimize bioavailability. For instance, liposomal encapsulation of curcumin enhances its stability and cellular uptake, making it a preferred form in high-efficacy supplements [14]. Meanwhile, consumer trends favoring transparency and sustainability are reshaping product formulations, with brands increasingly emphasizing organic certifications and carbon-neutral sourcing [8].

Figure 1 provides a comprehensive overview of the journey of natural products and extracts from their sources to their applications in dietary supplements and functional foods, highlighting the key processes and considerations involved. In summary, this chapter has explored the role of natural products and extracts in the development of dietary supplements and functional foods. We have discussed the various sources of these ingredients, including plants, animals, microorganisms, and marine sources, highlighting the bioactive compounds they contain and their therapeutic or nutritional benefits. The chapter has also addressed key extraction techniques, the importance of bioavailability and standardization in product development, and the growing consumer demand for natural, sustainable ingredients. Additionally, the challenges of safety, regulation, and quality control have been emphasized, alongside emerging technologies aimed at enhancing the efficacy of these natural ingredients. Ultimately, the increasing integration of natural products and extracts into modern health products reflects their continued significance and the evolving landscape of dietary supplements and functional foods.

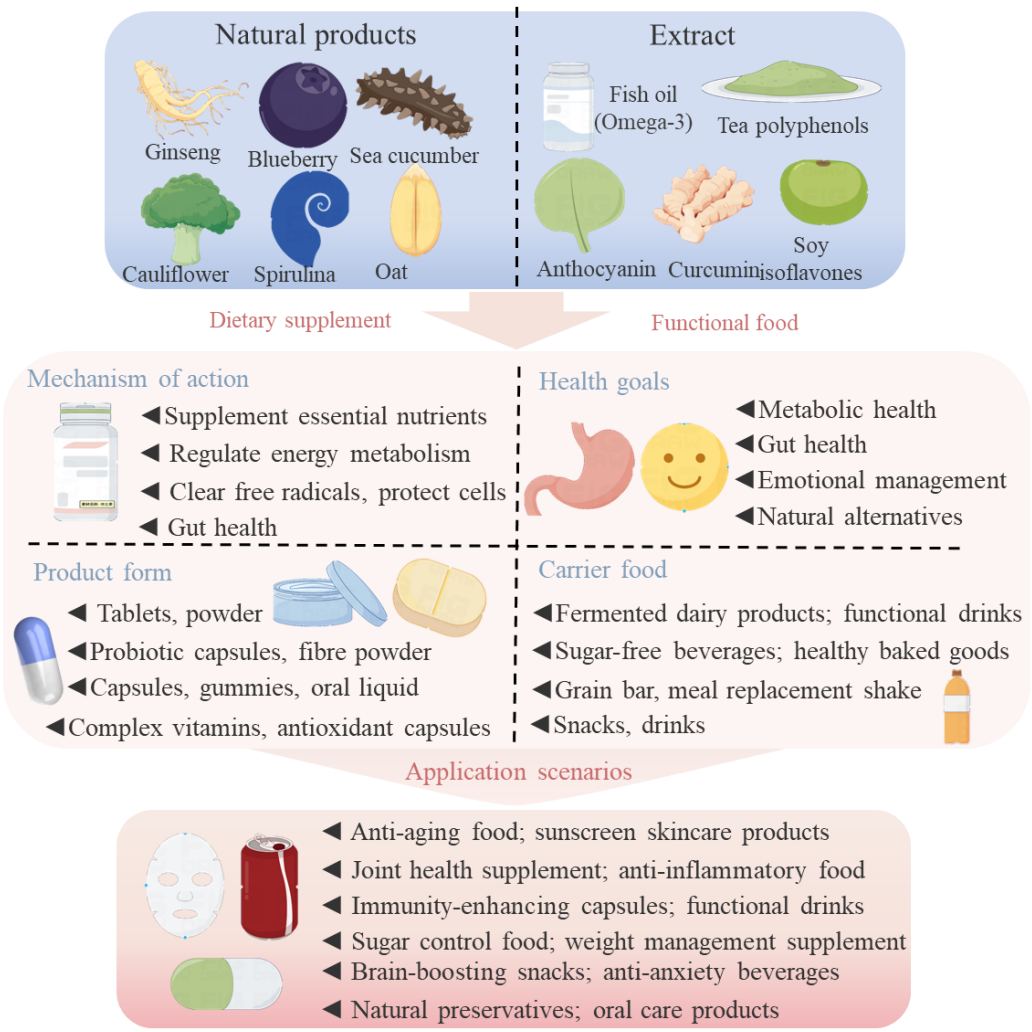

Figure 1. Overview of natural products and extracts in dietary supplements and functional foods

2. Sources of Natural Products and Extracts

Natural products and extracts are derived from a broad range of sources, each offering unique bioactive compounds with diverse health benefits. Understanding these sources and their potential is crucial for the development of effective dietary supplements and functional foods. The diverse origins of these products underscore the importance of sustainable and ethical sourcing practices to ensure their continued availability and responsible use. These sources can be broadly categorized into plant-based, animal-derived, and microbial/marine origins.

Figure 2 provides an overview of these sources, illustrating the rich bioactive profiles contributed by each category.

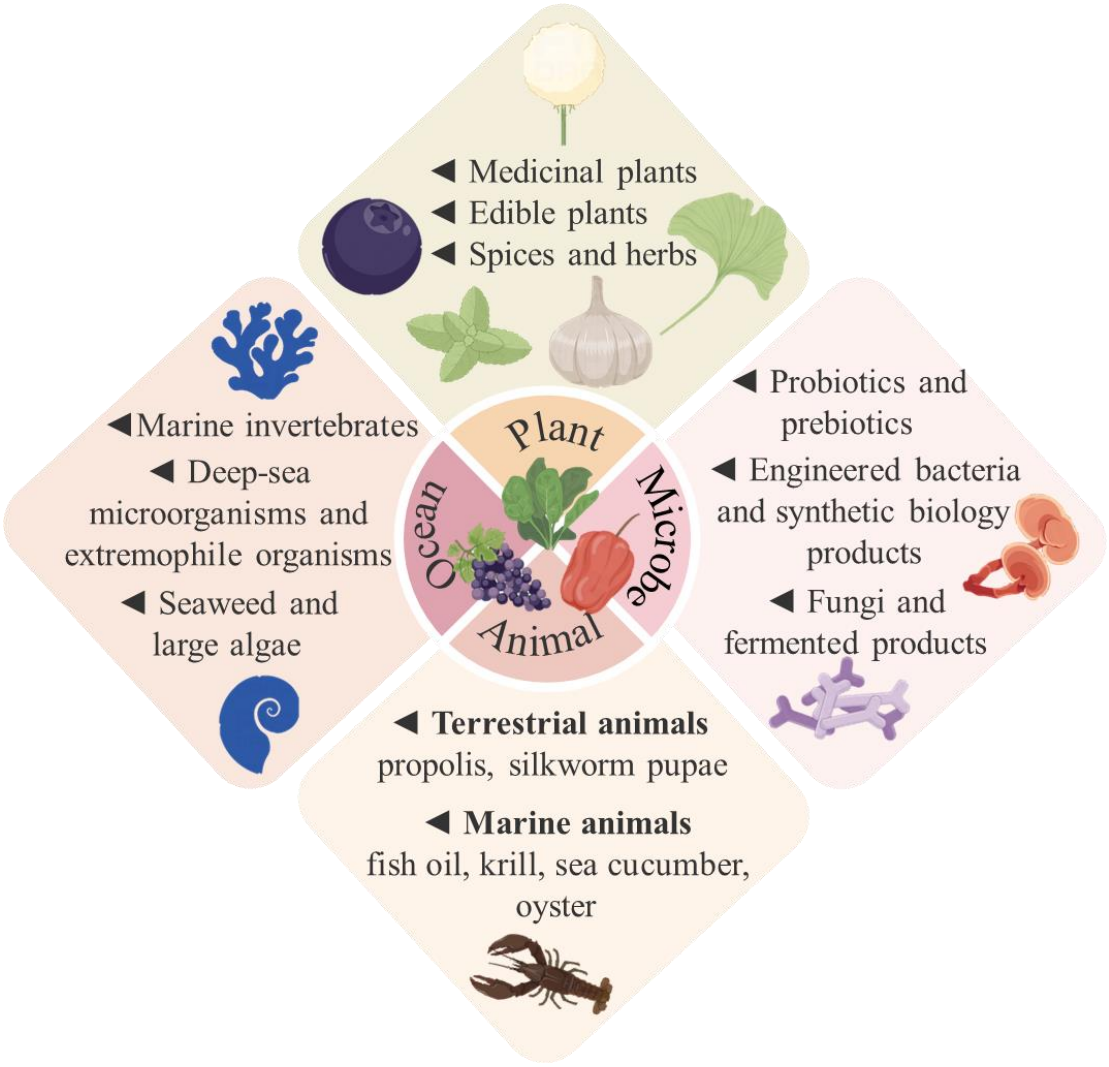

Figure 2. Sources of natural products and extracts

2.1. Plant-Based Natural Products

Plant-based natural products are among the most extensively studied and utilized sources of bioactive compounds. They encompass a wide variety of botanicals, including herbs, spices, fruits, vegetables, and other plant derivatives, each rich in specific phytochemicals. For example, turmeric (*Curcuma longa*), derived from the root

of the plant, contains curcumin, a compound known for its anti-inflammatory and antioxidant properties [1]. Curcumin has been extensively researched for its potential health benefits, including its role in supporting joint health, cognitive function, and overall well-being [15]. Similarly, green tea extracts, particularly those rich in epigallocatechin gallate (EGCG), are celebrated for their significant antioxidant, anti-inflammatory, and metabolic-regulating effects [5, 16]. Green tea polyphenols are commonly incorporated into functional beverages, weight management products, and supplements aimed at enhancing cardiovascular health and cognitive function.

Other notable plant-based products include *ginkgo biloba*, known for its cognitive-enhancing properties, and grape seed extract, which is rich in proanthocyanidins and provides potent antioxidant support [3, 17]. These extracts are often used in dietary supplements designed to support memory, concentration, and overall brain health. In addition to these, plant-based natural products contain a wide variety of phytochemicals, including polyphenols, alkaloids, terpenes, and flavonoids, each offering distinct health benefits. For example, quercetin and resveratrol, both polyphenols, are known for their antioxidant effects [18], while berberine, an alkaloid, has demonstrated significant pharmacological properties [4, 19].

2.2. Animal-Derived Natural Products

Animal-derived natural products also provide valuable bioactive compounds, often offering unique nutrients with specific health benefits. A prime example is fish oil, a rich source of omega-3 fatty acids—particularly eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA). These fatty acids are essential for cardiovascular health, brain function, and inflammation reduction [20]. Fish oil supplements are widely used to support heart health, cognitive function, and general well-being. Another important animal-derived product is collagen, a structural protein sourced from animal connective tissues that supports skin, bone, and joint health [21-22]. Collagen supplements are commonly used to promote skin elasticity, joint mobility, and bone strength.

Other notable animal-derived natural products include propolis and royal jelly. Propolis, a resinous substance collected by bees, has demonstrated antimicrobial, anti-inflammatory, and antioxidant properties, and is used in supplements and topical applications for immune support and wound healing [23-24]. Royal jelly, produced by honeybees, is rich in proteins, vitamins, and amino acids, offering immune-boosting and energy-enhancing benefits [25-26]. However, the use of animal-derived products raises important ethical and sustainability concerns, including the environmental impact of overfishing for fish oil and the treatment of animals in collagen production. Therefore, sustainable sourcing practices and ethical farming methods are essential to ensure the responsible use of these resources [27].

2.3. Microbial and Marine Sources

Microbial and marine sources represent a rich reservoir of bioactive compounds with unique health-promoting properties. Probiotics, such as *Lactobacillus*, are live microorganisms that confer health benefits when consumed in sufficient quantities. These probiotics are commonly found in supplements and fermented foods, where they support gut health, immune function, and overall well-being [28-29]. Spirulina, a type of blue-green algae, is another valuable microbial source, known for its high content of proteins, vitamins, and minerals. Spirulina's antioxidant, anti-inflammatory, and immune-boosting properties make it a popular ingredient in dietary supplements and functional foods [30-31].

Other beneficial microbial sources include chlorella, green algae rich in chlorophyll and other bioactive compounds that support detoxification, immune health, and general health maintenance [32-33]. Marine sources, such as marine algae, also offer unique health benefits. For instance, astaxanthin, derived from the algae *Haematococcus pluvialis*, is a potent antioxidant known for its ability to support eye health, skin health, and overall antioxidant defense [34-35]. These marine-derived compounds are increasingly used in dietary supplements to enhance various aspects of health and well-being.

3. Extraction and Preparation Methods

The extraction and preparation of natural products and extracts involve a range of techniques, from traditional methods to modern technologies, each with distinct advantages and challenges (Table 1). These methods are critical for obtaining bioactive compounds with high yield and purity while preserving their therapeutic properties. Traditional methods, such as decoction, maceration, and solvent-based extraction, are simple and cost-effective but may not be optimal for all compounds. In contrast, modern technologies, including supercritical CO_2 extraction, microwave-assisted extraction, and ultrasound-assisted extraction, offer higher yields and better preservation of bioactive compounds, although they typically require substantial investment in specialized equipment and expertise.

3.1. Traditional Extraction Techniques

Traditional extraction methods have been employed for centuries and continue to be relevant today due to their simplicity, cost-effectiveness, and ease of implementation. These techniques include decoction, maceration, hydro distillation, and solvent-based extraction using various solvents, such as water, ethanol, and hexane.

- Decoction involves boiling plant material in water to extract soluble compounds. While it is a straightforward and economical method, it may cause the degradation of heat-sensitive compounds [1].
- Maceration is a gentler process where plant material is soaked in a solvent (e.g., ethanol or water) for an extended period. Although this method is suitable for heat-sensitive compounds, it often results in lower yields and longer extraction times [36, 50].
- Hydro distillation utilizes steam to extract volatile compounds, such as essential oils, from plant materials. Although effective for heat-stable components, this method can degrade thermolabile compounds and is energy-intensive [6, 51].
- Solvent-based extraction involves soaking plant material in solvents like water, ethanol, or hexane. This versatile method can extract a wide range of bioactive compounds, but it may leave behind solvent residues and contribute to environmental pollution [13]. Despite these drawbacks, solvent-based extraction remains a widely adopted technique due to its low cost and broad applicability.

Table 1. Extraction and preparation methods of natural products and extracts

Category	Technology	Methods	Advantages	Disadvantages	References
Traditional techniques	Solvent Extraction	Organic solvents (ethanol, hexane) soaked or reflux extracted	Low cost, simple operation, wide applicability	Solvent residue risk; environmental pollution; low selectivity	[13]
	Soxhlet Extraction	Continuous reflux extraction: the sample is placed in a porous sleeve, and the solvent is repeatedly distilled	Highly efficient extraction of lipophilic or thermostable components (such as oil, wax); recyclable use	Time-consuming; high temperature leads to the degradation of heat-sensitive components; organic solvents present flammability and residue risks	[2]
	Hydro distillation	Steam distillation to extract volatile components (essential oils)	Suitable for heat-stable components, no solvent residue	High energy consumption, easy to damage thermosensitive components	[6]
	Maceration	The raw material is soaked in a solvent (ethanol, water, or oil) and left to stand	Simple operation, suitable for heat-sensitive components, flexible solvent selection	Long extraction time; large solvent consumption; low yield	[36]
	Cold Pressing	Mechanical pressing method (for oilseeds or citrus fruits)	Retain natural flavors and thermosensitive components, no chemical pollution	Low yield, only suitable for specific raw materials	[37]
Novel extraction technologies	Supercritical Fluid Extraction (SFE)	Supercritical CO_2 (SC-CO_2) extraction at high pressure and adjustable temperature	No solvent residue; high selectivity; environmentally friendly	High equipment cost, need high pressure operation	[38]

	Ultrasound-Assisted Extraction (UAE)	Ultrasonic cavitation breaks the cell wall and accelerates solvent penetration	High efficiency, low energy consumption	Possible to produce free radicals, damage sensitive components	[39]
	Microwave-Assisted Extraction (MAE)	Microwave heating accelerates molecular motion, selectively heating target components	Fast (minute-level), low solvent consumption, high yield	Need polar solvent, high equipment cost	[40]
	Pulsed Electric Field (PEF)	High-voltage pulse electric field destroys the cell membrane and releases intracellular components	Non-thermal technology, preservation of thermosensitive components, low energy consumption	The equipment is complex and has poor effects on non-conductive matrices	[41]
	Subcritical Water Extraction (SWE)	The water remains liquid at high temperatures (100–374°C) and high pressures (5–10 MPa), adjusting polarity to extract components	Green solvent; achieve adjustable polarity; efficiently extract thermostable components	High equipment cost; degradation of thermosensitive compounds; sensitive to operating parameters	[42]
	Enzyme-Assisted Extraction (EAE)	Cellulase/pectinase hydrolysis of cell wall polysaccharides	Improve yield, mild conditions, environmentally friendly	Enzyme cost is high, pH and temperature need to be precisely controlled	[43]
	Nanomulsion Technology	Encapsulate the active ingredients in nano-sized droplets of emulsion (liposomes, Nano capsules)	Improve bioavailability and enhance stability	The process is complicated and it is difficult to produce it on a large scale	[14]
Combination method	Ultrasound-Microwave Synergy	Ultrasonic pretreatment followed by microwave-assisted extraction	Combined with technical advantages, efficiency improvement	Optimize collaborative parameters; high equipment investment	[44]
	Enzymatic-SFE Hybrid	Supercritical fluid extraction after enzymatic pretreatment	Improve the purity of target components and reduce impurities	Multi-step operation, cost superposition	[45]

PEF-UAE Integration	Pulsed electric field pretreatment followed by ultrasound-assisted extraction (olive leaf polyphenol extraction)	Synchronous enhanced cell disruption, yield increased by 40%	Customized equipment is required, with high technical barriers	[46]
Enzyme-Microwave Synergy	Microwave-assisted extraction after enzymatic pretreatment (pectinase treatment of orange peel microwave extraction of flavonoids)	Improve efficiency and increase the purity of target components	Precise control of enzymatic conditions, high equipment complexity	[47]
PEF-SFE Integration	Supercritical fluid extraction after pulse electric field (PEF) pretreatment	PEF destroys the cell membrane, enhancing efficiency; heat-sensitive antioxidant components are retained	High equipment cost; need to optimize the electric field strength	[48]
EAE-Nanomulsion	Embedding in Nano emulsion after enzyme-assisted extraction	Improve efficiency, enhance stability, and increase bioavailability	Cost accumulation; difficulty in large-scale production	[49]

3.2. Modern Technologies

Modern extraction technologies have been developed to address the limitations of traditional methods, offering advantages such as higher yields, reduced solvent usage, and better preservation of thermolabile compounds. These technologies include supercritical CO_2 extraction, microwave-assisted extraction, ultrasound-assisted extraction, pulsed electric field (PEF) extraction, subcritical water extraction (SWE), enzyme-assisted extraction (EAE), and nanomulsion technology.

- Supercritical CO_2 extraction utilizes carbon dioxide in a supercritical state (high pressure and temperature) to extract a wide range of compounds. This environmentally friendly method leaves no solvent residue, is highly selective, and is ideal for extracting high-value compounds like essential oils and cannabinoids [38, 52]. However, the high cost of equipment and the need for specialized operators present significant drawbacks.
- Microwave-assisted extraction employs microwave energy to rapidly heat plant material, accelerating the extraction process. This method is fast, efficient, and reduces solvent consumption, making it suitable for large-scale applications [40]. However, it requires the use of polar solvents and can be expensive due to the specialized equipment involved.
- Ultrasound-assisted extraction uses ultrasonic waves to disrupt plant cells, enhancing the release of bioactive compounds. This method is highly efficient, requires less energy, and helps preserve thermolabile compounds [39, 53]. However, the generation of free radicals during the process may damage sensitive components.
- Pulsed electric field (PEF) extraction applies high-voltage pulses to disrupt cell membranes, facilitating the release of intracellular components. This non-thermal technology preserves thermosensitive compounds and has low energy consumption [41]. Nonetheless, the complexity of the equipment and its limited effectiveness on non-conductive matrices can be limiting factors.
- Subcritical water extraction (SWE) uses water at high temperatures (100–374°C) and pressures (5–10 MPa) to extract bioactive compounds. This green solvent

method allows for adjustable polarity and is efficient for extracting thermostable components [42]. However, the high equipment costs and potential degradation of thermosensitive compounds are notable limitations.

- Enzyme-assisted extraction (EAE) involves the use of enzymes like cellulase or pectinase to break down cell wall polysaccharides, improving yield and enabling operation under mild conditions [43]. However, the high cost of enzymes and the need for precise control of pH and temperature present challenges.
- Nanomulsion technology encapsulates active ingredients in nano-sized droplets, improving their bioavailability and stability [14]. Despite its promising applications, the process is complex and difficult to scale for large-scale production.

3.3. Standardization and Quality Control

Standardization and quality control are essential for ensuring the consistency and efficacy of natural products and extracts. Quantification of bioactive compounds using techniques such as high-performance liquid chromatography (HPLC) and gas chromatography-mass spectrometry (GC-MS) is crucial for verifying the potency and purity of extracts [54].

The quantification of bioactive compounds ensures that each batch of extract contains a consistent concentration of active ingredients. Techniques like HPLC and GC-MS provide precise measurements, allowing manufacturers to standardize their products [27]. However, achieving batch-to-batch consistency remains a significant challenge due to variations in raw materials, extraction conditions, and processing methods.

Several factors contribute to batch-to-batch variability, including the inherent heterogeneity of natural sources. Variations in plant species, growing conditions, and harvesting times can influence the concentration of bioactive compounds in raw materials [54]. Additionally, fluctuations in extraction parameters—such as temperature, pressure, and solvent composition—can impact the yield and purity of the extracts. To address these challenges, manufacturers must implement rigorous quality control

measures, including standardized extraction protocols, raw material testing, and finished product analysis.

4. Key Bioactive Compounds and Health Benefits

Natural products and extracts are rich sources of bioactive compounds that offer a wide range of health benefits. Understanding the specific benefits of these bioactive compounds is essential for the development of effective dietary supplements and functional foods [55]. Figure 3 illustrates the diverse bioactive compounds found in natural products and extracts and their corresponding health benefits, highlighting their roles in immune support, anti-inflammatory and antioxidant effects, cardiovascular health, cognitive function, and gut health.

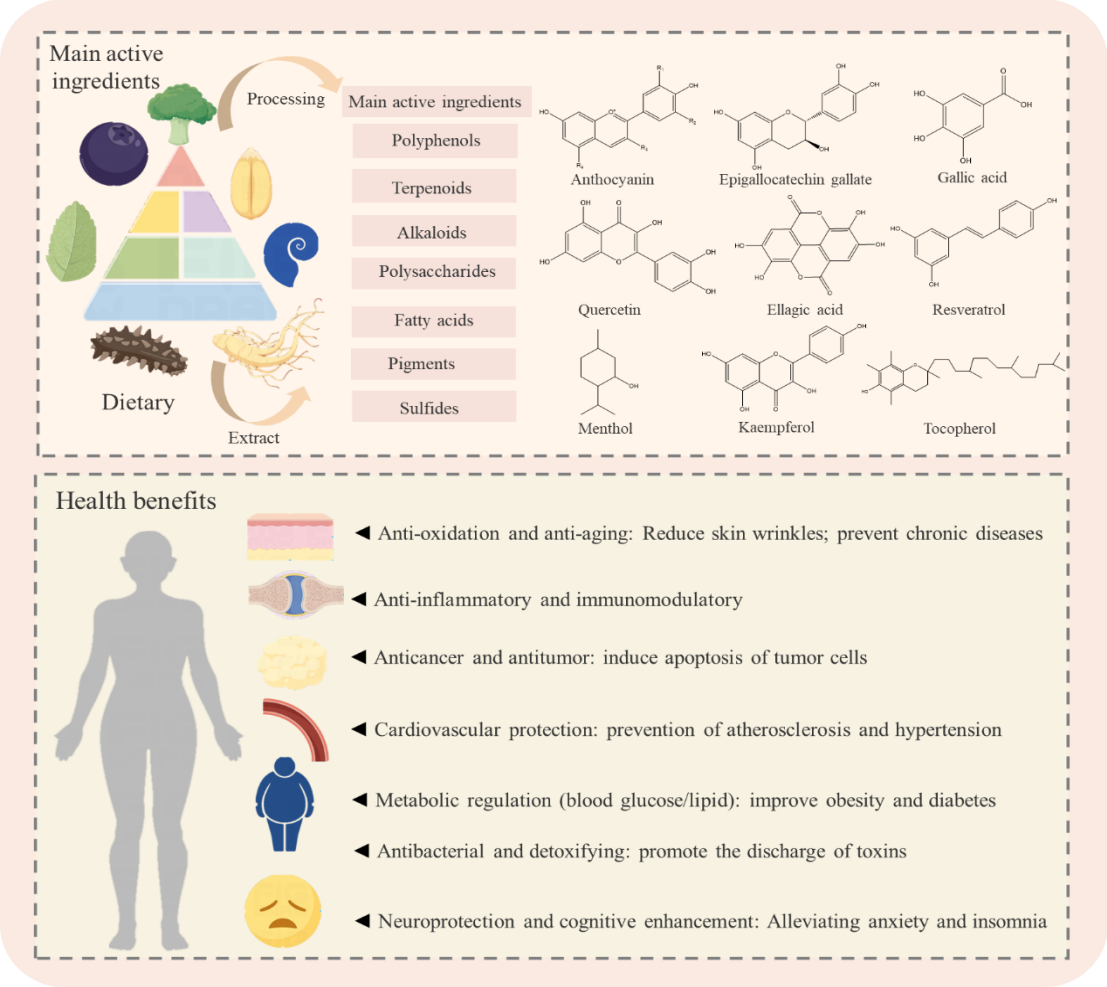

Figure 3. Key bioactive compounds and health benefits of natural products and extracts

4.1. Immune Support

Immune support is crucial for maintaining overall health and preventing infections. Several natural products and extracts are known for their immune-boosting properties. Echinacea is a well-known herb used to support the immune system [56]. It contains a variety of bioactive compounds, including alkyl amides, caffeic acid derivatives, and polysaccharides, which have been shown to enhance immune function and reduce the duration and severity of colds and other upper respiratory infections [11]. Elderberry is another popular natural product for immune support. It is rich in anthocyanins and other flavonoids, which have antiviral and anti-inflammatory properties [57]. Elderberry extracts have been shown to inhibit the replication of several viruses, including influenza [7]. β-glucans from mushrooms are also widely used for their immune-modulating effects. These polysaccharides can enhance the activity of immune cells, such as macrophages and natural killer cells, and support the body's defense mechanisms against pathogens [26]. They are commonly found in mushrooms like Reishi (*Ganoderma lucidum*) and Shiitake (*Lentinula edodes*).

4.2. Anti-Inflammatory and Antioxidant Agents

Anti-inflammatory and antioxidant agents play a critical role in reducing oxidative stress and inflammation, which are linked to various chronic diseases [58]. Curcumin, the active compound in turmeric, is a potent anti-inflammatory and antioxidant agent [59]. It has been extensively studied for its ability to inhibit inflammatory pathways and reduce oxidative stress. Curcumin is used in dietary supplements and functional foods to support joint health, cognitive function, and overall well-being [4]. Resveratrol, found in grapes and other berries, is another powerful antioxidant and anti-inflammatory compound [60]. It has been shown to protect against cardiovascular disease, neurodegenerative disorders, and certain types of cancer [39]. Quercetin, a flavonoid found in many fruits and vegetables, also exhibits strong antioxidant and anti-inflammatory properties [61]. It is used to support cardiovascular health, reduce inflammation, and enhance immune function [5].

4.3. Cardiovascular Health

Maintaining cardiovascular health is essential for overall well-being. Several natural products and extracts are known to support heart health [62]. Garlic extract (allicin) has been shown to have significant cardiovascular benefits. Allicin, the active compound in garlic, helps lower blood pressure, reduce cholesterol levels, and prevent blood clotting [63]. Hawthorn is another herb used to support cardiovascular health. It contains flavonoids and other bioactive compounds that help improve blood flow, reduce inflammation, and strengthen the heart muscle [64]. Omega-3 fatty acids, found in fish oil and some plant sources, are essential for cardiovascular health [65]. They help reduce inflammation, lower triglyceride levels, and improve overall heart function [20].

4.4. Cognitive Function

Cognitive function is vital for maintaining mental clarity and overall brain health [66]. Several natural products and extracts are known to support cognitive function and protect against neurodegenerative diseases [67]. *Ginkgo biloba* is a well-known herb used to support cognitive function. It contains flavonoids and terpenoids that improve blood flow to the brain, enhance memory, and protect against oxidative stress [3]. *Bacopa monnieri* is another herb used to support cognitive function. It contains bacosides, which have been shown to improve memory, reduce anxiety, and protect against neurodegenerative disorders [12]. Lion's mane mushroom is rich in hericenones and erinacines, which promote nerve growth factor (NGF) production and support cognitive health. It is used in nootropic supplements to enhance memory, focus, and overall brain function [68].

4.5. Gut Health

Gut health is essential for overall well-being and immune function [69-70]. Several natural products and extracts are known to support gut health and promote a healthy microbiome [71]. Prebiotics (inulin) are non-digestible fibers that promote the growth of beneficial gut bacteria. They help improve gut health, enhance nutrient absorption, and support overall digestive function [27]. Probiotics are live microorganisms that confer health benefits when consumed in adequate amounts [72]. They help restore the balance of gut bacteria, improve digestion, and boost immune function [9]. Ginger

extract has anti-inflammatory and anti-nausea properties [73]. It helps reduce inflammation in the gut, alleviate digestive discomfort, and support overall gut health [43].

5. Applications in Dietary Supplements and Functional Foods

Natural products and extracts have found extensive applications in both dietary supplements and functional foods, driven by their health benefits and the increasing consumer demand for natural and sustainable ingredients [74]. Understanding consumer trends and preferences is crucial for developing products that align with market demands and promote overall health [75]. Table 2 illustrates the diverse roles of natural products and extracts in supplement formulations, functional food innovations, and emerging consumer trends.

5.1. Supplement Formulations

Dietary supplements are concentrated sources of nutrients or other bioactive substances that provide nutritional or physiological effects, intended to supplement the diet. These supplements are available in various forms, including capsules, tablets, tinctures, and powders. The choice of formulation depends on the specific bioactive compounds and their intended effects [84].

- **Capsules and Tablets:** These are the most common forms of dietary supplements. Capsules offer a convenient and easy-to-swallow option, while tablets can be designed for sustained or controlled-release formulations [85]. For instance, turmeric supplements are often encapsulated to deliver a high concentration of curcumin, known for its anti-inflammatory properties [4]. Omega-3 fatty acids are frequently found in capsule form, providing support for cardiovascular health [20, 86].
- **Tinctures and Powders:** Tinctures are liquid extracts typically taken in small doses, making them popular for herbs and botanicals like echinacea and elderberry, known for their immune-boosting properties [11, 87]. Powders are versatile and can be added to smoothies, juices, or other beverages. For example, matcha powder, rich in epigallocatechin gallate (EGCG), is often used in energy bars and other functional foods for its antioxidant properties [5].

Table 2. Applications and roles of natural products and extracts in dietary supplements and functional foods

Dietary Sources	Extract	Bioactive compounds	Benefits roles	Applications	References
Turmeric	Nano-curcumin (liposomal)	Curcuminoids (Curcumin)	Anti-inflammatory, gut barrier protection	Enhanced bioavailability supplements	[11]
Green tea	Polyphenol extract	Epigallocatechin gallate (EGCG)	Antioxidant, metabolic regulation, cardiovascular support	Functional beverages, weight management products	[5]
Blueberries	Anthocyanin extract	Anthocyanins, phenolic acids	Cognitive support, antioxidant, anti-diabetic	Snack bars, powdered supplements	[76]
Soybean	Isoflavone extract	Genistein, Daidzein	Phytoestrogenic effects, bone health support	Menopausal supplements, plant-based milk	[77]
Lion's Mane Mushroom	Beta-glucan extract	Hericenones, Erinacines	Neurogenesis, cognitive enhancement	Nootropic supplements, brain health formulas	[12]
Ashwagandha	Withanolide-rich extract	Withanolides (Withaferin A)	Stress reduction, muscle recovery	Adaptogenic powders, sleep support capsules	[26]
Maca Root	Lipidic extract	Macamides, Glucosinolates	Hormonal balance, energy modulation	Menopause support, athletic performance blends	[75]

Sea Buckthorn	Flavonoid-rich oil	Palmitoleic acid, Quercetin	Skin repair, anti-aging	Topical serums, omega-7 supplements	[8]
Probiotics	Multi-strain formulations	Lactobacillus, Bifidobacterium	Gut-brain axis modulation, immune regulation	Synbiotic gummies, digestive health products	[9]
Beetroot	Nitrate-rich juice	Dietary nitrate	Blood flow enhancement, exercise performance	Pre-workout drinks, cardiovascular formulas	[78]
Chlorella	Cracked cell wall extract	Chlorophyll, CGF (Chlorella Growth Factor)	Heavy metal detoxification, antioxidant	Detox teas, green superfood powders	[32]
Elderberry	Anthocyanin concentrate	Sambucuside, Polyphenols	Antiviral, immune activation	Syrups, immune-boosting lozenges	[7]
Hemp Seed	Cold-pressed oil	Cannabidiol (CBD), Linoleic acid	Anxiety relief, anti-inflammatory	CBD-infused oils, plant-based protein bars	[79]
Astaxanthin	Haematococcus pluvialis extract	Astaxanthin	Ocular health, UV photoprotection	Eye health supplements, skincare serums	[34]
Garlic	Allicin extract	Organosulfur compounds	Antimicrobial, cardiovascular protection	Immune-boosting tablets, cooking oils	[63]
Pomegranate	Punicalagin extract	Punicalagins, ellagic acid	Antioxidant, anti-cancer, gut microbiota modulation	Juices, skin health supplements	[80]

Cranberry	Proanthocyanidin extract	A-type proanthocyanidins	Urinary tract health, anti-adhesion of bacteria	UTI prevention capsules, functional drinks	[81]
Ginseng	Ginsenoside extract	Ginsenosides (Rb1, Rg1)	Adaptogenic, energy enhancement, cognitive boost	Energy drinks, stress relief formulas	[82]
Chia seeds	Omega-3-rich oil	a-Linolenic acid (ALA)	Cardiovascular health, anti-inflammatory	Vegan omega-3 supplements, energy bars	[83]

- **Synergistic Blends:** Many supplements combine multiple ingredients in synergistic blends to enhance absorption and efficacy. For example, turmeric is often paired with black pepper, which contains piperine, a compound that significantly increases the bioavailability of curcumin [4]. Similarly, combinations like ginkgo biloba and bacopa monnieri, both of which support cognitive function, are frequently found in nootropic supplements [3, 12].

5.2. Functional Food Innovations

Functional foods are foods that are enhanced with specific ingredients to provide additional health benefits beyond basic nutrition [88]. The innovation in this category has led to the creation of numerous products incorporating natural extracts to promote health and well-being [89].

- **Fortified Beverages:** Beverages are a popular medium for incorporating functional ingredients. Herbal teas, for example, may include ingredients like echinacea and elderberry for immune support [7, 11], while kombucha—a fermented tea—is well-known for its probiotic content and digestive health benefits [9]. Other examples include omega-3-enriched beverages, often formulated with fish oil, to promote cardiovascular health [20].
- **Snack Bars and Probiotic Yogurts:** Snack bars have seen innovation with the addition of adaptogens such as ashwagandha and maca root, which are valued for their stress-relieving and energy-boosting properties [26, 90]. Probiotic yogurts, which contain live cultures of beneficial bacteria, are designed to support gut health and immune function [9].
- **Case Studies:** Several case studies exemplify the innovative use of natural products in functional foods [91-92]. For instance, matcha is increasingly incorporated into energy bars due to its high EGCG content, which provides antioxidant and metabolic benefits [93-94]. Another example is the development of omega-3-enriched eggs, providing a convenient source of essential fatty acids to support cardiovascular health [20, 95].

5.3. Consumer Trends

Consumer trends play a crucial role in shaping the development and market acceptance of dietary supplements and functional foods. Key trends include the demand for clean-label products, organic certifications, and transparency in sourcing [96].

- **Clean-Label Products:** As consumers become more health-conscious, there is an increasing preference for products with simple, recognizable ingredients and minimal processing [97]. Clean-label products are free from artificial additives, preservatives, and genetically modified organisms (GMOs). This demand has spurred the development of dietary supplements and functional foods that emphasize natural and wholesome ingredients [27].
- **Organic Certifications:** Organic certifications are another significant trend, reflecting consumers' concerns about the environmental impact of food production and the potential health benefits of organic ingredients [98]. Organic dietary supplements and functional foods are produced without the use of synthetic pesticides, fertilizers, or GMOs, offering a more sustainable and healthier product [99].
- **Transparency in Sourcing:** Increasingly, consumers are demanding transparency regarding the sourcing of ingredients. This includes information on where and how ingredients are grown, harvested, and processed. Ethical and sustainable sourcing practices are gaining importance, with certifications such as Fair Wild and USDA Organic becoming more prominent in the market [27].

6. Challenges and Regulatory Considerations

The incorporation of natural products and extracts into dietary supplements and functional foods presents a range of challenges and regulatory considerations. To ensure both safety and efficacy, issues such as adulteration, contamination, herb-drug interactions, and evidence gaps must be addressed. Furthermore, navigating the complexities of global regulatory frameworks and sustainability concerns is crucial for the responsible development and use of these products.

6.1. Safety and Efficacy Concerns

6.1.1. Risk of Adulteration, Contamination, and Herb-drug Interactions

Adulteration and contamination represent significant risks to the safety and efficacy of natural products. Adulteration can occur when a product is intentionally or unintentionally mixed with inferior or ineffective ingredients, which compromises its quality and potency. Contamination, often arising from inadequate manufacturing practices, can result in the presence of harmful substances such as heavy metals, pesticides, or microbial toxins. Additionally, herb-drug interactions pose a critical concern, as certain natural products may interfere with the efficacy of prescription medications or cause adverse effects, thereby potentially complicating medical treatments.

6.1.2. Evidence Gaps: Need for More Clinical Trials and Mechanistic Studies

While numerous natural products have a long history of traditional use and preliminary scientific backing for their health benefits, substantial gaps remain in the scientific evidence supporting their safety and efficacy. More clinical trials and mechanistic studies are essential to fully understand the bioavailability, pharmacokinetics, and potential side effects of bioactive compounds. Such studies are vital to establish clear guidelines for the appropriate use of these products in dietary supplements and functional foods [7].

6.2. Global Regulatory Frameworks

6.2.1. Comparison of Regulations

The regulation of dietary supplements and functional foods varies significantly across countries and regions, with each jurisdiction having its own set of guidelines and regulatory bodies. In the United States, the Dietary Supplement Health and Education Act (DSHEA) governs dietary supplements, ensuring that products are both safe and accurately labeled [100]. The European Food Safety Authority (EFSA), in the European Union, is responsible for evaluating the safety and efficacy of health claims made on food products [101]. Similarly, in Australia, the Therapeutic Goods Administration (TGA) oversees the regulation of dietary supplements and functional foods to ensure they meet safety and efficacy standards [102].

6.2.2. Labeling Requirements and Health Claim Approvals

One of the critical elements of regulatory frameworks is ensuring the accuracy of labeling and the proper approval of health claims. Manufacturers must provide clear and truthful information regarding the ingredients, dosage, and potential benefits of their products. Health claims made on supplements and functional foods must be substantiated by significant scientific evidence and approved by the relevant regulatory authorities. For instance, the FDA in the U.S. requires that health claims on dietary supplements be backed by substantial scientific agreement [100]. Likewise, EFSA evaluates the scientific validity of health claims before they can be used on food products in the European market [101].

6.3. Sustainability Issues

6.3.1. Overharvesting of Wild Plants

The overharvesting of wild plants is a growing concern, as it can lead to the depletion of natural resources and disrupt local ecosystems. Species such as wild ginseng and frankincense are particularly vulnerable to overharvesting, with the risk of diminishing biodiversity and negatively impacting the environment. Sustainable sourcing practices are essential to protect these valuable natural resources and ensure their availability for future generations [103].

6.3.2. Sustainable Sourcing Certifications

Sustainable sourcing is becoming increasingly important, with certifications like FairWild and USDA Organic playing a critical role in ensuring that natural products are harvested in an environmentally responsible and socially equitable manner. These certifications guarantee that natural products are sourced from well-managed ecosystems, promoting biodiversity conservation and fair labor practices [104, 105]. Manufacturers and consumers alike are increasingly recognizing the value of such certifications in fostering sustainable practices within the natural products industry [106].

7. Future Perspectives

The field of natural products and extracts is rapidly advancing, driven by breakthroughs in technology, novel discovery avenues, and the increasing interest in personalized

nutrition. These innovations present immense potential to enhance the efficacy, sustainability, and personalization of dietary supplements and functional foods. Future developments, such as CRISPR-edited plants, AI-driven extraction methods, and personalized nutrition approaches, promise to redefine the landscape of natural products. These emerging technologies and explorations into novel sources will further optimize the health benefits of natural products in supplements and functional foods.

7.1. Emerging Technologies

7.1.1. CRISPR-Edited Plants for Enhanced Bioactive Compound Production

CRISPR-Cas9 gene-editing technology offers unprecedented precision in modifying plant genomes to enhance the production of bioactive compounds. By altering specific genes in plants, researchers can significantly increase the yield of compounds such as flavonoids, alkaloids, and terpenes. For example, CRISPR-edited turmeric plants could be engineered to produce higher levels of curcumin, thereby amplifying its well-known anti-inflammatory and antioxidant properties. This advancement not only bolsters the efficacy of natural products but also aligns with sustainable agricultural practices by reducing the need for large-scale cultivation and minimizing environmental impact.

7.1.2. AI-Driven Extraction Optimization

Artificial intelligence (AI) and machine learning are transforming the extraction process by optimizing parameters like temperature, pressure, and solvent use to maximize the yield of bioactive compounds. AI models can predict the ideal conditions for extraction, reducing resource consumption and improving the purity and stability of compounds. For instance, AI can enhance supercritical CO_2 extraction, ensuring maximum yield while minimizing the use of solvents and preserving heat-sensitive bioactive compounds. These advances promise to make the production of natural extracts more efficient and environmentally sustainable.

7.2. Novel Sources

7.2.1. Understudied Botanicals

While many plants have been extensively studied for their health benefits, several botanicals remain underexplored. For example, *Withania somnifera* (*ashwagandha*) has been widely researched for its adaptogenic properties, but other species in the same family may also harbor beneficial bioactive compounds [26]. A deeper exploration into these lesser-studied botanicals could uncover novel compounds, thus broadening the range of natural ingredients available for dietary supplements and functional foods.

7.2.2. Marine Organisms

The oceans are a treasure trove of untapped bioactive compounds. Marine organisms, including algae, seaweeds, and marine microorganisms, possess unique compounds with proven health benefits [107]. For instance, *Haematococcus pluvialis*, a microalga, is known for producing astaxanthin, a potent antioxidant with a wide array of health benefits, particularly in the skin and cardiovascular systems [34]. Sponges, tunicates, and other marine organisms also produce unique compounds with therapeutic potential that can be explored for their use in functional foods and dietary supplements.

7.2.3. Extremophiles

Extremophiles are organisms that thrive in extreme environments such as volcanic hot springs, deep-sea hydrothermal vents, and polar ice caps. These organisms have developed specialized bioactive compounds to survive harsh conditions, and some of these compounds may possess unique health benefits. For example, extremophiles from the Antarctic produce peptides with potential antimicrobial and antioxidant properties [32]. Research into extremophiles could unlock novel bioactive compounds with applications in health, nutrition, and disease prevention [108].

7.3. Personalized Nutrition

Personalized nutrition aims to tailor dietary interventions, including dietary supplements, to the individual's unique genetic profile, microbiome composition, and overall health

status. This approach recognizes that individuals vary in their nutritional needs and responses to bioactive compounds [109, 110].

7.3.1. Tailoring Natural Products to Genetic Profiles

Genetic variations can significantly influence how individuals metabolize and respond to bioactive compounds. For instance, some people may possess genetic polymorphisms that affect the bioavailability and efficacy of flavonoids or polyphenols [111, 112]. Understanding genetic profiles can lead to more personalized and effective dietary supplement recommendations, optimizing health benefits while minimizing potential adverse effects. This precision medicine approach is poised to revolutionize how natural products are used in health and wellness [113, 114].

7.3.2. Microbiome Diversity

The human microbiome plays an integral role in overall health and can influence the effectiveness of dietary interventions. Microbial diversity impacts how individuals respond to dietary supplements, probiotics, and prebiotics. For example, some strains of probiotics may enhance gut health by promoting the growth of beneficial bacteria, while others may be more beneficial for specific individuals based on their microbiome diversity [115, 116]. Understanding the unique microbiome profiles of individuals could lead to more tailored and effective interventions, enhancing gut health and overall wellness.

8. Conclusion

This review has provided a comprehensive overview of natural products and extracts, highlighting their diverse sources, extraction methods, bioactive compounds, health benefits, applications, regulatory considerations, and future perspectives. Natural products from plant, animal, microbial, and marine sources offer a wide range of bioactive compounds that support immune function, reduce inflammation, enhance cardiovascular health, improve cognitive function, and promote gut health. Traditional and modern extraction techniques are crucial for obtaining high-quality extracts, while ensuring safety, efficacy, and sustainability remains a key challenge. Regulatory frameworks such as DSHEA, EFSA, and TGA play a crucial role in overseeing the quality

and labeling of these products. Future perspectives include emerging technologies like CRISPR and AI, exploration of novel sources, and personalized nutrition approaches, all of which hold significant promise for enhancing the efficacy, sustainability, and personalization of natural products.

Future research and application in the field of natural products and extracts should focus on enhancing extraction efficiency through modern technologies like AI-driven optimization and CRISPR-edited plants, exploring novel sources such as understudied botanicals and marine organisms, and advancing personalized nutrition strategies tailored to individual genetic profiles and microbiome diversity. Conducting more clinical trials and mechanistic studies will help fill evidence gaps and establish the safety and efficacy of these products. Promoting sustainable sourcing and cultivation practices is essential to protect biodiversity and ensure the long-term availability of natural resources. Additionally, harmonizing global regulatory frameworks can facilitate the development and marketing of high-quality natural products and extracts, ultimately benefiting consumer health and well-being.

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Conflicts of interest

The authors do not have conflict of interest.

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