

Advances in Natural Products: Extraction, Bioactivity, Biotransformation, and Applications

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1. Introduction

Natural products have served as a cornerstone of human health and well-being for centuries, providing a rich source of bioactive compounds with diverse chemical structures and biological functions. Derived from higher plants, algae, microorganisms, and other biological resources, these compounds continue to attract considerable scientific and industrial interest owing to their potential applications in pharmaceuticals, nutraceuticals, cosmetics, food systems, and agriculture [1,2]. In recent years, increasing consumer demand for natural and sustainable ingredients, coupled with advances in analytical and biotechnological techniques, has accelerated research into the discovery, characterization, and utilization of natural products [2,3].

The remarkable structural diversity of natural compounds underpins their broad spectrum of biological activities, including antioxidant, antimicrobial, anti-inflammatory, anticancer, neuroprotective, and cardioprotective effects [1,4]. As a result, natural products remain a vital reservoir for the development of novel therapeutic agents and functional ingredients [1,5]. At the same time, growing environmental concerns and the principles of the circular bioeconomy have encouraged the exploration of underutilized biological resources, agricultural by-products, and discarded biomass as sustainable sources of valuable bioactive molecules [6,7]. These developments have broadened the scope of natural product research beyond traditional medicinal plants, encompassing seaweeds, microalgae, fungi, bacteria, and other unconventional sources [2,6].

The efficient recovery of bioactive compounds from natural matrices remains a critical step in their valorization [8]. Conventional extraction techniques are increasingly being complemented or replaced by innovative and environmentally friendly approaches that enhance extraction efficiency while reducing solvent consumption, energy requirements, and environmental impact [8,9]. Technologies such as ultrasound-assisted extraction, microwave-assisted extraction, supercritical fluid extraction, pressurized liquid extraction, and the use of deep eutectic solvents have emerged as promising alternatives for obtaining high-quality extracts rich in targeted phytochemicals [9–11]. These advances are supported by sophisticated analytical platforms that enable comprehensive phytochemical profiling and facilitate the identification and quantification of biologically active constituents [3,12].

Beyond extraction and characterization, understanding the relationship between chemical composition and biological activity is essential for the development of effective natural-product-based formulations [4,12]. Advances in bioactivity screening, mechanistic studies, and omics-based approaches have provided deeper insights into the molecular pathways



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through which natural compounds exert their beneficial effects [12,13]. Such knowledge contributes to the rational selection of bioactive ingredients and supports the development of products with enhanced efficacy, safety, and functionality [13].

Another rapidly expanding area of research involves the biotransformation of natural products through enzymatic, microbial, or biotechnological processes [14,15]. Biotransformation offers unique opportunities to improve the bioavailability, stability, solubility, and biological activity of natural compounds while generating novel derivatives with enhanced properties [14]. The integration of biotechnology with natural product chemistry is opening new avenues for the sustainable production and functional optimization of bioactive molecules, thereby expanding their applicability across multiple industrial sectors [15].

The translation of natural product research into practical applications represents a key challenge and opportunity for both academia and industry [2,5]. Functional foods, dietary supplements, pharmaceutical preparations, cosmetic formulations, and agricultural biostimulants increasingly incorporate natural bioactive ingredients to meet consumer demands for safer, more sustainable, and health-promoting products [2,5,7]. Successful product development requires a multidisciplinary approach that integrates extraction technologies, chemical characterization, biological evaluation, formulation science, and regulatory considerations [3,8].

This Special Issue, entitled *Advances in Natural Products: Extraction, Bioactivity, Biotransformation, and Applications*, aims to provide a comprehensive overview of current developments and emerging trends in this dynamic field. The issue brings together original research articles and reviews that explore innovative extraction methodologies, phytochemical characterization, biological activity assessment, biotransformation strategies, and practical applications of natural products. Particular emphasis is placed on sustainable technologies, the valorization of underexploited biological resources, and the development of functional products with potential benefits for human health and industry.

The contributions collected in this Special Issue reflect the multidisciplinary nature of contemporary natural product research and highlight the significant progress achieved in recent years. Collectively, these studies demonstrate how advances in chemistry, biotechnology, pharmacology, food science, and materials science can contribute to unlocking the full potential of natural resources. Furthermore, they provide valuable insights into future research directions and emerging opportunities for innovation within the rapidly evolving landscape of natural-product-based technologies.

2. Overview of Published Papers in the Special Issue

2.1. Antioxidant Potential and Polyphenolic Composition of Acorn Flour from Different Mediterranean Oaks (*Quercus* spp.): A Comparative Study

The study investigated the antioxidant potential and polyphenolic composition of acorn flour obtained from six Mediterranean oak species. Different solvent systems and ultrasound-assisted extraction conditions were evaluated to determine their effectiveness in recovering polyphenols, tannins, and antioxidant compounds from acorn flour. The researchers compared the phenolic profiles among species and assessed how extraction parameters influenced the recovery of bioactive compounds.

The primary focus of the study was the valorization of acorns as a sustainable source of natural antioxidants and functional food ingredients. The results demonstrate significant differences among oak species regarding phenolic content and antioxidant activity. Furthermore, extraction conditions strongly affected the recovery of bioactive compounds, highlighting the importance of selecting appropriate extraction methods. The study suggests that acorn flour represents a promising raw material for the devel-

opment of functional foods and nutraceutical products due to its rich composition of health-promoting phytochemicals.

2.2. Sustainable Use of Fresh and Lyophilized Banana Peel Extracts as Biostimulants to Modulate Stress Tolerance and Bioactive Phytochemicals in Broccoli Microgreens

The study investigated the potential of fresh and lyophilized banana peel extracts as sustainable biostimulants for enhancing the growth, stress tolerance, and phytochemical composition of broccoli microgreens. The researchers evaluated how different forms of banana peel extracts influence plant development and the accumulation of bioactive compounds, with particular emphasis on improving the nutritional and functional quality of microgreens.

The primary aim of the study was to valorize banana peel waste by transforming it into a value-added agricultural biostimulant capable of promoting plant performance under stress conditions. The results show that banana peel extracts positively affected the growth and physiological status of broccoli microgreens while stimulating the production of beneficial phytochemicals, including antioxidant compounds. Both fresh and lyophilized extracts demonstrated biostimulant activity, although their effects varied depending on the treatment applied. The findings suggest that agro-industrial fruit waste can be successfully repurposed to improve crop quality and resilience while contributing to waste reduction and resource valorization.

2.3. The Effect of Essential Oils on Rumen Microbiota: Analysis of the Correlation Between Antibacterial Activity and Fermentation Modulation In Vitro

The study investigated the effects of various essential oils on rumen microbiota and their ability to modulate ruminal fermentation under in vitro conditions. The researchers examined whether the antibacterial activity of essential oils is directly associated with changes in microbial populations and fermentation parameters, aiming to better understand their potential as natural feed additives in ruminant nutrition.

The primary aim of the study was to evaluate the relationship between the antimicrobial properties of essential oils and their capacity to influence rumen fermentation processes. The results demonstrate that essential oils differ considerably in their effects on ruminal microorganisms and fermentation characteristics. While some oils exhibited strong antibacterial activity, their impact on fermentation was not always proportional, indicating that fermentation modulation depends on complex interactions within the rumen microbial ecosystem rather than solely on antimicrobial potency. The findings provide valuable insights into the mechanisms through which essential oils influence rumen microbiota and suggest that careful selection of specific oils is necessary to achieve desirable fermentation outcomes without adversely affecting beneficial microbial activity.

2.4. Response Surface Methodology-Based Optimization of Ultrasound-Assisted Extraction from Comarum palustre L.: Chemical Composition and Antioxidant Properties

The study focused on optimizing the ultrasound-assisted extraction of bioactive compounds from *Comarum palustre* L. (marsh cinquefoil), a plant recognized for its rich content of phenolic compounds and terpenoids. The authors applied response surface methodology (RSM) to evaluate the influence of extraction time and solvent composition on the recovery of antioxidant compounds. Various solvent systems, including ethanol, isopropanol, and acetone, were assessed to determine optimal extraction conditions.

The primary focus of the research was the development of an efficient extraction process capable of maximizing the yield of polyphenols and lipophilic bioactive compounds such as phytol and neophytadiene. The study demonstrated that optimized ultrasound-assisted extraction significantly enhanced antioxidant activity and total phenolic content.

These findings highlight the potential application of *C. palustre* extracts as natural antioxidant ingredients in cosmetic and nutraceutical products.

2.5. Phytochemical Composition, Biological Activity and Application of *Cymbopogon citratus* In Vitro Microshoot Cultures in Cosmetic Formulations

This research investigated the phytochemical profile and biological activity of in vitro microshoot cultures of *Cymbopogon citratus* (lemongrass). The authors characterized phenolic compounds using advanced analytical techniques and evaluated antioxidant activity, tyrosinase inhibition, and the suitability of the extracts for incorporation into cosmetic emulsions.

The main focus of the study was the utilization of plant tissue culture technology as a sustainable source of bioactive compounds for cosmetic applications. The results demonstrate that microshoot cultures produced valuable secondary metabolites with significant antioxidant properties and skin-related biological activities. Furthermore, the formulated cosmetic emulsions exhibited satisfactory stability and functionality, supporting the use of in vitro cultures as an alternative source of natural cosmetic ingredients.

2.6. In Vitro and In Silico Assessment of the Anticancer Potential of Ethyl Acetate/Water Extract from the Leaves of *Cotinus coggygia* Scop. in HepG2 Human Hepatocarcinoma Cells

The study examined the anticancer potential of an ethyl acetate/water extract obtained from the leaves of *Cotinus coggygia*. The extract was evaluated through both in vitro biological assays and in silico analyses to determine its activity against HepG2 human hepatocarcinoma cells. In addition to anticancer testing, antioxidant properties and phytochemical composition were also investigated.

The primary focus of the research was the identification of plant-derived compounds with potential therapeutic applications in cancer prevention and treatment. The results indicate that the extract exhibited promising cytotoxic and antioxidant activities, suggesting that *C. coggygia* could serve as a valuable source of bioactive compounds for future pharmaceutical and nutraceutical development. The combination of experimental and computational approaches provided a comprehensive evaluation of the extract's biological potential.

2.7. Formulation and Characterization of Hydrogel Based on Pectin, Collagen, Alginate, and *Myrtus communis* Essential Oil for Applications in Skin Regeneration

The paper described the development of a multifunctional hydrogel composed of pectin, collagen, alginate, and *Myrtus communis* essential oil for potential use in skin regeneration and wound-healing applications. The researchers evaluated the physicochemical, mechanical, antimicrobial, and biological properties of the hydrogel system.

The study primarily focused on creating biocompatible biomaterials capable of supporting tissue repair while simultaneously providing antimicrobial protection. The incorporation of essential oil contributed additional biological functionality, particularly antibacterial activity. The findings demonstrated that the developed hydrogel exhibited suitable structural stability and regenerative potential, indicating its promise as an advanced wound-dressing material for biomedical applications.

2.8. Antidiabetic and Anti-Inflammatory Potential of *Sorbus aucuparia* Fruits (Rowanberries) from Romania

The study investigated the antidiabetic and anti-inflammatory potential of *Sorbus aucuparia* fruits (rowanberries) collected in Romania. The researchers characterized the phytochemical composition of the fruit extracts and evaluated their biological activities through a series of in vitro assays related to glucose metabolism and inflammation.

The primary aim of the study was to assess whether rowanberries could serve as a valuable source of natural compounds with potential benefits for the prevention or management of diabetes and inflammatory disorders. The results reveal that the fruit extracts contained significant amounts of bioactive phytochemicals, particularly phenolic compounds, which contributed to their biological activity. The extracts demonstrated promising inhibitory effects on enzymes involved in carbohydrate digestion and exhibited notable anti-inflammatory properties. The findings support the further exploration of *S. aucuparia* fruits as functional food ingredients or natural products for the development of nutraceutical and pharmaceutical applications aimed at managing metabolic and inflammatory conditions.

2.9. The Effect of Selected Winter Wheat Cultivars and the Growing Season on the Antioxidant Activity, Polyphenol Profile, and Organoleptic Assessment of Beers Produced from Them

The study investigated how different winter wheat cultivars and growing season conditions influence the chemical and sensory properties of beer produced from these raw materials. The authors analyzed the antioxidant activity and polyphenol composition of beers brewed from selected wheat varieties, as well as their organoleptic (sensory) characteristics, including taste and aroma.

The main focus of the study was to determine the extent to which cultivar selection and environmental growing conditions affect the functional and quality attributes of beer. Special emphasis was placed on linking the phytochemical composition of wheat-derived beers with their antioxidant potential and sensory acceptability, highlighting the importance of raw material choice in brewing quality and bioactive properties.

2.10. *Sanicula europaea* L. Herb and Rhizomes with Root Extracts with Hemostatic, Wound Healing, Anti-Inflammatory and Antimicrobial Activity: Phytochemical and Pharmacological Research

The study investigated the phytochemical composition and biological activities of *Sanicula europaea* L. extracts obtained from the herb, rhizomes, and roots. The authors analyzed the presence of bioactive compounds and evaluated their pharmacological potential, particularly in relation to hemostatic, wound healing, anti-inflammatory, and antimicrobial effects.

The main focus of the study was to scientifically validate the traditional medicinal use of *Sanicula europaea* by linking its chemical profile with observed biological activities. Special attention was given to its potential application in developing natural therapeutic agents with antimicrobial and tissue-regenerative properties.

2.11. Enhancing Biscuit Nutritional Value Through Apple and Sour Cherry Pomace Fortification

The study investigated the use of apple and sour cherry pomace, valuable by-products of the fruit processing industry, as functional ingredients for improving the nutritional quality of biscuits. The researchers evaluated the effects of pomace incorporation on the chemical composition, antioxidant properties, and overall quality characteristics of the fortified biscuits.

The primary aim of the study was to valorize fruit processing waste by incorporating pomace into bakery products and assessing its potential to enhance nutritional and functional properties. The results show that the addition of apple and sour cherry pomace increased the content of dietary fiber, phenolic compounds, and antioxidant activity in the biscuits. Although pomace supplementation influenced certain physical and sensory characteristics, the fortified products maintained acceptable quality attributes. The findings support the development of value-added functional foods while promoting circular economy principles through the effective utilization of agro-industrial by-products.

2.12. Chestnut Burr as a Multifunctional Filler for PLA-Based Bio-Composites: Processing, Characterization, and Antioxidant Functionality

This research explored the utilization of chestnut burrs, an abundant agricultural residue, as a natural filler in polylactic acid (PLA)-based biocomposites. The study examined the processing behavior of the composites, their mechanical and thermal properties, and their suitability for additive manufacturing technologies such as 3D printing.

The main focus was on the sustainable valorization of agricultural waste and the development of environmentally friendly materials with added functionality. The incorporation of chestnut burr particles improved the antioxidant properties of the composites while maintaining acceptable processing characteristics, demonstrating their potential application in sustainable packaging and bio-based materials.

2.13. Incorporation of Black Currant Pomace into Emulsions for Reducing Saturated Fat in Shortbread Cookies

The study investigated the incorporation of black currant pomace, an agro-industrial by-product, into emulsions used for shortbread cookie formulation with the aim of reducing saturated fat content. The authors evaluated how the addition of pomace affects the physicochemical and functional properties of emulsions as well as the nutritional profile of the final baked products.

The main focus of the study was the valorization of fruit processing waste by using black currant pomace as a functional food ingredient. Special attention was given to improving the nutritional quality of cookies, particularly by reducing saturated fat while maintaining acceptable technological and sensory properties of the final product.

*2.14. Isolation of a Novel Bioactive Fraction from Saffron (*Crocus sativus* L.) Leaf Waste: Optimized Extraction and Evaluation of Its Promising Antiproliferative and Chemoprotective Effects as a Plant-Based Antitumor Agent*

The paper addressed the recovery of valuable bioactive compounds from saffron leaf waste, a largely underutilized by-product of saffron cultivation. An optimized extraction process was developed to obtain a phenolic-rich fraction, which was subsequently characterized using advanced analytical techniques.

The main focus of the study was the identification and evaluation of biologically active compounds with potential health-promoting properties. The extracted fraction exhibited significant antiproliferative and chemoprotective activities, suggesting its potential application as a natural source of plant-based antitumor agents. The study highlights the importance of transforming agricultural waste into high-value products for the pharmaceutical and nutraceutical sectors.

2.15. Natural Bioactive Compounds as Feed Additives: Strategies for Sustainable and Functional Livestock Production

The review explores the potential of natural bioactive compounds as feed additives for improving livestock health, productivity, and sustainability. The authors examine a wide range of naturally derived substances, including plant extracts, essential oils, polyphenols, flavonoids, organic acids, and other bioactive compounds, highlighting their roles in animal nutrition and production systems.

The primary aim of the review was to assess current strategies for incorporating natural bioactive compounds into livestock diets as alternatives to conventional feed additives. The authors discuss their effects on animal growth performance, immune function, gut health, feed efficiency, oxidative status, and disease resistance, as well as their potential to reduce the use of antibiotics and mitigate environmental impacts associated with animal production.

Overall, the review highlights the growing importance of natural bioactive compounds in the transition toward more sustainable and functional livestock production systems. The findings suggest that these compounds offer promising opportunities to enhance animal health and productivity while supporting consumer demand for safer, environmentally friendly, and sustainable agricultural practices. Further research is recommended to optimize their application, dosage, and long-term effectiveness under commercial farming conditions.

2.16. Chestnut and Grapevine By-Products: Bioactivity, Biotransformation, and Nutraceutical Applications

The review article summarized current knowledge regarding the valorization of chestnut and grapevine by-products generated by the agri-food industry. The authors discussed their phytochemical composition, including polyphenols, flavonoids, tannins, and other bioactive compounds, as well as their biological activities and potential health benefits.

The main focus of the review was the transformation of agricultural residues into value-added products through extraction, biotransformation, and formulation technologies. Particular attention was given to their applications in nutraceuticals, functional foods, and dietary supplements. The review emphasized the importance of sustainable resource utilization and circular economy principles, highlighting how agro-industrial by-products can be converted into high-value ingredients with antioxidant, anti-inflammatory, and health-promoting properties.

2.17. Innovative Microencapsulation Techniques of Bioactive Compounds: Impact on Physicochemical and Sensory Properties of Food Products and Industrial Applications

The review article summarized recent advances in microencapsulation technologies for protecting and delivering bioactive compounds in food systems. The authors discussed different encapsulation techniques such as spray drying, freeze drying, coacervation, and emerging nano-based approaches, as well as their effects on stability, release behavior, and sensory properties of food products.

The main focus of the review was the application of microencapsulation as a strategy to improve the stability and functionality of sensitive bioactive compounds, including polyphenols, essential oils, and other nutraceutical ingredients. Emphasis was placed on improving physicochemical properties, sensory acceptance, and industrial scalability in the development of functional and clean-label foods.

3. Conclusions

The contributions collected in this Special Issue provide a comprehensive overview of the current advances in the extraction, characterization, bioactivity assessment, biotransformation, and practical application of natural products. Together, the published studies demonstrate the remarkable potential of plant-derived compounds, agricultural by-products, microorganisms, and other biological resources as sustainable sources of high-value bioactive ingredients for food, pharmaceutical, cosmetic, agricultural, and biomedical applications.

Several papers highlighted the importance of innovative and environmentally friendly extraction technologies for maximizing the recovery of valuable phytochemicals while minimizing environmental impact. At the same time, numerous studies demonstrated the strong antioxidant, antimicrobial, anti-inflammatory, antidiabetic, anticancer, wound-healing, and biostimulant properties of natural products, confirming their relevance for the development of functional and health-promoting products. The application of advanced analytical methods, in vitro and in silico approaches, and formulation technologies fur-

ther expanded our understanding of the relationship between chemical composition and biological activity.

A particularly prominent theme throughout this Special Issue is the sustainable valorization of agricultural and food-processing by-products. Acorns, fruit pomaces, banana peels, chestnut burrs, saffron leaf waste, and other underutilized biomass streams were successfully transformed into valuable sources of bioactive compounds, functional ingredients, and innovative materials. These findings strongly support the principles of the circular bioeconomy and demonstrate how waste streams can be converted into economically and environmentally beneficial products.

The Special Issue also illustrates the growing importance of interdisciplinary approaches that integrate natural product chemistry, biotechnology, food science, pharmacology, materials science, and agricultural sciences. Such integration is essential for translating laboratory discoveries into practical applications that address contemporary challenges related to human health, sustainable food production, environmental protection, and resource efficiency.

Overall, the studies presented in this Special Issue confirm that natural products remain a rich and largely untapped reservoir of biologically active compounds with significant scientific and industrial potential. We hope that the findings reported herein will stimulate further research, encourage the development of innovative technologies and products, and promote the sustainable utilization of natural resources in accordance with the goals of a circular and bio-based economy. Future research should continue to focus on optimizing extraction and biotransformation processes, elucidating mechanisms of action, improving bioavailability and stability, and facilitating the successful commercialization of natural-product-based solutions.

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