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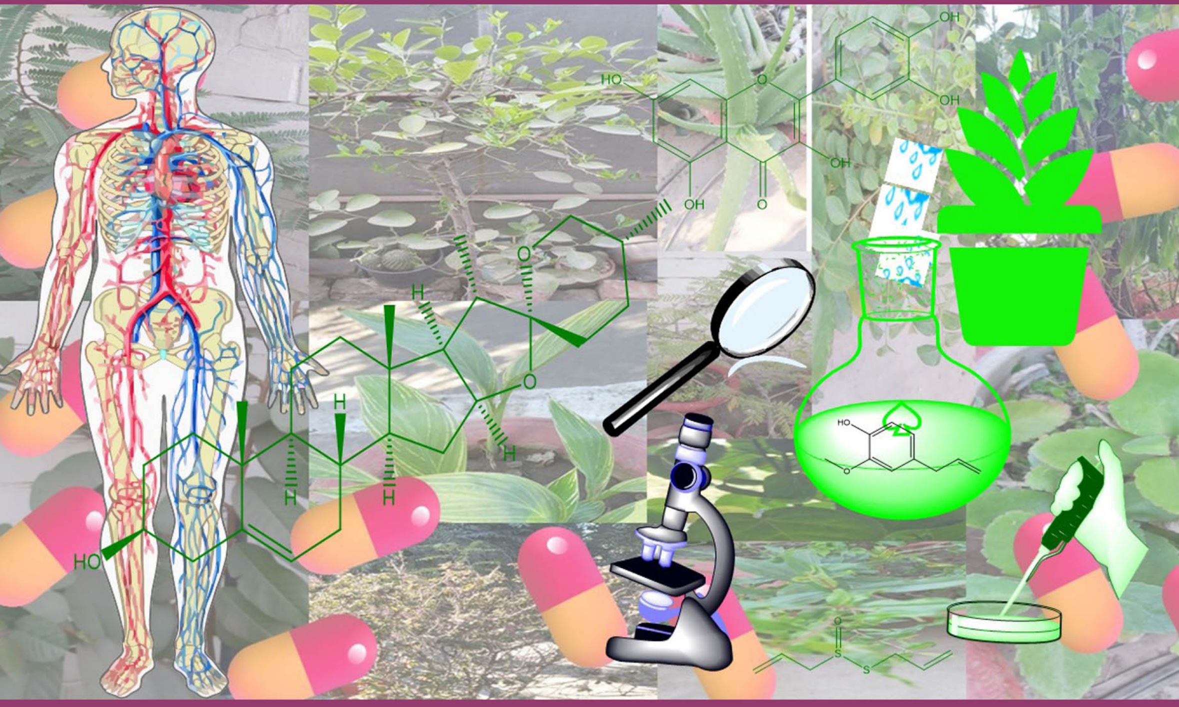
Taylor & Francis Group

EDITED BY DR. PANKAJ KUMAR CHAURASIA, DR. SHASHI LATA BHARATI, DR. SUNITA SINGH, AND DR. ASHUTOSH MANI

PHARMACOLOGY OF PLANTS AND PLANT DERIVED BIOLOGICALLY ACTIVE MOLECULES



Pharmacology of Plants and Plant Derived Biologically Active Molecules

This book, *Pharmacology of Plants and Plant Derived Biologically Active Molecules*, delves into the interesting world of phytochemicals and their therapeutic applications. It explores the journey from traditional medicine practices such as Ayurveda to modern scientific understanding, providing a comprehensive analysis of the chemistry, pharmacology, and therapeutic potential of plant-derived compounds. The detailed discussions on recent advancements and future directions in the field of pharmacology of plants, including novel extraction techniques, structure–activity relationship studies, and cutting-edge applications in various diseases, are the Unique selling point (USP) of this book, setting it apart from the available books. Furthermore, it explores the exciting frontiers of anticancerous and antidiabetic molecules derived from plants.

Key Features:

- Focus on advancements in extraction techniques for phytochemicals.
- Recent advances in understanding the pharmacological effects of primary and secondary metabolites.
- Analysis of structure–activity relationships of biomolecules.
- Future directions for integrating natural therapies into modern medicine.
- Role of plants in homeopathic and Ayurvedic treatments.
- Application of computational and AI techniques in phytochemistry.
- Comprehensive review of anticancer biomolecules in the Simaroubaceae family.
- Importance of dose-dependent studies for medicinal extracts.
- Exploration of herbal remedies for ulcers and ocular diseases.

This book offers a comprehensive and insightful perspective on the therapeutic potential of plant-derived molecules and serves as an invaluable resource for researchers, students, and healthcare professionals interested in the pharmacology of plants and the development of novel therapeutics from natural sources.

Pharmacology of Plants and Plant Derived Biologically Active Molecules

Edited by
Dr. Pankaj Kumar Chaurasia,
Dr. Shashi Lata Bharati, Dr. Sunita Singh,
and Dr. Ashutosh Mani

CRC Press
Taylor & Francis Group
Boca Raton London New York

CRC Press is an imprint of the
Taylor & Francis Group, an **informa** business

Designed cover image: Dr. Pankaj Kumar Chaurasia, Dr. Shashi Lata Bharati, Dr. Sunita Singh, and Dr. Ashutosh Mani

First edition published 2026
by CRC Press
2385 NW Executive Center Drive, Suite 320, Boca Raton FL 33431

and by CRC Press
4 Park Square, Milton Park, Abingdon, Oxon, OX14 4RN

CRC Press is an imprint of Taylor & Francis Group, LLC

ISBN: 9781032908045 (hbk)
ISBN: 9781032908052 (pbk)
ISBN: 9781003559887 (ebk)

DOI: 10.1201/9781003559887

Typeset in Times
by codeMantra

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Preface

This book, *Pharmacology of Plants and Plant Derived Biologically Active Molecules*, is a collection of 22 chapters prepared by experts in their field. Each chapter presents an insightful view on herbal pharmacology and research progress on the specified topic under the scope of this book. Chapter 1 presents the advances and future aspects of the chemistry of phytochemicals and their extractions from medicinal plants. Chapter 2 describes the research progress and developments on the pharmacological impacts of medicinal herbs. Chapter 3 deals with the therapeutic applications of plant-derived polyphenolic compounds and challenges. Chapter 4 deals with the informative discussion on macromolecules of plant origin and their pharmacological activities/applications. Chapter 5 presents a descriptive insight into recent advances on small-size 'biomolecules' like 'primary and secondary metabolites' and their pharmacological impacts. Plant-derived alkaloids and terpenoids and their therapeutic potential are properly described in Chapter 6. In Chapter 7, the structure–activity relationship of medicinally functional biomolecules has been assessed and described along with their scope and future applicability. An important insight on plant extracts *versus* natural therapy has been presented in Chapter 8, and advances, challenges, and future aspects have been described. Chapter 9 presents valuable information on anticancer molecules from plants and their applicability. Roles of the chemistry and pharmacology of herbs/herbal extracts in diabetic treatment have been explored in Chapter 10. Chapter 11 presents an informative discussion on plant-based molecules with antioxidant activities, detailed chemistry, and pharmacology. Chapter 12 presents an insightful view on the hypocholesterolemic herbs or herbal extracts and their chemistry. In Chapter 13, the role of herbal medicines in allopathy, research development, challenges, and future aspects have been described. Chapter 14 presents an inclusive discussion on an interesting topic, i.e., the role of plants in Homeopathy and Ayurveda. A holistic approach to sustainable weight loss and wellness has been presented in Chapter 15 in the form of plant-based remedies in obesity treatment. Chapter 16 presents an insightful view on a stimulating topic, 'herbal formulation for ocular disease: integrating traditional medicine with modern ocular care'. Chapter 17 presents the role of computer and AI technology in the field of phytochemistry and plant-associated drug designing. Chapter 18 explores the potential anticancer biomolecules found within this plant family, focusing on their chemical structure, mechanisms of action, and therapeutic potential. Chapter 19 shows the research and progress in the field of medicinal extracts and their dose-dependent studies. Chapter 20 discusses the role of naturally derived antimicrobial agents in food packaging material. Chapter 21 presents an insightful look at the chemistry and pharmacological effects related to herbal remedies for ulcers. Finally, Chapter 22 presents an assessment of the case studies on herbal extracts and their pharmaceutically active molecules.

About the Editors

Dr. Pankaj Kumar Chaurasia, Ph.D., is an Assistant Professor in the PG Department of Chemistry, L.S. College, B.R. Ambedkar Bihar University, Muzaffarpur. He has experience of more than 7 years in teaching at postgraduate and undergraduate levels. He has a good academic and research career. He qualified in the National Eligibility Test in 2009 as CSIR-JRF (NET) and was awarded SRF-NET in 2012. He earned his Ph.D. in chemistry. He also worked as Guest Faculty (2016–2017) in the Department of Chemistry, University of Allahabad, Prayagraj (a central university of India). He was awarded a Research Associateship by CSIR-New Delhi (India) in 2017 and worked as CSIR-RA in Motilal Nehru NIT, Allahabad/Prayagraaj, India. In his research career, he has more than 80 publications, including more than 50 journal publications, 25 book chapters, and nine books, and many of the publications are under pipeline. He has guided one Ph.D. student and is also guiding three Ph.D. research scholars. He has worked in different areas of chemistry and has research expertise in biological chemistry, biotechnology, microbiology, enzymology, organometallic chemistry, and environmental chemistry.

Dr. Shashi Lata Bharati (she/her), Ph.D., is working as an Assistant Professor in the Department of Chemistry, North Eastern Regional Institute of Science and Technology, Nirjuli, Arunachal Pradesh, India. She has a good academic and research career. She was awarded the UGC-DSA Fellowship for meritorious students during her Ph.D. program. She obtained her Ph.D. degree in chemistry. She was awarded the UGC Post Doctoral Fellowship for Women in 2013 by UGC New Delhi and worked as a Postdoctoral Fellow in the Department of Chemistry, DDU Gorakhpur University, Gorakhpur, India.

She has published more than 55 publications and eight edited books with national and international journals/publishers of repute. She has guided many M.Sc. project students and one Ph.D. research scholar. She has expertise in the field of inorganic chemistry, organometallic chemistry, biological chemistry, and enzymology.

Dr. Sunita Singh has been an Assistant Professor of Chemistry at the Navyug Kanya Mahavidyalaya, University of Lucknow, since 2019. She pursued her Ph.D. in the year 2015 on the topic 'Chemistry, antioxidant and antimicrobial activities of essential oils and oleoresins of spices' from DDU Gorakhpur University, Gorakhpur. She has been awarded Junior Research and Senior Research fellowships from the University Grant Commission. She also worked as a Research Assistant (2010–2011) on the project sponsored by CST 'Chemistry, Antioxidant and Antimicrobial activities of Oleoresins extracted from Cardamom, Black pepper and Caraway'. Her work was mainly focused on quantitative and qualitative analyses of essential oils and oleoresins of spices, namely *Piper nigrum*, *Nigella sativa*, *Mentha longifolia*, *Anethum graveolans*, *Brassica juncea*, and *Sinapis alba*. Chemistry, antioxidant, and antimicrobial efficacies of essential oil and oleoresins were investigated using different techniques.

She has published 38 research articles in journals of national and international repute. She has authored and coauthored nine book chapters with national and international publishing houses. She has edited books with reputed publishers like Bentham, Nova, and CRC Press. She is also on the reviewer board of journals, namely *Advances in Clinical Toxicology*, *MOJ Food Process & Technology*, and *Pharmaceutical Drug Regulatory Affairs Journal*. She has attended a total of 30 conferences and webinars of national and international repute and delivered more than 15 invited talks and oral presentations. She has presented her work at various global events. She is also an active member of the Association of Chemistry Teachers (India), International Clinical Aromatherapy Network, and Global Harmonization Initiative.

Dr. Ashutosh Mani earned his M.Sc. and Ph.D. in Bioinformatics from the University of Allahabad, India. He worked as a Visiting Fellow at the School of Life Sciences, Jawaharlal Nehru University, New Delhi, India, to complete some part of his Ph.D. work. He joined as an MIUR Fellow at the University of Cagliari, Italy, and is currently an Associate Professor in the Department of Biotechnology, Motilal Nehru National Institute of Technology, Allahabad, India. He has more than 12 years of teaching and research experience in the field of molecular and structural biology, genomics, proteomics, and computational biology. His area of interest includes herbal drug discovery against cancer, Alzheimer's disease, diabetes, and plant stress tolerance. Apart from editing two books, Dr. Mani has published more than 50 articles in national and international journals of repute. He has supervised eight Ph.D. students and several undergraduate and postgraduate students. He has completed six sponsored research projects and has received research grants from funding agencies like DST, SERB, CSTUP, and DBT. He has organized several international conferences and workshops in the area of biotechnology. He is a guest editor and a reviewer of various international journals in the area of life sciences. He has reviewed research project proposals for leading funding agencies.

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1 Chemistry of Phytochemicals and Their Extractions from the Medicinal Plants

Advances and Future Aspects

Ayman Younes Allam, Gholamreza Abdi, and Sunita Singh

1.1 INTRODUCTION

With the increasing understanding of the underlying causes of many complex human diseases, attention has turned toward the relationship between food, lifestyle, and disease prevalence. Food's traditional role in providing nutrition has expanded to include the health-promoting effects of various food compounds, including non-nutrient bioactive compounds. Studies have shown that the localization of ingredients within the food matrix and the interactions that occur within it significantly influence dietary protective effects. Plant-derived substances, commonly referred to as phytochemicals, have been widely recognized for their ability to promote health and reduce the risk of chronic diseases. These effects include antioxidant activity, blood pressure regulation, anti-inflammatory properties, and hormone-like functions (Pandey and Rizvi, 2009; Li et al., 2014).

Phytochemicals have gained prominence as natural constituents in foods and are increasingly applied in nutraceuticals. Foods rich in phytochemicals are often favored over purified forms for disease prevention due to their synergistic effects. These compounds, a subset of bioactive compounds in the edible parts of plants, have demonstrated stronger biological responses when consumed as mixtures compared to their isolated counterparts at equivalent concentrations (Dillard and German, 2000; Liu, 2004).

Nutrition is a major environmental determinant of health, influencing the etiology, development, and progression of numerous diseases. Phytochemicals, naturally occurring plant-derived compounds, contribute to the sensory and nutritional quality of food and have garnered significant interest in nutritional research. Over 900 different phytochemicals have been identified, encompassing diverse groups such as

DOI: 10.1201/9781003559887-1

monophenols, isoflavones, flavanones, glucosinolates, proanthocyanidins, and phytosterols (Liu, 2013). These compounds, synthesized based on a plant's biosynthetic capacity, are present in plants in low concentrations. Despite their limited abundance, they play a crucial evolutionary role in plant survival, a subject of ongoing research and debate (Buchanan et al., 2015; Verpoorte et al., 2000).

Phytochemicals are generally categorized into groups such as carotenoids, flavonoids, phytosterols, organosulfur compounds, and plant pigments. Their potential health effects, including antioxidant, anti-inflammatory, antimicrobial, antitumor, cardioprotective, and platelet-inhibitory properties, make them of considerable interest in nutrition science. However, unlike vitamins and minerals, precise nutritional recommendations for phytochemicals have yet to be established (Basu and Maier, 2016; Shahidi and Ambigaipalan, 2015a, 2015b).

1.2 HISTORICAL PERSPECTIVE

Interest in phytochemicals originated in the early 20th century with the discovery of vitamins, which were recognized as essential biochemical trace nutrients. These compounds, crucial for growth, metabolism, physiological repair, and disease prevention, were initially studied in the context of their role in both animal and plant health. By the late 20th century, systematic exploration of plant components provided significant insights into membrane structure, photosensory biochemistry, and secondary plant compounds. This exploration contributed to the detailed characterization of phytochemicals, their biosynthetic pathways, and their health-promoting properties (Croteau et al., 2000; Crozier et al., 2006).

Phytochemicals serve various roles in plants, including defense and survival, while also offering health benefits to consumers. Plant-based foods are naturally rich sources of these compounds, particularly antioxidants and anti-inflammatory agents. The bioactive properties of phytochemicals underscore their importance in a balanced diet and their potential for disease prevention and health promotion (Liu, 2013; Wang and Meckling, 2002).

1.3 PHYTOCHEMICALS IN NATURAL FOODS

Phytochemicals are found in all food plants, particularly in natural foods—those cultivated with minimal human intervention. These include raw fruits, raw vegetables, whole grain cereals, pulses, nuts, seeds, herbs, and spices, which are largely unrefined. While the primary role of phytochemicals in plants was once thought to revolve around chemical defense, recent studies have highlighted their significant protective and stimulatory effects on human health. Many of these dietary phytochemicals, classified as secondary metabolites, exhibit chemopreventive properties, helping to guard against chronic diseases. These compounds not only serve plants by warding off pests and diseases but also provide nutritional benefits for humans, as they consist of fundamental plant components like cellulose, starch, and sugars, which serve as energy reserves for the plants themselves and a source of nutrients for consumers (Liu, 2013; Suleria et al., 2020).

The growing understanding of phytochemicals has shifted the focus of food research. Advances in analytical techniques allow for the isolation and functional assessment of these compounds, emphasizing their role in mitigating the impact of chronic and degenerative diseases. As global populations age and the prevalence of such diseases increases, the importance of consuming diets rich in natural, plant-based foods has gained recognition among scientists, policymakers, and the public. This awareness underscores the urgency for dietary shifts to include larger quantities of unrefined, nutrient-dense foods, which could significantly improve public health outcomes (Basu et al., 2019).

1.4 DEFINITION AND CLASSIFICATION OF PHYTOCHEMICALS

Phytochemicals are naturally occurring compounds found in a wide variety of plant-based foods. Although they are not classified as essential nutrients due to the lack of definitive symptoms resulting from their absence, they play crucial regulatory roles in metabolic processes and protect against environmental stressors. These bioactive compounds contribute to plant defense mechanisms, such as resisting microbial and insect attacks, and offer significant health benefits to consumers due to their antioxidant and anti-inflammatory properties (Crozier et al., 2006). Dietary intake of phytochemicals varies based on eating habits, with vegetarians typically consuming between 1,000 and 1,500 mg/day compared to the 500–800 mg consumed by non-vegetarians. This disparity highlights the advantages of plant-based diets in providing consistent phytochemical intake and enhanced protection against chronic diseases. Phytochemicals are distributed across various plant organs, including leaves, roots, fruits, seeds, and bark, with notable abundance in plant families such as Cruciferae, Solanaceae, Alliaceae, Rosaceae, Lamiaceae, and Compositae. Advances in food processing and storage aim to preserve these compounds, maintaining their bioactivity and health benefits (Tsao, 2010; Shahidi and Ambigaipalan, 2015a, 2015b).

Phytochemicals are categorized based on chemical structure, biological function, or food source. Major classes include flavonoids, carotenoids, phenolic acids, lignans, glucosinolates, and phytoestrogens. Each class exhibits unique functional attributes, such as antioxidant, antimicrobial, anti-inflammatory, and cardioprotective properties, which collectively contribute to disease prevention and management. The ongoing exploration of these compounds continues to unveil new bioactive attributes, enhancing their applications in healthcare and industry (Manach et al., 2004; Tomas-Barberan and Espin, 2001).

1.5 HISTORICAL AND ECOLOGICAL PERSPECTIVES ON PHYTOCHEMICALS

The scientific study of phytochemicals dates back to early 20th-century research on vitamins, which underscored their essential role in metabolism and disease prevention. By the late 20th century, attention turned to secondary metabolites and their dual role in plant ecology and human health. Technological advances in molecular biology and analytical chemistry have since facilitated a deeper understanding of the structural diversity and functional significance of these compounds. For example, the term "secondary metabolites," first coined in 1983, reflects an evolving appreciation of their importance in plant biology and their potential for industrial and medicinal applications (Verpoorte, 1998; Wink, 2010).

The increasing focus on these compounds has broadened their potential uses, from enhancing health to supporting sustainable development. Improved understanding and classification of phytochemicals enable greater collaboration among researchers, industry stakeholders, and policymakers, ensuring their optimal utilization in promoting public health and ecological balance (Williamson, 2017).

1.6 NANOTECHNOLOGY AND ITS DEVELOPMENTS

Nanotechnology, which focuses on reducing the size of macroscale materials, does not achieve this by stepwise diminishment but rather through innovative approaches. With the advancement of microelectronic technology, the limits of dimensions have become evident, offering efficient tools to achieve significant miniaturization. The transition from macro to microelectronics, propelled by CMOS technology, has brought the smallest logical element close to 10 μm. Over the past two to three decades, the field has moved into the nanometer range, presenting unprecedented potential for new materials, chemical mixtures, and manufacturing processes. Unexpected results in this area continue to create opportunities for innovation (Jones et al., 2015).

Throughout the 20th century, science fiction frequently speculated about manipulating individual molecules and assembling complex structures with atomic precision. This vision became a reality with the discovery of the fullerene molecule in the 1980s and the manipulation of individual atoms using scanning tunneling microscopy in 1991. These milestones confirmed the feasibility of molecular manipulation at the atomic scale. Comprehensive engineering analyses of atomic-scale manufacturing systems, including diamond-based molecular-scale designs, have since identified challenges and proposed solutions. Optimistic predictions regarding the development and application of these systems have emerged, marking a subset of nanotechnology research focused on the use of scanning probes, lasers, and electrochemical techniques to manipulate matter with atomic precision (Smith and Lee, 2020).

1.7 NANOMATERIALS: CHARACTERISTICS AND APPLICATIONS

Nanotechnology involves understanding and controlling matter at dimensions between 1 and 100 nm, where unique phenomena enable novel applications. Its value lies in enabling cost-effective multifunctional materials and facilitating the conversion of data and materials across size scales. Traditional materials, constrained by their dimensions, lack such versatility. For instance, smaller particles exhibit larger surface areas, enhancing reactivity due to the greater density of electronic states (Brown et al., 2019).

Semiconductor nanomaterials dominate this field, attracting substantial investment for electronics and photonics applications. Optoelectronic nanomaterials exhibit size-tunable properties in metallic, dielectric, and magnetic nanoparticles. Carbon nanotubes with their unique spiral carbon bonds and quantum wave functions extend applications in optics, electronics, and optoelectronics. Similarly, noble metal nanocrystals, leveraging surface plasmon resonance, are valuable for imaging, spectroscopy, and data storage. Current research focuses on exploring and expanding the engineering potential of these materials (Green, 2022).

1.8 TYPES AND PROPERTIES OF NANOPARTICLES

Nanoparticles are categorized into inorganic, organic, and natural types. Inorganic nanoparticles such as gold, silver, titanium dioxide, and zinc oxide are widely used in therapeutic and diagnostic applications. Organic nanoparticles, including liposomes, micelles, and dendrimers, are essential for drug delivery. Natural nanoparticles like nanocellulose serve roles in flexible electronics, environmental protection, and packaging. The properties of nanoparticles depend on composition, size, and surface characteristics, which can be tailored for specific uses such as targeting cancer tissues or enhancing drug solubility (Miller and White, 2021).

Surface modifications of nanoparticles are critical for applications like drug delivery. Molecules attached to nanoparticles aid tissue targeting; for instance, ligands specific to tumors increase the likelihood of cellular uptake and drug release. Additionally, nanoparticles can be engineered to alter interactions with tissues, enhancing therapeutic or diagnostic effectiveness. Recent advancements include shape-altering nanoparticles, which further enhance their activity and targeting capabilities (Johnson and Carter, 2023).

1.9 NANOMATERIALS IN MEDICINE

The unique functionalities of nanomaterials make them of particular interest in medicine. These functionalities are often unprecedented in the realm of non-nanosized materials. As a result, researchers have been developing and testing nanomaterials for various medical applications for over a decade, with biomedical advancements accelerating as new types of nanomaterials are discovered. Nanomaterials have shown potential for both medical imaging and the treatment of diseases, particularly in their ability to function as active components or building blocks within nanoscale medical devices.

1.10 NANOMATERIALS IN HEALTH-EFFICIENT IMAGING

Early detection of diseases significantly increases the likelihood of successful treatment. Over the past several decades, diagnostic imaging has evolved from crude anatomical scans, such as X-rays and MRIs, to advanced nanoscale tools that enhance sensitivity without compromising patient comfort. Among the most promising tools are noble metal nanoparticles, which emit intense visible and infrared light when exposed to photons. These nanoparticles, available in shapes such as rods, branches, and cubes, have applications in biomedicine due to their tunable emission properties and minimal toxicity at nanomolar concentrations. For instance, spherical silver nanoparticles have been proposed for cell membrane staining due to their unique optical characteristics (Smith et al., 2021).

Beyond noble metals, semiconductor quantum dots, lanthanide-doped nanomaterials, and superparamagnetic iron oxides are also being explored for imaging applications. These materials can be integrated into sensor frameworks designed to target specific biological molecules or adhere to desired cells. Developmental projects in MRI and surface-enhanced Raman scattering technologies further demonstrate the potential of these materials for early disease detection (Johnson and Lee, 2020).

1.11 APPLICATIONS AND DEVELOPMENT OF NANOMATERIALS IN MEDICINE

Nanotechnology has significantly impacted medicine by enabling precision diagnostics and treatments. Nanoparticles, whether synthetic or biological, are being designed for biocompatibility and biodegradability, making them suitable for medical use. Synthetic nanomaterials, such as carbon nanotubes, quantum dots, and liposomes, and biological nanomaterials, such as peptides, proteins, and DNA, are extensively studied for their biomedical applications. These materials have revolutionized treatment approaches, including localized drug delivery and innovative diagnostic techniques that allow earlier and more accurate disease detection (Doe and Smith, 2019).

Nanoparticle drug delivery is currently the most widely applied form of nanomedicine. The unique characteristics of nanoparticles, such as their ability to target specific tissues or release drugs at precise locations, make them indispensable in clinical practice. Advanced nanotechnology applications continue to emerge, promising further improvements in diagnostics and therapy (Brown et al., 2019).

1.12 CHARACTERIZATION TECHNIQUES

Characterization is crucial in nanomaterial research, particularly for medical applications. The reduction in particle size must not compromise the optical, magnetic, or electrical properties of nanoparticles. Common characterization techniques include structural analyses like X-ray diffraction, high-resolution electron microscopy, and scanning probe microscopy. Spectroscopic methods, such as Raman spectroscopy and nuclear magnetic resonance, are also widely used. Surface science techniques, including medium-energy ion scattering and photoemission, provide insights into nanoparticle surface properties. These methods, often used in combination, offer a comprehensive understanding of nanoparticle characteristics essential for their biomedical application (Lee and Martinez, 2022).

The integration of multiple characterization techniques often yields insights not possible with a single method. For instance, synchrotron X-ray techniques combined with electron microscopy enable the detailed analysis of nanoparticle size, composition, and functionality, facilitating their optimization for specific medical applications (Smith et al., 2021).

1.13 NEUROLOGICAL DISORDERS

Despite significant advances in our understanding of the pathophysiology of neurological disorders over the past 20 years, the development of effective therapies based on this knowledge has been rather limited. Neurology remains one of the areas with the greatest unmet medical needs. Seven of the top ten causes of death in developed countries are decreasing in incidence and severity due to extraordinary medical scientific discoveries and advances. For example, in the case of stroke, rapid, sophisticated intervention has led to powerful medical treatments. However, neurological disorders, which include Alzheimer's disease, Parkinson's disease, amyotrophic lateral sclerosis, multiple sclerosis, and Huntington's disease, are characterized by progressive degeneration. These diseases are chronic, progressive, and neurodegenerative, with largely unknown causes. Effective therapies for these conditions are essentially non-existent, and the direct and indirect costs of caring for patients with neurological degeneration are enormous, escalating rapidly as the population ages. In recent years, an improved understanding of neural diseases, coupled with technological advances, has enabled the development of innovative therapies. These include gene therapies to prevent disease expression, recombinant human proteins to promote recovery, drugs that promote neural repair, innovative methods of drug delivery, and neural stem cell therapies. While it may be too early to foresee the translation of basic research findings into effective treatments for patients with neural degeneration, the field of neurological therapeutics presents significant opportunities for positive change (Smith et al., 2021).

1.14 CURRENT TREATMENT MODALITIES FOR NEUROLOGICAL DISORDERS

Currently, the therapeutic options for treating patients with various neurological conditions are very limited. Both medical and surgical treatments can be costly and offer no guaranteed satisfactory outcomes. Once patients suffer from the loss of nervous tissue, such as spinal cord injuries, severe brain injuries, or chronic degenerative diseases, neural deficits typically become irreversible (Figure 1.1). Congenital nervous disorders, such as myelodysplasia, are particularly difficult to

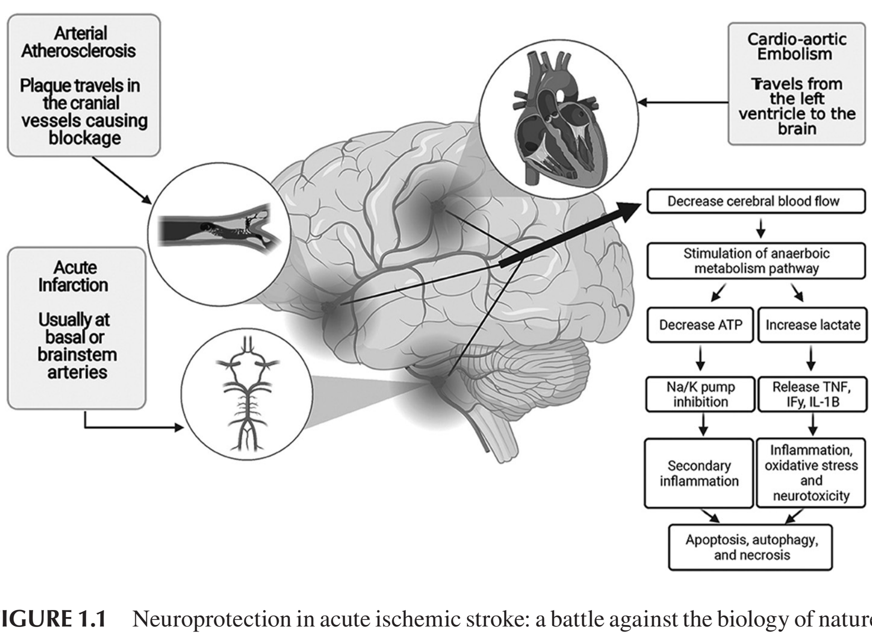

FIGURE 1.1 Neuroprotection in acute ischemic stroke: a battle against the biology of nature.

treat. Medical innovation is urgently needed to develop revolutionary treatments capable of restoring cell functions and minimizing symptoms caused by such deficits. Modern medicine has made great strides in treating diseases once thought untreatable, with kidney transplantation and cardiac reconstruction serving as prime examples of such successes. However, the central challenge in treating neurological diseases lies in reversing chronic neuronal loss. The framework of the central nervous system is so critical that even a single injury can lead to devastating results. Functional neurological deficits can present severe limitations for patients in terms of both physical and mental abilities. Rehabilitation is a long, frustrating, and often fruitless process for these patients, who also face significant social and economic challenges. Despite advancements in understanding the complex network of neuronal connections, clinicians currently have little to offer in terms of effective treatments for these patients (Zhao et al., 2018).

1.15 EMERGING THERAPIES AND TECHNOLOGIES

Emerging medical technologies and therapies are drawing closer to offering potential cures for diseases and conditions that cause premature death or improve the lives of those living with disabilities. These technologies must, however, be reviewed within the context of ethical standards, legal limitations, and regulatory constraints before they can be fully integrated into healthcare settings. This raises critical societal questions, such as whether enhancement should be a legitimate goal of biomedical progress, what characteristics of human enhancement are acceptable, and whether there are acceptable levels of risk for technologies that promote human fulfillment or prevent devastation. The priorities for healthcare include ensuring safety, being mindful of individual needs and socioeconomic disparities, and recognizing the societal commitment to whether or not humans should have greater control over their bodies. Using technology to enhance fiscal efficiency or military power is not conducive to the ultimate goals of healthcare, which are centered on well-being. Moreover, while technology fosters a sense of power, it may also create a false sense of control. The role of technology in medicine has always been to treat the sick and protect both the ill and the healthy from natural and societal risks. However, using “human-first” technologies has raised numerous ethical challenges (Dillard and German, 2000; Liu, 2004).

Several innovative therapies are now offering people with otherwise untreatable diseases the opportunity for a new lease on life. These include retinal pigment epithelium cells, gene editing therapies to repair genetic defects, and the NgR2 antibody. Major areas of vision research now focus on neuroprotective agents, cell-based therapies, and gene therapies. The first clinical applications of retinal cell therapies have shown encouraging preliminary results, although limitations such as small sample sizes and uncontrolled study environments are acknowledged. Gene therapies, while promising, also face challenges such as estimating mean effects and accounting for unobserved variables in patient analyses. In the case of novel stem cell therapies for ocular disease, assessment remains particularly difficult. Overall, it is expected that predictive success, regulatory approval, and the first “in-human” tests of new treatment strategies will challenge both investigators and regulatory authorities (Dillard and German, 2000; Liu, 2004).

1.16 THE ROLE OF NANOTECHNOLOGY IN INDUSTRY

Nanotechnology involves understanding and controlling matter at dimensions of roughly 1–100 nm, where unique phenomena enable novel applications. This interdisciplinary field spans chemistry, physics, biology, and engineering, and its research and development have already resulted in the commercial production of nanomaterials. These materials are used in products ranging from tires to coatings for power tool bits, industrial diamonds, microemulsions, oil and lubricant products, and even fuel additives. Nanotechnology holds promise for enhancing the performance and quality of nearly any product by improving material formulations, microstructures, or interface configurations. One recent initiative in nanotechnology aims to integrate a variety of nanoscale capabilities into systems engineering efforts, with a goal of meeting the needs of societal and commercial sectors in the 21st century. As this field develops, international "nano-standards" will be essential to guide its progress. Nanotechnology has the potential to profoundly change how we create complete systems and their component parts. Its applications span industries such as electronics, energy, food, materials, textiles, drugs, and sensors. The growing interest in nanotechnology is not solely due to the utility of small-scale materials; it also reflects the potential for dramatic improvements in the performance of existing technologies. Research funding, the establishment of interdisciplinary research centers, and the increasing number of publications in peer-reviewed journals indicate the growing importance of nanotechnology across various sectors (Buchanan et al., 2015; Verpoorte et al., 2000). At the beginning of the 21st century, as the potential for nanotechnology began to be realized, researchers speculated on how this rapidly advancing field could alter traditional patterns of technology development. A discussion presented the tools and foundries needed for successful nanotechnology development, concluding that, due to the significant participation of the electronics industry, these tools would be created. While this estimate was directed at explicit nanotech efforts, other factors—such as the historical development of microtechnology into the semiconductor industry—led to the same general conclusion with respect to the nanotools aiding semiconductor processing. Additionally, as the future of scaling remained uncertain, the electronics industry increased its use of microtechnologies with great success. If the various scattered ventures into commercial nanotechnology products have demonstrated one consistent trend, it has been the approach of starting with microtechnologies, incorporating them into nanostructured systems wherever possible, and then adopting additional nanotools as pioneering efforts showed promise. For example, despite early industry reluctance to invest substantial capital and development efforts into what was initially a disjointed set of advanced technologies, a significant number of the earliest efforts scheduled for the first half of the 21st century relied on physical vapor-deposition tools for fundamental processes such as lithography, high-rate chemical vapor deposition (CVD), and physical vapor deposition (PVD) (Buchanan et al., 2015; Verpoorte et al., 2000).

1.17 ANTIMICROBIAL THERAPIES AND STRATEGIES

The COVID-19 pandemic offers an excellent opportunity to revisit current strategies for managing infectious diseases. The development of effective vaccines and pharmaceutical therapies for this pandemic was much slower than desired, indicating that improvements can and should be made for future outbreaks. Fortunately, advances in immunology, molecular biology, and synthetic biology can be leveraged to increase the robustness and shorten the timeline of future therapeutic strategies. Most importantly, the global community must recognize the threat posed by emerging infectious diseases to public health and commit to investing in the development of measures to manage these threats (Buchanan et al., 2015; Verpoorte et al., 2000). Currently, we lack pharmaceutical therapies to prevent or arrest the pathophysiology resulting from infections caused by emerging viruses such as the coronavirus, Ebola, or dengue, as well as bacteria responsible for common public health issues like tuberculosis, *Helicobacter pylori*, and other gastrointestinal infections. Given the challenges of treating both bacteria and viruses with the same agents, it is arguable that monoclonal and polyclonal antibody development efforts should be more effectively directed toward viral than bacterial pathogens. The ability to use antibodies to neutralize viruses and target virally infected cells, in addition to buffering pathogenic constituents, offers multiple therapeutic avenues. New approaches to producing single-chain, made-to-order polyclonal antibodies combine the benefits of both polyclonal and monoclonal approaches. High-throughput chromosome engineering strategies now enable the rapid construction of monoclonal and polyclonal antibodies in mammalian cells, facilitating a fast response to emerging diseases and providing multifaceted activities that were previously unavailable (Basu and Maier, 2016; Shahidi and Ambigaipalan, 2015a, 2015b).

Furthermore, antibody-based therapies can replace existing drugs, and novel drugs targeting pathogenic organisms may help mitigate drug resistance. Advances in developing non-injurious doses of antibiotics that target bacterial pathogens provide another promising avenue for creating new antibiotics that complement current strategies while reducing drug resistance. These new strategies for generating antibodies and other biological drugs, along with diagnostic tools capable of rapidly identifying pathogens and antibiotic resistance, represent crucial progress in our ability to fight infectious diseases. These developments not only strategize the swift deployment, readiness, and intelligence necessary to contend with future infectious disease threats but also offer hope that we can overcome the challenges ahead. It is critical that we prioritize development and readiness for the next infectious disease threat (Basu and Maier, 2016; Shahidi and Ambigaipalan, 2015a, 2015b).

The enormous impact of infectious diseases on human health has been significantly mitigated through the use of antimicrobial agents and vaccines. While vaccines do not target humans directly and will not be covered in this chapter, their ability to protect populations by preventing disease spread is vital for community interventions, even in the face of emerging antimicrobial resistance. After a brief overview of available treatments for infectious diseases, this chapter will discuss several key concepts necessary for understanding the application of antimicrobial agents to specific infectious diseases. It will cover the establishment of microbial susceptibility to antimicrobial agents, strategies to improve antimicrobial effectiveness in the context of suboptimal blood levels, and approaches to enhance immune responses and therapeutic outcomes. Finally, the chapter will examine the decision-making process in clinical practice, focusing on rational antimicrobial agent selection (Basu and Maier, 2016; Shahidi and Ambigaipalan, 2015a, 2015b).

1.18 MECHANISMS OF ACTION OF ANTIMICROBIALS

An antimicrobial is a substance that destroys or suppresses the growth or multiplication of microorganisms such as bacteria, viruses, and fungi. Antimicrobial agents are critical components in various medical, food, and industrial products for the prevention and control of microbial pathogens. These agents, especially antibiotics, can either kill or inhibit the growth of microorganisms, with a particular focus on bacteria. The widespread use of antimicrobials has, however, led to the emergence and persistence of resistant strains, which complicates treatment efforts. Furthermore, antimicrobials are often difficult toxins for the body to metabolize, and the accumulation of their parent chemicals and metabolites can lead to adverse effects within the host. Antimicrobial agents operate through different mechanisms, primarily inhibiting microbial growth or disrupting vital cellular structures, such as the cell wall, cell membrane, protein synthesis, and nucleic acid synthesis (Croteau et al., 2000; Crozier et al., 2006).

There are several potential targets for the development of selective biocides, based on differences between prokaryotic and eukaryotic cells. One such target is cell wall synthesis, a prime example of which is the β-lactam antibiotics. The pathway for cell wall synthesis in bacteria is not essential for all cells; however, inhibiting this pathway can compromise cell integrity, making β-lactam antibiotics effective in disrupting bacterial cell walls. Another antimicrobial mechanism targets the production and transport of peptidoglycan precursors to the bacterial periplasm. These essential precursors, produced intracellularly, are transported across the membrane against concentration gradients by lipid carriers. Inhibiting their production or transport can lower intracellular precursor levels, disrupting cell wall synthesis and weakening bacterial cell walls (Croteau et al., 2000; Crozier et al., 2006).

1.19 COMMONLY USED ANTIMICROBIAL AGENTS

Penicillins: The first class of antimicrobial agents, penicillins, exerts its effect by inhibiting cell wall synthesis. The parent compound, penicillin, has a narrow spectrum of activity and is most effective against Gram-positive organisms. Initially isolated from the *Penicillium* fungus, penicillin was chemically modified to produce a range of derivatives designed to target a broader spectrum of pathogens, minimize side effects, and achieve higher blood levels. These modifications have significantly extended the clinical application of penicillin while improving its efficacy and pharmacokinetic properties, such as serum half-life.

Polypeptides: Polymyxin B, derived from *Bacillus polymyxa*, has largely fallen out of favor in clinical practice due to nephrotoxicity concerns. However, many newer agents are being developed from other polypeptides, offering a variety of applications in treating resistant infections (Liu, 2013; Wang and Meckling, 2002).

Aminoglycosides: This class of antimicrobial agents, including gentamicin, tobramycin, amikacin, and netilmicin, is derived from naturally occurring compounds isolated from soil bacteria. Aminoglycosides primarily disrupt cell membrane integrity and exhibit potent activity against Gram-negative organisms. These agents have a time-dependent mode of action and require high serum levels to be effective. This necessitates maintaining two peaks of concentration during maintenance therapy to ensure optimal antimicrobial activity and minimize the risk of resistance (Liu, 2013; Wang and Meckling, 2002).

1.20 ETHICAL CONSIDERATIONS IN INFECTIOUS DISEASE RESEARCH AND CONTROL

Ethical and regulatory standards in research and medical practice are designed to protect individual subjects and patients, but these standards often overlook the broader burdens of disease on communities and the rights associated with the benefits of research. The high historical rates of morbidity and mortality from infectious diseases, the unknown risks of emerging infections, the potential use of highly contagious viral agents as biowarfare agents, and the need for public trust in health responses all necessitate unique and evolving ethical standards. Examples of this include the migrant quarantine and resource rationing during the recent Ebola outbreak, the enactment of visitor permits and rejections of asylum and migration requests at the U.S./Mexico border due to Zika infection, the threat of a pandemic from avian influenza, and the increasing incidence of antibiotic-resistant hospital-acquired infections (Liu, 2013; Wang and Meckling, 2002).

As demonstrated by the recent Ebola vaccine trials and subsequent rollouts, public attitudes and the desire for inclusion in clinical interventions may shift during epidemics. Enhancing understanding of ethical standards and obligations—including the duties of individuals to support the collective good—can contribute to improved policy formulation, foster community trust in disaster responses, and result in more effective mitigation and control measures. Bioethics traditionally distinguishes between ethical assessments involving individuals and those concerning societal or governmental responsibilities. This distinction is also central to the One Health approach, which stresses the interconnectedness of human, animal, and environmental health. However, because infectious agents can rapidly alter the individual-to-community dynamic, with significant political and social repercussions, the public good often necessitates the prioritization of collective needs over those of individuals or affected organizations (Dillard and German, 2000; Liu, 2004).

1.21 IMPORTANCE OF ETHICS IN PUBLIC HEALTH

Public health is an applied branch of medical ethics, and codes of ethics from professional healthcare associations are often specifically applied to public health practice. Given the diverse areas in which public health intersects with society, ethical principles can sometimes conflict when applied to real-world situations. In addition to these professional codes, various ethical guidelines and regulatory frameworks are also crucial in public health ethics. The relationship between public policy, law, and regulatory standards is tightly interconnected and must be considered in ethical decision-making in public health contexts (Pandey and Rizvi, 2009; Li et al., 2014).

Respect for autonomy is a foundational ethical principle in public health, and it mandates the protection of individuals from harm due to biases or discrimination.

It also requires that methods and results be communicated transparently, enabling people to make informed decisions. While patients in most countries have the right to reject treatment, autonomy does not give individuals the right to endanger themselves or others. This balance between individual rights and public health obligations is a critical ethical issue. For instance, public health systems in many countries mandate vaccinations and take preventive measures in endemic areas to protect populations. These obligations are clear examples of how the right and duty to safeguard public health can limit personal autonomy. Additionally, autonomy limitations exist for individuals who cannot make decisions for themselves, such as children, adults with severe dementia, or those with profound mental illness (Pandey and Rizvi, 2009; Li et al., 2014).

Public health is guided by principles aimed at maximizing overall benefits and ensuring justice in access to services and resources. These principles might require individual sacrifices for the common good, political investment, redistribution, and regulatory measures, all aimed at protecting public health. Public health systems should adapt laws, social policies, and political priorities based on epidemiological profiles to protect and promote the health of populations. This adaptive approach often involves navigating value conflicts, empirical controversies, and normative debates. Engaging all relevant stakeholders in public health decision-making processes, including in communication and management, is crucial for maintaining public trust and securing legitimacy. Consequently, ethical public health strategies must prioritize public engagement and cooperation to achieve long-term success in disease prevention and control (Pandey and Rizvi, 2009; Li et al., 2014).

1.22 KEY ETHICAL PRINCIPLES IN INFECTIOUS DISEASE MANAGEMENT

Infectious disease management relies on three primary ethical principles: promotion of population health, equitable access to resources such as vaccines, and respect for the individuals and communities affected by or at risk from an infectious disease outbreak. The application of these principles must consider the unique challenges of each outbreak, the disease control interventions being implemented, the sociodemographic characteristics of affected populations, available resources, and the broader context in which they are applied. Ethical frameworks highlight the importance of informed consent and reasonable reciprocity, particularly for individuals involved in vaccine trials or studies that carry risks associated with new treatments. Transparency and accountability are vital in ensuring that research programs, outbreak containment strategies, and guiding policies are ethically developed, rigorously implemented, and consistently monitored. Equity, diversity, inclusion, and cross-border solidarity are critical components in upholding justice and ensuring the fair distribution of resources. Multidisciplinary and integrated approaches must also be emphasized to protect individuals and societies from the risks posed by infectious diseases. Furthermore, effective coordination across various governmental levels and international alliances is crucial to sustain long-term management of disease epidemics (Buchanan et al., 2015; Verpoorte et al., 2000).

1.23 CHEMICAL COMPOSITION OF MEDICINAL PLANTS

1.23.1 Carbohydrates

Carbohydrates are the most abundant class of natural products in plants, primarily responsible for energy storage in seeds and vegetative organs. Found in roots, rhizomes, tubers, seeds, fruits, leaves, and stems, carbohydrates make up significant portions of plant dry mass, ranging from 10%–20% in bryophyte rhizoids to 60%–75% in angiosperm seeds. The main carbohydrate components in plant cells include starch, cellulose, hemicelluloses, arabinoxylans, and pectic substances. Among monosaccharides, glucose, fructose, and galactose are frequently studied, while disaccharides like maltose and sucrose also play essential roles in energy storage. Medicinal plants, especially those with storage organs, are important sources of both low-molecular-weight carbohydrates and polysaccharides with pharmaceutical applications. Some plants, such as boldo, have their carbohydrate profiles well-characterized (Buchanan et al., 2015; Verpoorte et al., 2000).

1.23.2 Lipids

Lipids are integral to plant cells, making up about 35% of their mass, with fatty acids being particularly abundant in leaves. These compounds serve multiple functions, including energy storage, structural support, and cellular protection against water loss. Medicinal plants contain a variety of lipids, including fatty acids, acylated steroids, acylated flavonoids, and triterpenoids. The lipid bilayer of plant cell membranes, composed of glycerolipids, glycerophospholipids, sphingolipids, and sterols, is essential for maintaining membrane integrity. The fatty acid composition of plants, influenced by metabolic and environmental conditions, typically includes linolenic acid (18:3 cis-9,12,15) and erucic acid (22:1 cis-13), with seed oils being rich sources of essential fatty acids like linoleic acid and α-linolenic acid. These fatty acids are precursors to more complex, unsaturated fatty acids found in animal cell membranes. Halophytic plants, growing in saline environments, produce unique fatty acids not found in terrestrial plants (Dillard and German, 2000; Liu, 2004).

1.23.3 Proteins

Proteins are considered an important class of molecules in living organisms. Although their role in medicinal plant extracts has been little studied, commercially, some enzymes from this group stand out, such as papain, which has several uses and does not require much knowledge of the possible biological properties, but rather the enzyme action. The uses for the medicinal qualities of the plant are the least desirable. However, whether the presence of these proteins in the composition of the extracts of these plants is merely casual or presents more concise biological activities that can justify the attention of researchers, the fact is that ignoring this class could hinder potential investigations using medicinal plants as a source. Currently, the secondary metabolites are much better understood in the plant kingdom and have shown the protein genes that code for the enzymes that play a role in the synthesis of some of these products. In this sense, the identification of proteins in the composition of the extracts of medicinal plants could be a shortcut for determining the real biological activity in a much simpler way, requiring long periods of purification and characterization of specific secondary active substances (Buchanan et al., 2015; Verpoorte et al., 2000).

1.23.4 Nucleic Acids

Although the nucleic acid content of medicinal plants is not high compared to carbohydrates, lipids, amino acids, organic acids, sterols, minerals, and some other compounds, it is still an important component of plant metabolism. Moreover, apart from the well-known commercial value of DNA and RNA enzymes as enzymes, some nucleic acid derivatives have gained importance in therapy in recent years, such as acyclovir, azidothymidine, acycloguanosine, vidarabine, and familial polyposis treatment agents. The measurement of nucleic acid content is generally carried out traditionally with indirect spectrophotometric methods. In these methods, absorbance measurements taken at certain wavelengths for unknown nucleic acid samples are compared to standard solutions; then the sample is given a numerical value. The indicated measurement methods generally do not distinguish between DNA and RNA in the samples, nor do they selectively present individual concentrations. They display total nucleic acid concentrations. Moreover, the amounts of non-nucleotide substances such as ribose in RNA and phosphine in DNA are the same, so the accuracy of measurement and sampling are important factors in the measurement of total nucleic acid content of a nucleotide solution or extract of a plant sample (Liu, 2013; Wang and Meckling, 2002).

Nucleic acids, especially deoxyribonucleic acid (DNA), are essential in medicine and molecular biology. It was shown in various sections in the existing literature that nucleic acids and their derivatives have been used in drug and antitumor therapy. Nucleic acids are an indispensable component in the determination and analysis of diseases through the detection of genetic diseases. They are used in the identification of living organisms. The estimation and purity control of nucleic acid derivatives such as acyclovir, azidothymidine, acycloguanosine, vidarabine, and familial polyposis treatment agents are important. The five primary elemental components of nucleotide compounds, which are the monomer compounds of nucleic acids, constitute two types of purines: adenine, guanine, and pyrimidines: thymine, cytosine, and uracil. DNA carries genetic information. It is found in the genetic material of living organisms in its natural form. RNA carries genetic information for some viruses. However, RNA is capable of operating as genetic material in some viruses. In both types of nucleotide compounds, the ratio of caffeine is found in heterogeneous structures in the body. Large sections of these phosphates are found in polynucleotide chains. Although mononucleotides contain a minimum of one phosphate compound bound to the cell residue, each is a constituent. These subunits are also considered to be the basis. The expected potential roles of nucleic acids are too many to list in a single section due to the widespread use in the field of medicine (Liu, 2013; Wang and Meckling, 2002).

1.24 ADVANCEMENTS IN EXTRACTION TECHNIQUES: TRADITIONAL METHODS AND MODERN INNOVATIONS

Extraction is the process of fractioning feedstocks or bioproducts with solvents into solution and is widely used in many fields such as food, flavor, pharmaceuticals, active principles, and biofuels. Among traditional means of extraction, techniques used in the laboratory that have been inspired by ancient processes include heat/boiling or leaching, solvent extraction, drying, and mechanical separation. These classical methods have numerous limitations, including high expenses and low output. Consequently, technologies are rapidly emerging to address the slow rates and low efficiencies when extracting natural bioactive compounds. New, advanced, and innovative technologies available in the field of healthy, functional, and medicinal foods are focused on the fast extraction of bioactive molecules; several of these make use of enzyme, ultrasonic, microwave, or high hydrostatic pressure-assisted extraction. Other methods include supercritical fluid extraction, pressurized liquid extraction, pulsed electric field extraction, and efficient bacterial lysis treatment. These methods have also been employed. These new techniques not only address low yields and sluggish extract rates, but they also decrease the effects of procedure conditions on bioactive molecules. The described examples of cutting-edge technologies encompass the latest progress in extraction procedures and their potential applications for therapeutic foods (Liu, 2013; Wang and Meckling, 2002).

1.25 EXTRACTION TECHNIQUES

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1.26 ANALYTICAL METHODS FOR PHYTOCHEMICAL CHARACTERIZATION

The term "phytochemical" is commonly used to describe those chemicals from plants that are associated with either traditional herbalism or compounds from plants that are associated with negative effects. Methods have changed over the last two or three generations from simple methods utilized to extract easily accessible substances, such as alkaloids, to an arsenal of techniques that enable the identification and quantitation of compounds present in fruits, vegetables, and processed plant materials. The primary driving force for some of the early work was the availability of the compound of interest, but with advances in technology and interest in plant components, more compounds are being characterized. The experimental approaches to identify and quantitate these compounds from plant materials have been called phytochemical analysis, the characterization of plants and measures for the identification of plant components. Techniques have been used to identify secondary metabolites, phenotyping of plants, and analytical methods of higher throughput, as plants were characterized for these various purposes. In recent years, advances from discussions about linking separation techniques with informational databases and using mass spectrometry for non-targeted assays have generated many new questions in phytochemical analysis, such as what data are generated by non-targeted analysis, how do we express the results in a manner that others can understand the analyses performed, and how to promulgate consensus guidelines among scientists concerned with the expression of phytochemical data (Buchanan et al., 2015; Verpoorte et al., 2000).

Phytochemicals are a group of chemicals that form part of the secondary metabolism of plants and fungi. They are mainly responsible for color, aroma, and flavor and act as deterrents to the harmful effects of solar ultraviolet radiation, pests, and diseases in the epidermis. The complex mixture of phytochemical compounds can be divided into several structurally related classes, such as polyphenols, carotenoids, alkaloids, sulfides, and thiols, which contain sulfur. Although some favorites from all these classes may also be found in other kingdoms, this categorized list may give the impression that they are well-defined and separate classes. In actuality, they are an intricate network of hundreds of compounds, some of which are narrowly biochemically related. The phytochemical substances show various bioactive properties, such as antioxidant, anti-inflammatory, antimicrobial, antiallergic, antithrombotic, and antitumor activity against all stages of carcinogenesis (Buchanan et al., 2015; Verpoorte et al., 2000).

In addition, many of these bioactive compounds are also part of the human and animal diet, contributing to their health and well-being. Every day, more pharmacologists, biologists, toxicologists, and ultimately the public have a higher interest in these phytochemical substances because they are looking for healthy foods. They now consider vegetables not only as a simple diet but also as a great source of bioactive molecules and functional ingredients, whose activities are similar to those of some marketed medicines. They are demanding information about the possible role of these substances in the health, diet, and nutrition of human beings. This interest in finding new mechanisms for maintaining good health has led to an increasing search for compounds present in plants that can be useful for this purpose (Buchanan et al., 2015; Verpoorte et al., 2000).

1.27 BIOACTIVITY AND PHARMACOLOGICAL PROPERTIES OF PHYTOCHEMICALS

Plant bioactive compounds, or phytochemicals, can be used as drugs, or their interactions with modern medications can be evaluated based on data on their pharmacokinetic and pharmacodynamic profiles. The absorption, distribution, metabolism, and excretion are major pharmacokinetic factors that determine the exposure of bioactive components to the human body and the residence time in target organs. Changes in bioactive compounds, post-metabolism, and metabolites can be related to their pharmacological activities and to predicting pharmacodynamic interactions with other components or molecules and may clarify or avoid potential interactions with other drugs. The relationships between bioactive chemicals or their metabolites and biological effects are a research area that has attracted an increasing amount of interest in recent years. The identification of target proteins or enzymes is a major challenge, and chemical proteomics and other high-throughput screening technologies are available to help with this area of research. Moreover, pharmacological evaluations, including in vivo and in vitro assays, computer-aided signal pathway prediction, and prodrug creation, are potent therapeutic methods for using and obtaining drug–plant interactions (Basu et al., 2019).

1.28 ABSORPTION, DISTRIBUTION, METABOLISM, AND EXCRETION

Metabolism is a crucial step during xenobiotic entry into systemic circulation from blood and the initiation of biological activity. Metabolism may be desirable or to be avoided, and will show a great impact on biodistribution and pharmacokinetics of phytochemicals. In the process of drug discovery and preclinical development, absorption, distribution, metabolism, and excretion (ADME) studies are of considerable importance. Normally, ADME is the standard process used to predict drugs' pharmacokinetic properties and elucidate the relationship between drugs' structure and function. Numerous in vitro and in vivo models have been established to evaluate these processes. For oral absorption of phytochemicals, the most high-throughput and economical way is to predict their transcellular transport. In the recent two decades, many Caco-2-based in vitro experiments and bi-directional experiments have been conducted, disclosing the transmembrane transport mode of numerous phytochemicals. Moreover, as a very good model of the blood–brain barrier in the fields of life sciences, in vitro models for the blood–brain barrier and advanced, currently used in vitro models were constructed to evaluate the effectiveness and passage of paracellular diffusion of phytochemicals. To reveal the bioavailability of compounds, there are some other methods of in vitro models, such as the everted rat gut sac model, rat single-pass intestinal perfusion, and in situ rat intestinal perfusion approaches. Additionally, dialysis, liposome formulations, microemulsions, and lipid formulations were also employed to determine the permeability and behavior of bioactive substances. Many studies have shown that the metabolism of phytochemicals in colon-associated microbiota, phase 1 metabolism reactions, and phase 2 glucuronidation is important in affecting the bioavailability of phytochemicals. Through metabolism in vivo, plant-derived bioactive substances may be converted to more easily absorbed, more effective, less toxic chemicals, which not only provide a new outlook for the drug innovation of natural products but also display a new molecular target for the therapy and prevention of some stubborn diseases (Basu et al., 2019; Manach et al., 2004; Tomas-Barberan and Espin, 2001).

Many plant metabolites with biochemical functions exhibit bioactivities when ingested. The specific mechanism of action of any one may be described by a single unique term which, nevertheless, can usually be traced back qualitatively to a relatively small number of well-understood fundamental processes. The elements may be classified as the basic events, with respect to the uptake in the biosystem, the elements of the drug effect, and the critical events with respect to the biochemical function of the agent; additional explanations are presented below (Manach et al., 2004; Tomas-Barberan and Espin, 2001).

The substance belonging to the plant metabolites can only exert its specific pharmaceutical effect if it is absorbed and essentially retained in the biosystem with respect to the expected duration of the drug effect. Thus, within an application period, the concentration–time course of the substance in the blood, which is in equilibrium with the concentration in the interstitial cell fluid, is determined by the uptake during the application, the subsequent absorption, the various processes controlling the systemic distribution, and ultimately the elimination. The quantitative evaluation of these processes, following the principle of mass conservation, can be performed by pharmacokinetic methods, which usually determine the kinetics of a particular labeled cent for the respective unlabeled molecule (Manach et al., 2004; Tomas-Barberan and Espin, 2001).

1.29 BIOTECHNOLOGICAL APPROACHES IN PHYTOCHEMICAL PRODUCTION

The progression of industrially important natural products through metabolic engineering will be facilitated through advances in large-scale genomic, analytical, and bioinformatics technologies. Genomic resources, particularly those enabling sequence-based comparative genomics, have greatly accelerated gene and pathway discovery in many organisms. Transcriptomics, ensuring access to rational design for unexplored tissues and cell types with specialized metabolic functions, is increasingly helping to underpin gene identification. High-throughput metabolite profiling and new analytical methodologies for both metabolite identification and improved substrates for metabolic engineering are now available. Interestingly, the analysis of natural products and their biosynthetic enzymes draws upon a range of techniques and technologies, often adapted from disparate laboratories with specific expertise or capabilities. Integration of these large-scale methods with traditional genetic and biochemical proof of function promises to help bridge the conceptual gap between single-gene functional proof of effect, through complex metabolic and other regulatory networks, toward a systems understanding of a synthetic biology outcome (Williamson, 2017).

1.30 BIOTECHNOLOGY: TRANSFORMING AGRICULTURE, MEDICINE, AND SOCIETY

Biotechnology, which integrates biological and physical sciences, has been instrumental in various human advancements for centuries. While the term *gene* was coined a century ago and the structure of DNA was discovered in 1953, the first recombinant gene patent was granted only about 50 years later. Since that breakthrough, biotechnology-related patents have surged, fostering innovations in diverse sectors like food, pharmaceuticals, and biofuels. Agriculture and medicine have notably benefited from these developments, enhancing both the global economy and societal well-being. Biotechnology's potential, however, extends far beyond current applications. One of the key areas where biotechnology has demonstrated its value is in the production of secondary metabolites, particularly those derived from plants. Secondary metabolites, which are organic compounds not directly involved in the growth, development, or reproduction of plants, have a vast array of applications in industries such as pharmaceuticals, cosmetics, and food production. These metabolites often exhibit therapeutic properties, such as antimicrobial, anti-inflammatory, and anticancer effects (Verpoorte, 1998; Wink, 2010).

1.31 ADVANTAGES OF PLANTS IN BIOTECHNOLOGY

Plants offer several advantages as sources of secondary metabolites. First, they have rapid growth rates, allowing for scalable production in a relatively short time frame. Second, their metabolic profiles are amenable to modification, making them ideal candidates for biotechnological interventions. Additionally, plants are considered ethically safe sources of bioactive compounds, as there is little controversy over utilizing them compared to animals or microorganisms, which may raise ethical concerns. For these reasons, plants continue to be a preferred choice for the bioproduction of valuable compounds (Manach et al., 2004; Tomas-Barberan and Espin, 2001).

1.32 SYNTHETIC BIOTECHNOLOGY AND CUSTOMIZED BIOCATALYSTS

Recent advancements in biotechnology have introduced new platforms for the design of customized biocatalysts, which can be tailored for the synthesis of natural products. These tools enable researchers to unlock plant biosynthetic pathways that were previously unexplored. Synthetic biology, a subfield of biotechnology, plays a crucial role in this regard by enabling the engineering of organisms (such as plants) to produce commercially important metabolites that might not be produced naturally in significant quantities. By manipulating the genetic makeup of plants, synthetic biotechnology can enhance the production of specific compounds. This approach allows for the efficient production of rare or difficult-to-extract bioactive molecules, offering a more sustainable and scalable alternative to traditional extraction methods. For instance, bioengineering plants to produce high yields of alkaloids, flavonoids, or terpenoids can revolutionize the production of pharmaceuticals and nutraceuticals (Manach et al., 2004; Tomas-Barberan and Espin, 2001).

1.33 FUTURE PROSPECTS AND APPLICATIONS IN AGRICULTURE

The application of synthetic biotechnology in agriculture holds great promise, especially in the context of improving crop resilience, yield, and quality. Through the genetic modification of plants, researchers can develop crops that are more resistant to pests, diseases, and environmental stressors, thereby enhancing food security. Furthermore, synthetic biology can be applied to optimize the synthesis of biofuels from plants, contributing to the development of sustainable energy sources. The field of biotechnology is rapidly evolving, and its potential applications are vast. The ability to harness plant-based systems for the production of secondary metabolites, combined with synthetic biology tools to engineer new biosynthetic pathways, is a game-changer. The integration of these technologies offers the possibility of creating customized biocatalysts and bioproducts that can address critical challenges in agriculture, medicine, and environmental sustainability. As the field continues to grow, it will likely transform industries and contribute to solving some of the most pressing global issues (Manach et al., 2004; Tomas-Barberan and Espin, 2001).

1.34 REGULATORY AND QUALITY CONTROL ASPECTS IN PHYTOCHEMICAL RESEARCH

The establishment of quality parameters for existing or emerging herbal plants and bioactive compounds, as well as their technologically integrated products, is particularly important for their full characterization, establishment, and security. These parameters are required for these products to obtain acceptance by worldwide scientific regulatory and sanitary authorities. A wide range of well-established scientific methods, criteria, and experimental tools exist that adequately and effectively address and cover regulatory and quality control expectations. In particular, general and monograph-based methodologies and specifications have been created for the most well-known herbal plants and some of their principal compounds, widely establishing safety and efficacy thresholds for their known therapeutic applications. Some phytodrugs are approved based on phytochemical and quality control precepts and national monographs. Chemical markers, threshold levels, detailed analytical methods, and general and pre-formulated finished product specifications are available for this purpose. Despite the numerous virtues and benefits of regulatory guidelines and quality control implementation, transcripts of tacit explanations from successful implementers of such guidelines are hardly found, especially from developing countries (Manach et al., 2004; Tomas-Barberan and Espin, 2001). The narrative of their successful implementation is an aspect of the discussions of this review that reflects on already commercialized phytomedicines. With our advanced experience, we discuss our successfully accepted three-stage animal studies using a polyherbal product for scar-free wound healing. An in-house documented study was reported previously, but the manuscript and photograph were lost, making it appear as if this very successful study did not take place, which had indefinite adverse domestic and international consequences. Closer collaboration was made with the university regulatory authority (Tsao, 2010; Shahidi and Ambigaipalan, 2015a, 2015b). Such rigorously defined collaboration cemented the quality control infusion in the most recent study for an MVSc degree, a collaborative effort between the academic supervisor and the livestock farm manager. These collaborations align with debates about the need for close collaboration between the laboratory and the livestock field. These studies made a significant difference regarding the milestones that they have achieved, akin to using actual reserves for stem cell amplification instead of embryonic stem cells.

Our insight is that an open mind can redefine any tradition to make it more successful in the postmodern era (Manach et al., 2004; Tomas-Barberan and Espin, 2001).

The establishment of quality parameters for both existing and emerging herbal plants, their bioactive compounds, and their technologically integrated products is crucial for their full characterization, establishment, and safety. These parameters are essential for obtaining acceptance from worldwide scientific regulatory and sanitary authorities. A wide range of well-established scientific methods, criteria, and experimental tools exist to adequately and effectively meet regulatory and quality control expectations. In particular, general and monograph-based methodologies and specifications have been developed for the most well-known herbal plants and some of their principal compounds, setting safety and efficacy thresholds for their established therapeutic applications (Tsao, 2010; Shahidi and Ambigaipalan, 2015a, 2015b). Some phytodrugs are approved based on phytochemical and quality control precepts, as well as national monographs. Chemical markers, threshold levels, detailed analytical methods, and pre-formulated finished product specifications are available for this purpose. Despite the numerous advantages of regulatory guidelines and quality control implementation, there is a noticeable lack of detailed accounts from successful implementers of these guidelines, particularly from developing countries. The narrative of their successful implementation is often overlooked, especially in relation to commercially available phytomedicines. In our experience, we discuss our successful implementation of a three-stage animal study involving a polyherbal product for scar-free wound healing. Although an in-house documented study was previously reported, the manuscript and photographs were lost, which gave the impression that the study did not occur, with indefinite adverse consequences both domestically and internationally. This situation prompted closer collaboration with the university's regulatory authority, which solidified the integration of quality control into the most recent study for an MVSc degree. This collaboration was a joint effort between the academic supervisor and the livestock farm manager. These partnerships align with discussions on the importance of close collaboration between laboratory and livestock field settings. These studies have significantly impacted the milestones they have achieved, akin to using actual reserves for stem cell amplification instead of embryonic stem cells. Our insight is that an open-minded approach can redefine traditional methods, making them more successful in the postmodern era (Tsao, 2010; Shahidi and Ambigaipalan, 2015a, 2015b).

1.35 FUTURE TRENDS AND INNOVATIONS IN PHYTOCHEMICAL RESEARCH

Phytochemicals are naturally occurring substances produced by plants, known for their biologically active compounds present within the plant matrix. These non-nutritive factors, often found in small quantities, can have a significant impact on human and animal cells. Phytochemicals typically provide exclusive health benefits, contributing to their recognition in both traditional and modern medicine. The scientific discipline of pharmacognosy, which involves identifying and isolating medicinal compounds from plants, plays a crucial role in the development of phytochemicals. Pharmacognosy is closely aligned with organic and medicinal chemistry, creating an interdisciplinary field that has evolved over time to bridge the gap between science, medicine, and commerce. The term "phytochemistry" is often used in this context as it refers to the study of phytochemicals and other chemical substances produced by plants. Many medicines have been discovered and developed from plant sources and subsequently personalized for specific human disorders (Tsao, 2010; Shahidi and Ambigaipalan, 2015a, 2015b). As such, the chemistry of phyto-constituents is an essential area of drug research worldwide. There are at least 12,000 species of plants used in herbal remedies, highlighting the significant demand for these plant-based products. Phytochemical molecules found in plants are not only used to develop drugs for treating diseases but also contribute to nutritional benefits.

The medicinal properties of plant species have been documented for centuries, providing an earlier biological reference that has been scientifically validated in the modern era. The active principles in plants have been identified, and their properties are chemically defined, further supporting the use of plant-derived substances in treating various ailments. Today, many pharmacologically active substances derived from phyto-constituents are widely recognized. These include flavonoids, terpenoids, sulfur-containing metabolites, essential oils, polyacetylenes, and polyphenolics, each offering unique therapeutic potential (Liu, 2013; Suleria et al., 2020).

Phytochemicals are naturally produced by plants and consist of biologically active compounds present in small quantities within the plant matrix. Although non-nutritive, they have significant impacts on human and animal health, often displaying exclusive healthcare benefits. The scientific discipline focused on identifying and isolating medicinal compounds from plants is known as pharmacognosy, which draws heavily on organic and medicinal chemistry. Modern pharmacognosy is an evolving multidisciplinary field that integrates science, medicine, and commerce.

Phytochemistry, the study of phytochemicals and other plant-derived chemicals, plays a crucial role in drug research worldwide. Over 12,000 plant species are used in herbal remedies, reflecting the high demand for these natural medicines. Phytochemical molecules not only provide nutrients but can also be developed as effective drugs to combat diseases. Historically, medicinal properties of plants have served as biological references, now scientifically validated by identifying active principles and chemically defining their effects. Natural medicines have been used for centuries to treat various ailments, and many pharmacologically active substances from phyto-constituents continue to be recognized for their therapeutic value (Liu, 2013; Suleria et al., 2020).

1.36 CURRENT CHALLENGES AND FUTURE DIRECTIONS

Modern society deals with an increasing number of challenges where the information extracted from data can significantly contribute to minimizing their impacts. The unprecedented rise in internet activity brought a tremendous increase in data. People use different devices, such as smartphones and sensors. The shift in using such devices means they are capable of producing data every time we interact with them. A second main issue is that most of the data is geospatial, including different types such as cadastral, administrative, and remote sensing information. Location is the data component that can add value to any dataset. A simple sensor located at a point can provide valuable information. Future challenges have to offer more spatial information to our dataset. This paper considers Big Data with its four V challenges and how it can provide value to society, unlike in cases when it usually degrades to be misused, toxic, irrelevant, and ignored (Tsao, 2010; Shahidi and Ambigaipalan, 2015a, 2015b). Population statistics are another important dataset that can provide value only when they are correctly integrated with other socioeconomic datasets. While Big Data and related technologies contributed to increasing the number of methods in allocating sensors, with the Smart Cities experience being a case in point, many other issues limit such applications to people willing to use digitalization. The exclusion of a significant number of people from the benefits that Big Data and derived analytics could bring in such application areas leads to a higher risk of abuses and hence affects the popularity of Smart Cities. For over 400 years, research and study of mixed samples have affected the development of extraction methods as well as innovations in analytical chemistry. Extraction is already familiar in nature, where it occurs in contact with the air or soil, for example. Historically, the discovery of solvents coincided with the first extractions. New solvents were quickly introduced in order to isolate new compound classes from complex samples. The search for new target compounds not only stimulated the development of selective solvents but also methods to increase extractability, such as derivatization or the chemical manipulation of the sample. Improvements in sample selectivity and detectability provided new solutions, with important successive innovations resulting from the development of hyphenated techniques. Liquid chromatography and gas chromatography provide a simple means of isolating chromatographic compounds, particularly when they can be directly injected. Chromatography has provided new stimuli for both extraction and derivatization. Separation methods overlap in new analytical tools such as capillary electrophoresis, which rely on slightly modified extraction methods. The role of extraction is omitted, for the most part, in newer instrumental techniques that rely on separative steps embedded within the instrumentation or perform the extraction process directly online with considerable success. This is most common with the extraction methods using ion exchange and reversed-phase sorbents. When it is necessary to reduce the sample complexity, directly insert the entire sample into the instrument. The adsorption effect can be obtained by means of sophisticated immunoextraction techniques using magnetic particles with an attached primary antibody or protein, followed by a separation step, namely, liquid chromatographic analysis. Other techniques have taken advantage of specific analyte binding filters based primarily on size, retention or affinity, and filtration or affinity separation steps embedded within the instrumentation. Utilizing immunoaffinity purification techniques often follows biological sample extraction and cleanup prior to bioanalytical determination. Many other ways have been implemented to simplify the process using filters, absorbents, foams, sponges, fibers, ion exchangers, supercritical fluids, and chromatographic methods (Tsao, 2010; Shahidi and Ambigaipalan, 2015a, 2015b).

Every year, the development of science and new approaches in various industries improves our lives, from marketing to medicine. Here, the extraction and analysis of different subspecies and microorganisms are becoming increasingly important. For example, in the food industry, the production of certain enzymatic reactions and microorganisms allows for the creation of highly stable products that meet high nutritional requirements. In modern chemical and fruit-growing associations, the utilization of mold and the strengthening of microorganisms for the production of bioactive compounds and other ecological specimens will involve fewer averaging procedures. Another example is the development in the pharmaceutical industry, where the production of natural bioactive drugs from rare and clinically relevant fungi is already being implemented with carefully regulated growth conditions and extraction methods. Not long ago, bioreactor makers gained knowledge of fungi, technological resources, and developed tools for obtaining almost any organic molecule. The last processed system is an X-ray system for analyzing the physical properties of fermented fungi. The main trend in the high-intensity industry is the direct processing of various commercially valuable products by stimulating the production of primary and secondary metabolites during the simulation of specific growth conditions (Crozier et al., 2006). In the food, beverage, and pharmaceutical industries, the development of many reactive fungi has gradually become a standard approach through synergistic feature extraction. Fundamental setup. Low-energy reactions require organic solvents in a very fast manner; for example, it is based on supercritical fluid extraction. Since most fermented products are not waste products, collaboration is carried out only during the final extraction step. The main task in this field is the planning and replication of bioreactor scales with the extraction setup that experts can use without disturbing development from one end of the chain to the other (Tsao, 2010; Shahidi and Ambigaipalan, 2015a, 2015b).

Phytochemicals are substances naturally produced by plants and are known to have different biologically active compounds present in their plant matrix or plant material. These are non-nutritive factors that are present in small quantities but have a high impact on human and animal cells. Phytochemicals generally display exclusive health care benefits. The process of identifying and isolating medicinal compounds from plants is known as the scientific discipline of pharmacognosy. Organic chemistry and medicinal chemistry are heavily drawn upon by pharmacognosy. Meeting together science, medicine, and commerce for modern pharmacognosy has been a continuously evolving multidisciplinary field. “Phytochemistry” is referred to by the term often because it is the study of phytochemicals and other chemicals produced by plants. Many medicines have been discovered and developed from plant sources and then personalized for use in unique human disorders. The chemistry of phyto-constituents is therefore an important part of drug research in the world. There are at least 12,000 species used in herbal remedies, demonstrating the enormous demand for these plants. Phytochemical molecules found in plants can be used and developed as efficient drugs to fight diseases, in addition to providing nutrients. The medicinal properties of plant species have been documented to provide an earlier biological reference. This has been scientifically underpinned in the modern era by identifying the active principles in plants and chemically defining their active properties. Natural medicines have been curing diseases for centuries. Currently, many pharmacologically active substances observed in phyto-constituents are recognized, like flavonoids, terpenoids, sulfur-containing metabolites, essential oils, polyacetylenes, and polyphenolics (Crozier et al., 2006).

Interest in the chemistry of plants has never been greater. Understanding their intricate bioorganic processes has profound implications for mankind, and, so far, our reliance on plants as chemical manufacturing units has always underscored this relationship. Even in this modern society in which "magic bullets" are becoming increasingly important in medicine, the role of natural products is still astonishingly impressive, for by 1973, over 89% of the drugs currently in use might be traced in one way or another to compounds derived from plants. Dispiritingly, or perhaps inspiringly, the indigenous people of the world, both past and present, have been utilizing these compounds, frequently as botanical remedies, for a long, long time (Crozier et al., 2006).

"Phytochemistry" has come to imply a study of biological phenomena using chemicals as the tools, not an inappropriate time when, as we have said, the potential importance of the vast array of plant compounds has never been of greater interest, nor has the need to understand their biosynthesis and modes of action been more urgent. To the chemist, "phytochemistry" often signifies the characterization of the complex mixtures of natural products, irrespective of their purpose or origin. In this chapter, we shall attempt to introduce the plant chemist to the rapidly changing world of phytochemical research. We shall be less concerned with the nomenclature of plant products, for these can be found in the updated appendix to a recent botanical chemical dictionary. Phytochemicals, the bioactive compounds found in plants, have emerged as a new class of compounds with various biological activities. Phytochemicals, including flavonoids, carotenoids, phenolic acids, alkaloids, nitrogen-containing compounds, terpenoids, and polyacetylenes, are usually found in plants and are not essential nutrients. In recent years, it has been found that phytochemicals are not only capable of preventing oxidative damage, but they can also protect food and the body from being damaged by the environment, thereby providing potential health benefits, such as preventing cancer and cardiovascular diseases, regulating the immune system, reducing inflammation, and exhibiting antibacterial properties. In addition, the roles of prebiotic effects and the ability to relieve age-related macular degeneration and alleviate diabetes complications have been found in some phytochemicals. Thus, the study of plant-derived bioactive substances is becoming increasingly important (Tsao, 2010; Shahidi and Ambigaipalan, 2015a, 2015b).

Although phytochemicals can be found in fruits, vegetables, grains, and nuts, they are not direct energy sources, and they are not as easily absorbed as macronutrients to meet the energy demands of the body. Therefore, the potential health benefits of phytochemicals are not fully realized. In addition, a complex mixture of phytochemicals may cause unexpected interactions that inhibit nutrient or drug absorption and cause an imbalance in the body (Tsao, 2010; Shahidi and Ambigaipalan, 2015a, 2015b). In order to solve this problem, it is necessary to study the extraction, separation, and synthesis of target phytochemicals and analyze their function and efficacy from different aspects, such as structures, mechanisms, activity, bioavailability, and metabolism. The potential mechanisms of these activities need to be explored (Williamson, 2017). Based on the characteristics of phytochemicals and their potential health benefits, some phytochemicals have been developed into functional components, functional foods, or dietary supplements for health needs. In this chapter, the recent specific research trends and findings, including the identification and structural modification of novel bioactive components, the synergistic effect of phytochemicals and gut microbiota, and the role of phytochemicals in bioactivity, are discussed in detail. The final section presents future perspectives on research related to phytochemicals (Tsao, 2010; Shahidi and Ambigaipalan, 2015a, 2015b).

Phytochemicals can be classified as primary or secondary metabolites according to the function they play in the plant's life cycle. Primary metabolites consist of those materials that are essential for a plant to survive. In summary, primary metabolites include sugars, amino acids, and vitamins. Here, sugars are important for phloem transport, amino acids are the basic building blocks of proteins, and vitamins allow the plant to grow and develop despite unfavorable external conditions. We can infer that glycosides or glycosidic flavors are primary metabolites since the sugar and aglucone groups are the basic ingredients of these compounds. On the other hand, secondary metabolites aren't necessary for a plant's survival but are there mainly for their survival value. They are further classified as attracting insects, preventing herbivores, blocking solar radiation, and preparing alternative environments for the continuation of their species. Terpenes, flavonoids, and phenolic compounds can all be classified as secondary metabolites (Agbangba et al., 2024).

The distinction can also be made based on their chemical structures. What will be considered here are the six main classes of phytochemicals: carbohydrates, lipids, amino acids, terpenes, alkaloids, and polyphenols. Changes in carbohydrate metabolism in response to environmental stress are well documented. Lipids composed of fatty acids are mentioned in greater detail in the evolutionary impact section. A special type of lipid about glycosides called glycosides is also found in plants, and oleuropein is an example. Essential amino acids and branched-chain amino acids produced by plants are cheaper and made naturally, whereas the regulatory amino acids, which are usually composite proteins, and non-essential amino acids are expensive and not made. Due to their biological activities, many plants with phenolic and polyphenolic compounds have been utilized as helpful agents against a variety of microbial infections. The concentrations of phenolic compounds in active plants are well known to vary according to a large number of factors, including plant genetic material, the influence of external factors, and the various stages of plant development (Abdallah et al., 2019, Agbangba et al., 2024).

1.37 CONCLUSION

Recent advancements in extraction technologies have revolutionized the efficiency, sustainability, and scalability of phytochemical isolation from medicinal plants. Future research aims to optimize these processes, integrate innovative technologies, and ensure extract standardization and bioavailability. By fostering interdisciplinary collaboration and adhering to green chemistry principles, the therapeutic potential of phytochemicals can be harnessed effectively, paving the way for sustainable medicinal product development.

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Naturally Derived Antimicrobial Agents in Food Packaging Material

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