NOVEL EXTRACTION METHODS FOR HERBAL PRODUCTS

A COMPREHENSIVE REVIEW

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Novel Extraction Methods for Herbal Products: A Comprehensive Review

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FOREWORD

The journey from raw plant materials to refined herbal products is a path steeped in history, science, and innovation. As humanity has sought to harness the medicinal and therapeutic powers of nature, the methods of extraction and processing have evolved dramatically. From the simplest of water decoctions to the sophisticated technologies of today, each advancement in extraction techniques represents a leap forward in our ability to produce safer, more effective, and higher-quality herbal products. **"Novel Extraction Methods for Herbal Products: A Comprehensive Review"** comes at a pivotal moment in this evolutionary journey. In an era where consumers are increasingly aware of and interested in the quality and efficacy of the products they use, the demand for pure, potent, and consistent herbal extracts has never been higher. At the same time, the industry faces mounting pressures to reduce environmental impact and improve sustainability in its practices. This book addresses these challenges by providing a detailed exploration of the latest extraction methods that are redefining the herbal industry. It serves as a bridge between traditional techniques and innovative technologies, offering readers a comprehensive understanding of the principles, applications, and benefits of each method.

For researchers and scientists, it provides a solid foundation and reference point for advancing their work in herbal extraction. For industry professionals, it offers practical insights and case studies that can be directly applied to improve processes and product quality. For educators and students, it serves as an essential resource for learning about the latest advancements and trends in the field. One of the standout features of this book is its balanced approach. While it thoroughly explores the technical aspects of each extraction method, it also emphasizes the real-world applications and implications. This dual focus ensures that readers not only gain a theoretical understanding of novel extraction techniques but also learn how these methods can be implemented in practice to enhance product development and meet consumer expectations.

The editors have strived to highlight the critical issues of quality control, environmental impact, and economic viability, providing a holistic view of the challenges and opportunities facing the herbal industry. By doing so, it encourages readers to think critically about the choices they make in their extraction processes and to consider the broader implications of their work. Also, I would like to compliment the authors of all the chapters and acknowledge their efforts in publishing this comprehensive book.

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PREFACE

In an era of increasing interest in natural products and herbal remedies, the methods used to extract active compounds from plants have become a focal point of research and innovation. This book aims to provide a comprehensive guide to novel extraction methods in the herbal industry, highlighting advancements, challenges, and future directions. Whether you are a researcher, industry professional, or student, this book will equip you with the knowledge to understand and apply cutting-edge extraction techniques. The scope of this book encompasses the entire landscape of novel extraction methods used in the herbal industry. It covers a broad range of essential topics for understanding and implementing advanced extraction techniques. This comprehensive guide aims to provide readers with a deep, thorough understanding of historical context and evolution, fundamental principles, modern and innovative techniques, technological advancements, quality control and standardization, environmental and economic considerations, case studies and real-world applications, and future trends and opportunities.

The primary purpose of this book is to serve as an authoritative resource for individuals and organizations involved in the herbal industry. This book is a resource for the herbal industry, providing a comprehensive understanding of novel extraction methods, educating on best practices, promoting sustainable extraction methods and quality control, and navigating regulatory requirements. It encourages innovation and development in the field, identifies knowledge gaps and offers strategies to overcome technical, economic, and regulatory hurdles.

By covering these aspects, **"Novel Extraction Methods for Herbal Products: A Comprehensive Review"** aims to be an indispensable reference for researchers, manufacturers, educators, and practitioners in the herbal industry. It seeks to empower readers with the knowledge and tools needed to leverage novel extraction methods for the development of high-quality, effective, and sustainable herbal products.

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CHAPTER 1

An Introduction to the Herbal Industry and the Importance of Extraction Methods

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Abstract: Due to demand from customers for natural and alternative healthcare remedies, the global market for herbal medicines is rapidly growing. Pharmaceuticals, cosmetics, dietary, and functional food supplements are just a few of the many unique products available on the market. All of these products are in high demand since they are reasonably priced, safe, and have few adverse effects. This industry, which includes cosmetics, pharmaceuticals, nutraceuticals, and functional foods, is a prime example of the immense potential of herbal materials. Worldwide, there is a growing interest in research on natural products. The extraction of bioactive compounds is a crucial stage in the research of natural products. Quickly screening a growing variety of elements has become more challenging. Currently, extraction involves separating the chemical constituents of plant tissues that are therapeutically active from those that are inert, utilizing a variety of extraction procedures. The quality and reliability of subsequent analytical processes depend on the chosen extraction method, making it a crucial decision. The main objective of extraction is to achieve economic viability, environmental friendliness, reduced extraction time, and higher yields of biologically active compounds without compromising biological activity.

Reports indicate that contemporary techniques offer numerous benefits over conventional ones, including reduced processing times, reduced solvent needs, enhanced retention of biological activity, increased yields, and reduced energy consumption. The targeted phytoconstituents, economic feasibility, environmental effects, and plant matrix all play a role in selecting the extraction technique. Both regulatory requirements and customer demand for upscale herbal products depend on understanding and simplifying these processes. This chapter discusses the magnitude of the herbal sector, its market potential, and the necessity of choosing the right extraction technology to ensure sustainability and product innovation.

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Keywords: Cosmetics, Functional foods, Nutraceuticals, Sustainability, Traditional extraction techniques.

INTRODUCTION

The production, manufacturing, and commercialization of herbs used for medicinal, aromatic, and cosmetic purposes are all included in the rapidly developing herbal sector. For thousands of years, numerous societies, such as India, Egypt, and China, have made use of the medicinal qualities of plants to produce a variety of products, such as herbal remedies, nutritional supplements, aromatic oils, and natural beauty items. Modern herbal therapy is based on traditional treatments such as Ayurveda, Chinese and American medicine systems. The understanding of the medicinal qualities of plants has developed over the ages and combined with contemporary science and technology [1].

Market Growth and Trends

Increasing consumer demand for natural goods has led to a significant boom in the herbal industry over the past few years. Concerns about artificial chemicals in pharmaceutical and personal care products, the negative side effects of contemporary pharmaceuticals, the inability to cure chronic illnesses, and bacterial resistance have all contributed to the rise in popularity of herbal remedies in recent years. The pharmaceutical sector makes a substantial contribution to the expansion of the world economy. The herbal medicine market generates $50.9 billion in revenue [2]. 70% of the herbal industry's annual exports consist of raw ingredients, valued at an estimated $10 billion. Ethnic communities have created 25,000 formulations that require recognition, validation, and documentation, and about 8000 herbal species are utilized in ethnomedicine [3]. Many people use herbal products for basic medical requirements, according to the WHO. More than 70% of contemporary drugs in India are derived from natural resources. Synthetic counterparts have been developed using prototype compounds derived from plants. Approximately 80% of antibacterial, immunosuppressive, cardiovascular, and anticancer medications are currently made from plants. Of the 177 approved anticancer medications, more than 70% are derived from natural substances. In Chile and Colombia, 71% and 40% of the population, respectively, use herbal medicine, according to the WHO's Regional Office for the Americas. Herbal medicines are widely used by 70–80% of people in wealthy nations, while 46%, 49%, and 70% of people are expected to use them in Australia, France, and Canada, respectively. About 158 million Americans use herbal or natural remedies. Only 15% of the 250–400 thousand plant species in the world are thought to have had phytochemical studies conducted, and only 6% have had their biological activity investigated. Over 120 chemical moieties originating from plants are used to treat life-threatening conditions, and natural compounds or their derivatives are present in more than 60% of clinically used medications [4]. It is anticipated that the worldwide market for herbal medicines will continue to grow due to a wider choice of products and new uses. The herbal sector is being shaped by a few major trends [5]

- **Health and Wellness:** Customers are using natural remedies for managing chronic illnesses and preventive healthcare as the value of health and wellness rises.
- **Sustainability:** Sustainable sourcing and production practices are becoming increasingly important to both consumers and businesses. Fair trade, organic farming, and ethical harvesting are important considerations.
- **Innovation:** Advancement in herbal goods is being propelled by developments in formulation science, extraction technology, and quality assurance. Herbal remedies are becoming more useful and effective due to new delivery methods like encapsulation and nano-formulations.
- **Regulation:** As the market for herbal goods expands, regulatory frameworks are being developed to ensure the efficacy, safety, and quality of herbal goods. Gaining access to marketplaces and attracting clients requires adhering to these rules.

The herbal industry has a wide range of stakeholders, including:

- **Cultivators:** Farmers and agricultural businesses who specialize in producing medicinal and aromatic plants.
- **Manufacturers**: Companies that extract, process, and formulate herbal goods.
- **Distributors:** Wholesalers and merchants, such as health food stores, pharmacies, and online platforms, bring herbal goods to retail.
- **Researchers:** Innovative extraction techniques are being developed by research organizations such as colleges and universities to explore the medicinal qualities of plants [5].

The industry can be categorized into a number of groups based on the types of items produced:

- **Dietary Remedies:** Tablets, tinctures, powders, and capsules are examples of herbal products.
- **Essential oils** are concentrated extracts of plants used in aromatherapy, skincare, and the development of other therapeutic products.
- **Herbal medicines:** Decoctions for the treatment of particular medical diseases that are based on both traditional and contemporary herbal knowledge.

CHAPTER 2

Evolution of Extraction Techniques

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Abstract: The chapter explores the development of the extraction process technology used for herbal product production, focusing on the transition from conventional solvent-based techniques to more environmentally sustainable approaches. Breakthroughs in this field include the introduction of Soxhlet extraction, Microwave-Assisted Extraction (MAE), Solid Phase Extraction (SPE), and Supercritical Fluid Extraction (SFE). Such innovations improve automation, effectiveness, and selectivity, thereby reducing resource use and environmental impacts.

Keywords: Microwave Assisted Extraction (MAE), Soxhlet extraction, Solid Phase Extraction (SPE), Supercritical Fluid Extraction (SFE).

INTRODUCTION

Crude medications are substances collected from plants, animals, and minerals that are either unrefined or only slightly treated and used in medicine. There are numerous historical medical systems around the world that have been used for centuries, and some are still in use in contemporary medicine. Please take note that crude medications can be dangerous if misused, as they may interact with other medications and pose risks when taken in excess. Consulting a healthcare provider before using any crude medications is essential [1]. Based on anecdotal evidence and historic use, crude drugs may be useful for some diseases. Because of their natural compositions, they may have fewer adverse effects than contemporary prescription medications, are frequently more accessible and less expensive, and serve as the foundation for numerous pharmaceutical discoveries. However, there are dangers such as inconsistent ingredient concentrations due to a lack of standardization, possible contamination with hazardous compounds, haz-

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ardous drug interactions, unknown efficacy due to inadequate testing, and risks from improper use without expert advice. The active constituents of crude drugs are chemical compounds that are responsible for their medicinal properties. These can be various types of molecules, depending on the source of the crude drug [1]:

1. **Plant-based crude drugs:** These drugs often contain active constituents like alkaloids (Morphine, quinine, ephedrine), glycosides (Digoxin, senna glycosides, salicin), terpenoids (Artemisinin, gingerols, ginkgolides), flavonoids (Quercetin, silymarin, apigenin), and volatile oils (Menthol, cineole, limonene). These include herbs, shrubs, spices, roots, bark, leaves, flowers, and fruits.
2. **Animal-based crude drugs:** These drugs may contain active constituents like hormones (Thyroxine, insulin, estrogen); enzymes (Papain, bromelain, trypsin); peptides (Bee venom peptides, salmon calcitonin, thymosin); and lipids (Omega-3 fatty acids, squalene, lanolin). These also include organs, tissues, and secretions from animals. Some common examples are bee pollen, royal jelly, shark cartilage, and deer antlers.
3. **Mineral-based crude drugs:** Natural compounds with therapeutic properties obtained from mineral sources are known as mineral-based crude drugs. Contrary to crude drugs derived from plants or animals, which are derived from biological sources, minerals are extracted from the soil and comprise elements, salts, and compounds that have medicinal properties. These drugs have been used for centuries to treat a wide range of illnesses in both conventional and alternative medicine; for instance, magnesium (Epsom salts), calcium (oyster shells), iron (ferrous sulfate), sodium chloride (table salt), potassium chloride, Kaolin, bentonite clay, *etc*.

Crude drugs can vary in composition and potency, and even within the same plant or animal, variations can occur depending on factors such as growing conditions, processing methods, and storage. Because of this, it is crucial to see a healthcare professional before using any basic medication. They can offer advice on possible drug interactions, side effects, and the right dosage [2].

Importance of Extracting Active Constituents from Crude Drugs

Drug discovery emphasize on removing the active chemicals from crude medications, which are made up of subtle mixes derived from natural sources. Active ingredients are isolated during the extraction process, increasing potency and consistency and resulting in improve precision dosing and predictable therapeutic effects. It improves safety by reducing risks linked to inactive substances and standardizes quality for clinical use. Isolated compounds facilitate further research, enable various dosage forms, enhance stability and storage, support large-scale production, and minimize environmental impact by reducing waste. Overall, extraction significantly optimizes the efficacy and safety of pharmaceutical products [3].

Numerous approaches are used for the extraction of medicinal plants, such as percolation, decoction, digestion, infusion, maceration, ultrasound and microwave-assisted extractions, superficial extraction, Soxhlet extraction, *etc*. Also, different chromatographic techniques like thin-layer chromatography, gas chromatography, paper chromatography, and high-performance liquid chromatography are used in the separation and purification of the bioactive compounds (Fig. **1**)

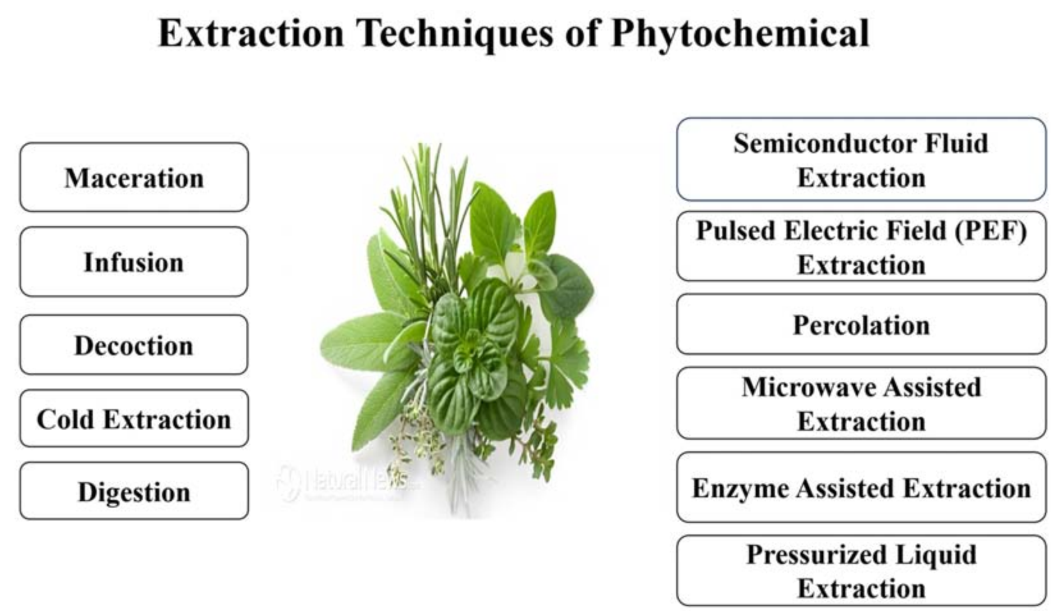

Fig. (1). Different extraction techniques of phytochemicals.

The choice of a suitable extraction process depends on the pH of the solvent, type of plant material, solvent used, temperature, solvent-to-sample ratio, and the proposed use of the resulting products. In general, antioxidant analysis of plants or spices consists of two steps: Extraction (maceration, percolation, Soxhlet) is followed by analysis (high-performance liquid chromatography, gas chromatography or GC–MS, HPLC-MS, MS, and spectrophotometry). The extraction procedure requires several hours, but analysis is completed in 15 to 30 minutes [4].

CHAPTER 3

Fundamentals of Extraction and their Applications

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Abstract: The fundamental principles of extraction methods, including solubility, partition coefficient, and efficiency-affecting components, are included in this chapter. The partition coefficient helps in determining the distribution of substances between immiscible phases, and solubility determines a substance's choice for a specific solvent, depending on solubility and interactions of components. Efficiency is affected by components such as temperature, pH, particle size, and solvent amount/type, which also influence extraction quality and quantity. Following these principles, proper selection of the solvent and process influencing parameters is important for maximizing phytoconstituents recovery with less amount of deterioration. The specificity, sustainability, and overall efficiency of isolated therapeutic constituents for research and therapeutic purposes in extraction are all improved by following these ideas.

Keywords: Efficiency, Extraction procedures, Phytoconstituents, Partition coefficient.

INTRODUCTION

Extraction is an effective technique used across various scientific and industrial fields to isolate compounds of interest from complex mixtures. The main difficulty in extraction is to separate a specific compound or a group of compounds and eliminate undesirable compounds. This method depends on the concepts of solubility and partitioning, in which chemicals disperse between two immiscible phases, usually one that is solvent-rich and the other that contains the sample matrix [1]. Factors affecting extraction efficiency include pH, temperature, solvent polarity, and the physical properties of the compounds being treated. Understanding these principles helps researchers select appropriate solvents, optimize extraction conditions, and improve the quantity, quality, and selectivity of the extracted compounds. Knowing the fundamentals of extraction ensures

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accurate and effective isolation of targeted compounds for application in various fields such as environmental, food science, and pharmaceutical research.

Herbal or traditional medicine is made by extracting and processing medicinal plants or by preparing them for trial. Timely and proper plant collection, professional authentication, adequate drying, and grinding are all necessary to prepare medicinal plants for experimentation. Next comes the extraction, fractionation, and, if required, isolation of the bioactive component. It also entails figuring out the quantity and quality of bioactive ingredients. A summary of the extraction, isolation, and purification of natural compounds is shown in Fig. (**1**). Because of their nature, accessibility in local communities, affordability, ease of administration, and potential lack of complications, plants have recently gained international recognition as a source of medicine. Additionally, in cases of drug resistance and a variety of adverse effects, herbal therapy may be a helpful alternative treatment [2, 3].

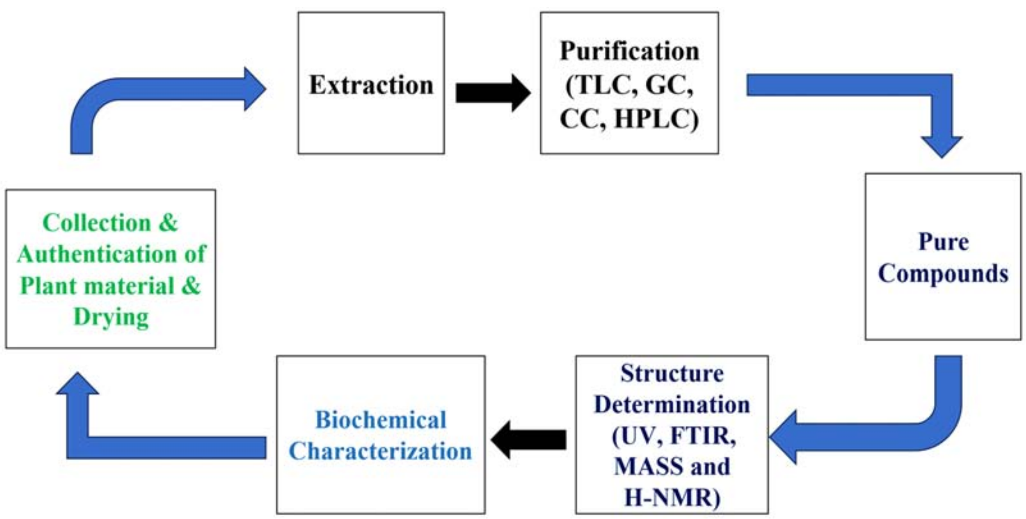

Fig. (1). Summary of extraction, isolation and purification of natural compounds.

Principles of Extraction

1. **Solubility:** The varied solubility of solvents in substances is exploited throughout the extraction process. The solvent, temperature, pressure, and chemical makeup of the substance all affect solubility. Compounds with comparable polarity dissolve in similar liquids. Polar substances dissolve more readily in polar solvents (such as ethanol and water, *etc*.), whereas non-polar substances dissolve better in solvents that are not polar (such as benzene and hexane, *etc*.).

2. **Partition coefficient/Distribution coefficient:** In a mixture of two immiscible liquids at equilibrium, the distribution coefficient (K) is the ratio of the concentration of the solute in one solvent phase to its concentration in the other solvent phase at equilibrium.

$$K = \frac{\text{Conc. of solute in organic phase}}{\text{Conc. of solute in aqueous phase}}$$

It determines a compound's distribution between two phases. The partition coefficient, which is based on the solvents used and the type of substance, affects the extraction efficiency.

1. **Phase equilibrium:** The extraction process creates an equilibrium between the two phases, which are typically aqueous and organic, in which the target compound is dispersed based on its partition coefficient. To achieve balance and maximize recovery, it might be necessary to do successive extractions.
2. **Selectivity:** The ability to isolate the targeted compound preferentially by removing the undesirable compounds is known as selectivity. Various parameters/factors involved in extraction methods play an important role in increasing the selectivity of compounds.
3. **Efficiency:** Various factors, including contact time, speed, and the solvent-to-crude drug ratio, affect extraction efficiency. By proper selection of these factors, efficiency is increased [4].

Factors Affecting Extraction Efficiency (Fig. 2)

1. **Selection of Medicinal Plants:** Ethnopharmacology plays an important role in the selection of herbal plants that are beneficial in the management of illness. It is the study of how people have used these herbal remedies for different diseases across various cultures and helps in identifying and understanding the therapeutic properties of the plants that are believed to have been used historically for the management of certain illnesses. This information helps choose which plants to extract as it provides information about the potential medicinal properties of specific plant species. Contrarily, chemotaxonomy is the study of a plant's chemical composition and classification based on its taxonomical status and chemical components. To determine whether specific compounds or molecular clusters are responsible for a plant's therapeutic properties, it is necessary to analyze the plant's chemical profile. Chemotaxonomy guides the choice of plants that possess particular biologically active substances for extraction and aids in understanding the variety of chemicals present in plants. By combining

CHAPTER 4

Traditional Extraction Methods: The Base for Modern Herbal Extraction

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Abstract: Conventional extraction techniques are essential methods that have been utilized for a long time to obtain bioactive compounds, valuable materials, and essential oils from natural sources, including minerals, plants, and animal tissues. This chapter explores traditional methods such as steam distillation, Soxhlet extraction, percolation, maceration, and decoction. These techniques have served as the basis for contemporary advances in extraction processes and continue to be employed for their cost-effectiveness, simplicity, and compatibility with various materials. In this chapter, different techniques are compared in terms of their concepts, procedures, and effectiveness, along with their respective privilege and drawbacks. Important aspects that influence the effectiveness of traditional extraction are also highlighted. A review of sustainability and the modern adaptations of these age-old methods illustrates their ongoing relevance across sectors such as food manufacturing, cosmetics, and pharmaceuticals. This chapter emphasizes the advantages and disadvantages of traditional methods while outlining their concepts and practices. It establishes a foundation for discussing modern techniques that address the limitations of conventional approaches while enhancing adaptability, affordability, and productivity. By integrating both traditional and modern technologies, it emphasizes the importance of revolutions in today's industrial applications and demonstrates the evolution of extraction technology.

Keywords: Decoction, Infusion, Maceration, Percolation, Steam distillation, Soxhlet extraction.

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INTRODUCTION

Extraction is a vital procedure in many domains, including food science, health, cosmetics, and the chemistry of natural products. It entails extracting flavourings, fragrances, essential oils, bioactive compounds, and other significant elements from natural sources. The oldest and most well- established methods for this purpose are conventional extraction procedures, which were developed over centuries of empirical knowledge and cultural practices. Simple mechanical and solvent-based processes that make use of readily available equipment and ingredients are the foundations of conventional extraction methods. Even while traditional methods can sometimes be time-consuming and less effective than modern technologies, they have greatly benefited early medicine, herbal treatments, methods of cooking, and handcraft businesses. Many techniques, including maceration, infusion, decoction, percolation, distillation, and pressing, have been used to extract active compounds from minerals, plant materials, and animal products. Two key components of conventional extraction methods are the use of natural solvents like water, alcohol, or oils and processes that require minimal technological intervention. For instance, during maceration, plant material is steeped in a solvent at room temperature, while during decoction, water-soluble components are removed. Distillation is another ancient technique that uses heat to evaporate volatile materials, which are then collected and condensed [1].

Modern extraction technology has advanced, yet traditional techniques are still used and have important cultural, medicinal, and commercial value because there aren't enough resources for them. Around the world, traditional techniques for extracting herbal medicines have been used for generations. These techniques can effectively extract a range of active ingredients from plants and are frequently easy to use.

The most widely used conventional extraction techniques are discussed below:

Maceration

Maceration is a straightforward, reliable, and non-thermal technique commonly employed to extract active substances from raw plant materials and performed at room temperature or a bit warmer. This method involves soaking the plant material in a solvent—like water, alcohol, or oil—for an extended period, allowing for the extraction of active substances that can undergo further processing. It is commonly utilized in manufacturing aromas, cosmetics, food products, and herbal treatments. This method is favored for its simplicity, ability to safeguard heat-sensitive substances, and minimal equipment requirements. The nature of the material influences the different kinds of maceration techniques, the type of extract sought, the solvent used, and the purpose for which it is intended.

Types of Maceration

- **Simple Maceration:** The most straightforward and often used kind of maceration involves immersing finely crushed or coarsely chopped plant material in a suitable solvent for a set period of time, typically a few hours to several days, at room temperature.
- **Double Maceration:** This method uses the same plant material and a different solvent for each of two sequential macerations, thereby increasing extraction efficiency.
- **Multiple Maceration:** This technique is a continuation of double maceration and involves multiple extractions that are performed sequentially, each using a different solvent.
- **Cold Maceration:** This type of maceration is carried out at low or room temperature and helps preserve heat-sensitive substances such as volatile aromatic molecules, vitamins, and essential oils.
- **Alcoholic Maceration:** It is a widely used method (especially for tincture preparation) that uses ethanol or a mixture of ethanol and water as the solvent.
- **Oil Maceration:** Here, vegetable oil such as olive, sunflower, or almond oil is used as a solvent for soaking plant material and for extracting fat-soluble compounds [1, 2].

Process

The maceration process is illustrated below in Fig. (**1**). The essential steps are crushing the raw material, immersing it in a solvent (such as water, alcohol, or oil), and allowing it to stand for a predetermined amount of time, usually a few hours to days while stirring occasionally, in order to allow the desired compounds to diffuse out into the solution [1].

Advantages

- **Compatible with various solvents:**This method is capable of working with solvents like water, alcohol, and oils, allowing for flexibility according to the solubility of the compound of interest.
- **Ease and cost-effectiveness:** It requires minimal equipment and specialized knowledge, making it suitable for small-scale extraction and practices in traditional medicine.
- **Expandable:** The method can be easily scaled up for greater volumes by using larger containers while maintaining a consistent solvent-to-drug ratio.

CHAPTER 5

Novel Extraction Methods

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Abstract: In the field of isolation of bioactive compounds, new extraction methods have emerged as a cutting-edge alternative to classical extractions that offer significant advantages in terms of efficiency, effectiveness, and specificity. Among these techniques are Pressurized Liquid Extraction (PLE), Supercritical Fluid Extraction (SFE), Microwave-Assisted Extraction (MAE), Ultrasonic-Assisted Extraction (UAE), and Ionic Liquids (ILs). These approaches maintain the longevity of the extracted products while using reduced amounts of solvents, shorter process times, and higher yields. This chapter addresses the basic principles involved in each method, their various uses and applications across different industries, and the factors that determine their choice over traditional extraction approaches. The increasing demand for environmentally friendly processes has fueled the adoption of green extraction techniques across academic institutions and industries. Contrary to the traditional processes that involve high solvent use and extended time periods without necessarily being effective, these newer techniques have proved more efficient and environmentally sustainable. Future research on developing new extraction processes that are environmentally sustainable, less resource-intensive, and consistent with sustainability goals will go a long way toward environmental conservation.

Keywords: Green extraction techniques, Microwave-assisted extraction, Pressurized liquid extraction, Supercritical fluid extraction, Ultrasound-assisted extraction.

INTRODUCTION

The botanical industry is experiencing a stimulating revitalization in extraction technology that has far outgrown the refined point of merely extracting the chemical active or drugs of major interest. The traditional extraction methods,

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such as maceration, Soxhlet extraction, and hydrodistillation, have significant drawbacks, including the use of large solvent quantities and long processing times that can lead to heat-sensitive component degradation. Modern technologies provide sustainable and environmentally friendly alternatives that enhance extraction efficiency while preventing substance degradation through advances in chemistry and physics [1].

The Trend for Green Extraction Techniques

In the late 20th century, as people became more aware of environmental issues, scientists began to explore alternative methods to those used by their predecessors that would be less harmful to the environment. The concept of "green chemistry", developed in the 1990s by Paul Anastas and John Warner, had a large impact on the development of sustainable process conditions. Hazardous waste minimization, energy efficiency, and controlling waste generation are emphasized in greener chemistry. Here, we aim to present various new green extraction methodologies such as SFE, MAE, UAE, PLE, and ILs to illustrate how these techniques have enhanced the efficiency, selectivity, and environmental soundness of phytochemical isolation protocols. These novel extraction techniques were introduced in response to a demand to reduce hazardous solvents, energy consumption, and waste production [2, 3]. The most popular methods are:

Supercritical Fluid Extraction (SFE)

Bioactive compounds can be isolated from a solid or liquid matrix using this novel extraction technique, which employs supercritical fluids, typically carbon dioxide (CO_2). This strategy has been applied to specific fields, *e.g.*, pharmacognosy, for its efficiency, environmental-friendliness, and selectivity.

Principle

- **Supercritical State:** When the temperature and pressure are both higher than the critical values, a substance is called a supercritical fluid. For CO_2, this occurs at T>31.1 °C and P>73.8 bar. In this state, CO_2 exhibits properties of both a liquid and a gas, making it an excellent extraction tool.
- **Extraction Mechanism:** When in its supercritical state, CO_2 is somewhere between a liquid and a gas. This distinctive combination enables CO_2 to enter the solid matrix and dissolve its target compounds effectively.
- **Selective Extraction:** Pressure and temperature can be adjusted during SFE to direct the solvent to selectively extract certain compounds. This is crucial for selectively recovering useful substances while excluding undesirable compounds 4.

- **Safe and Eco-friendly:** With its non-flammability, CO_2 is widely available and commonly used in our daily life. It can be removed simply by reducing the extraction pressure, leaving no solvent in the final product. Therefore, SFE is considered a green extraction process compared to classical solvent-based methods.

Process

- **Preparation:** The solid or liquid sample (*e.g.*, plant material) is prepared and placed in an extraction vessel.
- **Supercritical CO_2 pressurization:** CO_2 is pressurized above its critical point.
- **Extraction:** The supercritical CO_2 flows to the extraction vessel and contacts the material, dissolving the target component.
- **Isolation:** Recharging or cooling CO_2 liberates the active chemicals in their dissolved state. The latter results in an extract with high potency after CO_2 is removed from the extracted chemicals.
- **Recovery:** The recovered molecules are collected, often in another room, for further processing or analysis 4. A schematic diagram of the SFE process is shown in Fig. (**1**).

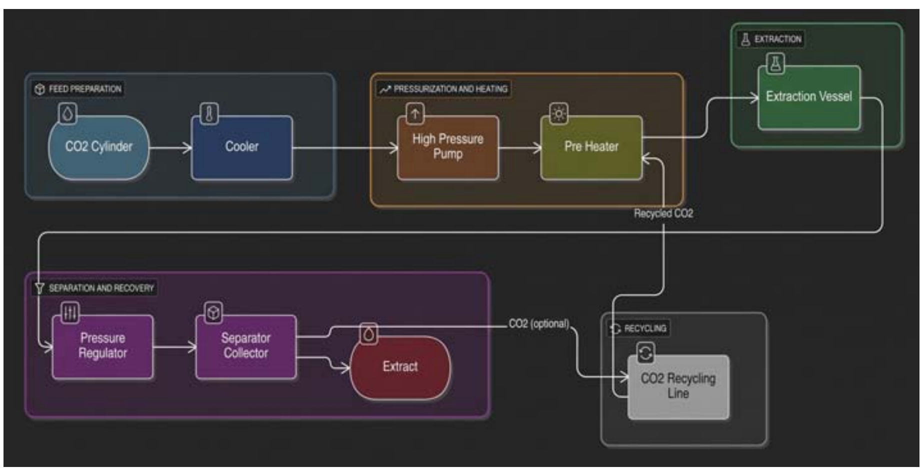

Fig. (1). Schematic of supercritical fluid extraction unit.

Advantages

- **High Extracting Rate:** It offers better mass transfer, enabling the solvent to be used more effectively. Unlike conventional methods, higher levels of bioactive molecules can be produced.
- **Selective extraction:** The modifiable properties of CO_2 allow selective extraction from tinctures, eliminating unwanted material.

CHAPTER 6

Application of Novel Extraction Methods: Case Studies

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Abstract: Innovative extraction techniques yield bioactive chemicals that are more sustainable and efficacious than those obtained through conventional techniques. Pressurized Liquid Extraction (PLE), Microwave-Assisted Extraction (MAE), Enzyme-Assisted Extraction (EAE), Ultrasound-Assisted Extraction (UAE), and Supercritical Fluid Extraction (SFE) are among the sophisticated extraction techniques that are used and discussed in this chapter. In many branches of pharmaceutical sciences, these techniques have been successfully used to increase product yield and purity while using less energy and solvents. Various case studies have been performed to evaluate the importance of these techniques in enhancing the phytoconstituent content. Thus, the innovative extraction processes provide a platform for sustainable practices in industrial applications and advancing research and product development. The featured case studies demonstrate the efficacy, sustainability, and practical potential in the pharmaceutical and herbal sectors by illustrating how innovative extraction techniques translate theoretical concepts into useful applications.

Keywords: Extraction, Extraction techniques, Industrial applications, Phytochemicals, Sustainable practices.

INTRODUCTION

Novel extraction techniques have transformed the process of extracting bioactive components from natural sources by offering higher efficiency, sustainability, and product quality than traditional methods. Pressurized Liquid Extraction (PLE), Enzyme-Assisted Extraction (EAE), Microwave-Assisted Extraction (MAE), Ultrasound-Assisted Extraction (UAE), and Supercritical Fluid Extraction (SFE) are some of the cutting-edge methods intended to increase yield while maintaining

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the integrity of substances that react negatively to solvents and heat [1–3]. As demonstrated by case studies in the pharmaceutical industry, these methods not only optimize extraction but also reduce manufacturing costs and their environmental impact. Analyzing real-world applications reveals how these innovations promote research and commercialization while also assisting in the production of high-quality products. This chapter emphasizes the utility of new extraction methods by presenting selected case studies that demonstrate how they can be applied to distinct phytochemical classes. Ultrasound-Assisted Extraction (UAE) significantly improves processing efficiency and yield when essential oils are extracted. It has been demonstrated that polyphenols can be extracted efficiently using Microwave-Assisted Extraction (MAE), which has better selectivity and uses less solvent. It is explained how well Supercritical Fluid Extraction (SFE) separates terpenoids and cannabinoids in an environmentally friendly manner. Furthermore, one example is the way Enzyme-Assisted Extraction (EAE) enhances polysaccharide extraction by speeding up cell wall disintegration. Collectively, these case studies demonstrate a clear link between modern extraction ideas and their practical industrial uses.

APPLICATION OF UAE IN ESSENTIAL OIL EXTRACTION

Ultrasound-Assisted Extraction (UAE) improves the extraction of chemicals from plant-based matter by using ultrasonic vibrations. Essential oils and other bioactive substances are extracted from medicinal herbs using UAE in pharmacognosy. When compared to more conventional extraction techniques such as solvent extraction or steam distillation, this approach is renowned for being effective, time-saving, and ecologically benign [4 - 6]. Pretreatment with ultrasonic technique significantly increased the yield of a number of plant extracts, when compared to conventional Hydro-Distillation (HD). Ultrasound-Assisted Extraction (UAE) enhanced the yield of cinnamon bark by 56.94%; however, specific reductions in extraction time were not mentioned. The yield of betel leaves increased by 22.22% (from 0.18% to 0.22%), and the extraction time was shortened by 15 to 30 minutes with ultrasonic pretreatment (28 kHz, 15 min). Ultrasound-Assisted Hydro-Distillation Extraction (UAHDE) of citronella grass enhanced the extraction yield by 27–40%, depending on the technique, indicating a faster extraction rate. Additionally, the total polyphenol content increased from 14–18% using traditional reflux extraction to 22–28% with UAHDE (a 40–60% improvement). This approach also significantly reduced the extraction time from 2–3 hours to less than 10 minutes. The applications of essential oils in various industries are summarized in Fig. (**1**).

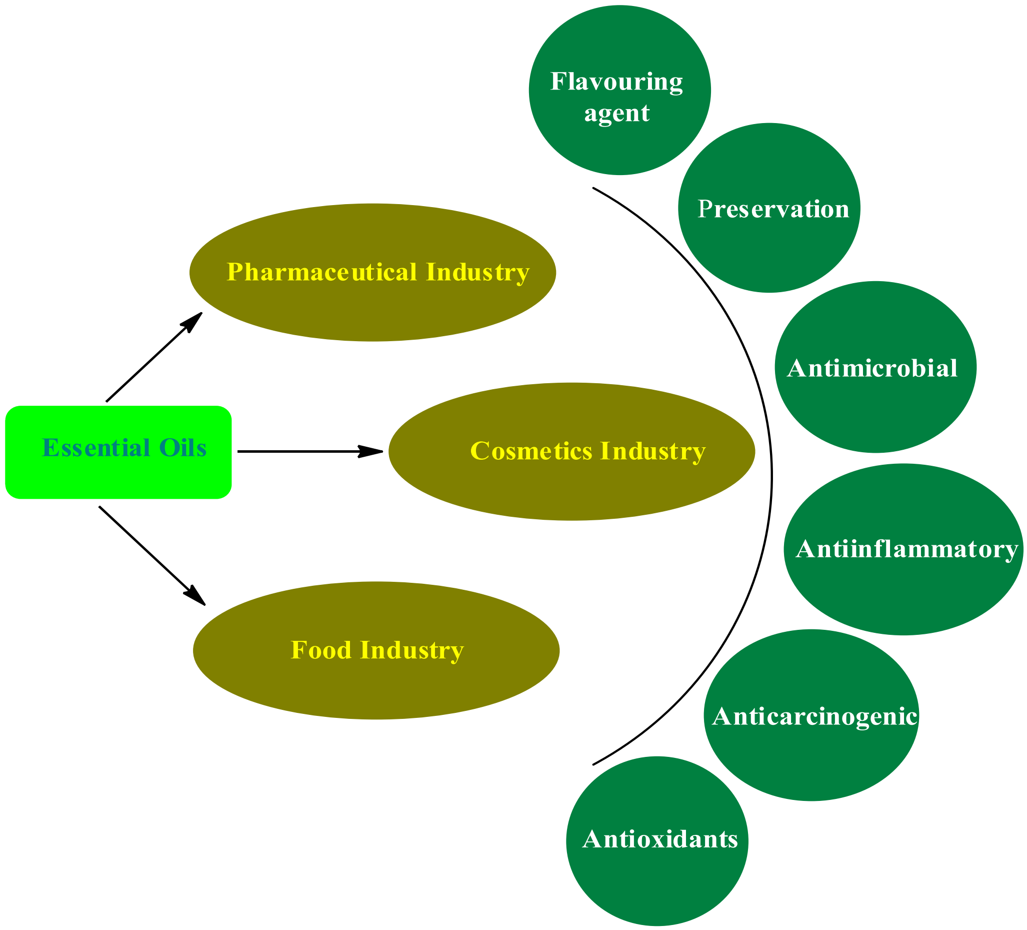

Fig. (1). Applications of essential oils in various industries.

Principle

Ultrasound-Assisted Extraction (UAE) uses ultrasonic waves to create cavitation bubbles in the extraction medium. When these bubbles burst, strong shear forces and microjets are generated, which break down plant cell walls and encourage the release of essential oils [7].

Advantages

- **Increased Efficiency:** The UAE can extract essential oils more quickly and with higher yields than conventional methods.
- **Reduced Solvent Use:** The process often requires less solvent, making it a greener alternative.

CHAPTER 7

Technological Advancements

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Abstract: Modern industrial innovation nowadays primarily depends on automation and robotics integration, which drives improvements in efficiency, precision, and scalability across a range of industries, including the rapidly expanding field of herbal extraction. Robotic and automated platforms are being utilized more often by cutting-edge technologies like Artificial Intelligence (AI), machine learning, and high-resolution sensors to optimize extraction processes, enhance process control, and ensure consistent product quality. Automation reduces operational variability and human error, while intelligent machines deliver high accuracy and reproducibility while executing complex, multi-stage extraction operations and handling raw plant materials. By boosting extraction yields, accelerating processing, and enhancing safety by reducing operator exposure to hazardous solvents and high temperatures, these developments significantly support the nutraceutical, phytopharmaceutical, and essential oil production sectors. Nevertheless, despite these advantages, problems including high capital costs, system interoperability, and the need for workforce training still have an impact on adoption. This overview demonstrates the revolutionary impact that automation and robotics have had in developing breakthrough herbal extraction procedures to produce a more efficient, intelligent, and future-ready extraction process. Additionally, it offers strategic suggestions for resolving implementation issues.

Keywords: Automation, Artificial Intelligence (AI), Herbal extraction, Machine learning, Robotics integration.

INTRODUCTION

Numerous industries, including manufacturing, logistics, healthcare, and agriculture, are being transformed by automation and robotics. Robotics is the design and operation of robots to perform specific tasks, whereas automation is the use of technology to carry out tasks with minimal human intervention [1-2].

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When combined, they increase safety, accuracy, productivity, and efficiency. New technologies have enhanced product quality, efficiency, and sustainability in herbal extraction. Approaches like Supercritical Fluid Extraction (SFE) [3] and Ultrasound-Assisted Extraction (UAE) shorten processing times while increasing yield. Additionally, these methods safeguard heat-sensitive chemicals, increase purity, and minimize the use of hazardous solvents [4-5]. Large-scale production is enabled by automation and analytical instruments like HPLC, which aid in maintaining consistent quality. These technologies offer long-term economic and environmental advantages despite their potentially high initial cost. In general, they encourage innovation in drug discovery and natural product research [6-7].

Applications of Robotics in Different Fields

- **Manufacturing:** By improving productivity, precision, and speed, robotics has significantly enhanced the manufacturing industry. Assembly, welding, material handling, painting, packaging, and quality control are all often carried out by robots [8].
- **Healthcare:** By optimizing surgical accuracy, patient care, and laboratory automation, robotics is advancing healthcare. Surgery, rehabilitation, pharmacy automation, imaging, and patient assistance all employ robots. These solutions enhance patient safety, accelerate recovery, and improve accuracy [9].
- **Logistics and Supply Chain:** Order picking, packing, delivery, inventory monitoring, and warehousing are all aided by robots. They improve worker safety, reduce labor costs, cut down on mistakes, and boost productivity [10].
- **Agriculture:** Robotics supports crop monitoring, harvesting, planting, soil analysis, and fertilization. This increases crop yield, improves quality, reduces labor dependency, and promotes sustainable farming [11].

Robotics in Manufacturing

The advent of robotics has had a profound impact on the manufacturing sector. Robots give businesses a competitive edge by increasing accuracy, efficiency, and scalability.

Principal Advantages

- **Automation of repetitive tasks**: Robots carry out precise, repetitive tasks such as assembling and welding.
- **Greater efficiency:** Robots can work nonstop.
- **Improved quality control:** Sensors assist in identifying flaws and preserving uniformity.
- **Reduced expenses:** Over time, lower labor and material waste expenses.
- **Increased safety:** Robots perform hazardous jobs, reducing the possibility of

accidents.

- **Adaptability:** Today's robots can be reconfigured to perform various tasks.
- **Collection of data:** Integrated sensors aid in performance monitoring and enhance decision-making.

Advanced Robotics Technologies

Recent advancements include cooperative robots (cobots) and AI-powered robots. Cobots are designed to operate securely alongside humans, increasing productivity without replacing workers.

Robotics in Healthcare

Robotics is transforming healthcare by improving medical procedures, patient aid, and surgical accuracy. It enhances accessibility, efficiency, and overall patient satisfaction.

Key Applications of Robotics in Healthcare

Robotics is transforming healthcare by improving precision, safety, and efficiency in many medical areas [12].

- **Computerized surgical procedures:** Surgeons can perform intricate procedures with greater precision and control thanks to devices like the da Vinci Surgical System. These procedures result in quicker recuperation, smaller wounds, and reduced blood loss.
- **Rehabilitation:** After surgeries, spinal injuries, or strokes, patients can regain movement with the help of assistive technology and robotic exoskeletons.
- **Patient Support:** Robots help elderly and disabled patients with everyday tasks, prescription reminders, and psychological support.
- **Telemedicine:** Doctors can monitor and evaluate patients directly with telepresence robots, which eliminates the need for in-person visits.
- **Robotic Pharmacy:** Robotic techniques minimize human mistakes by efficiently sorting, packaging, and dispensing pharmaceuticals.
- **Infection Control:** Hospital rooms are cleaned by UV robots, which also stop infections from spreading.
- **Imaging and Diagnostics:** Robotic systems support high-precision scans, surgeries, and radiology.
- **Laboratory Automation:** Robots improve speed and accuracy by handling sample preparation and testing.
- **Medical Training**: Students can safely practice procedures using robotic simulators.

CHAPTER 8

Quality Control and Standardization

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Abstract: Standardization and quality control of crude medications are crucial for minimizing variation and guaranteeing the consistency of their active ingredients. These procedures ensure the strength, safety, and quality of herbal products while satisfying consumer preferences and legal requirements. The best methods and strategies for preserving extract quality are examined in this chapter, with a focus on enhancing the extraction operation and putting strict quality control measures in place. It also highlights the crucial role of standardization processes in ensuring the reliability and uniformity of the final product. It underscores the importance of standardization for achieving consistency, particularly when dealing with natural products, as unpredictable raw materials pose serious challenges. The focus is on regulatory frameworks that ensure compliance across industries such as pharmaceuticals, nutraceuticals, food, and cosmetics, including Good Manufacturing Practices (GMP) and pharmacopoeia standards. In order to preserve the integrity of extraction procedures and products, this chapter emphasizes the importance of reference standards, quality benchmarks, and validation techniques.

Keywords: Extraction, Good manufacturing practices, Nutraceuticals, Pharmaceuticals, Standardization.

INTRODUCTION

Standardization and quality control of crude medications are crucial for minimizing variation and guaranteeing the consistency of their active ingredients. Specifically when using extracts from natural sources, these processes ensure the final product's safety, purity, and consistency [1]. Changes in raw materials, handling conditions, and environmental factors can significantly affect the results of the extraction process. In the absence of rigorous quality control procedures,

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the potency, effectiveness, and purity of extracts may vary, posing issues for the pharmaceutical, food, cosmetic, and nutraceutical industries [2]. The process of generating uniform rules and regulations to ensure that each product batch meets preset requirements, thereby guaranteeing its reliability and functionality, is known as standardization [3]. Analytical techniques like mass spectrometry, gas chromatography, spectroscopy, and High-Performance Liquid Chromatography (HPLC) are crucial for assessing the homogeneity of the extracted components and establishing the connection between standardization and extraction [4]. In order to ensure the safety of products, reliability, and regulatory compliance, this chapter examines the concepts and practices of standardization and quality control. It also discusses ways to reduce the difficulties caused by the inherent unpredictability of natural goods [5]. Industries can enhance product performance and maintain a competitive edge in the global market by using strict control of quality and standardization procedures [6].

Importance of Quality Control in Extraction

Pharmacognosy relies heavily on Quality Control (QC), especially when it comes to the extraction of bioactive compounds from medicinal plants. It ensures the consistency, safety, and efficacy of plant-derived compounds. Methods for quality control are crucial for confirming the extraction process, ensuring that the finished product is free of impurities, and ensuring that the desired active components are present in the correct quantities [7]. This chapter examines the significance of quality control in extraction methods, with a focus on its practical relevance. Various methods of quality control are discussed below in Table **1**.

Table 1. Methods of quality control.

Quality Control	Description	Significance	Refs.
Ensuring consistency and reproducibility	Standardized the extraction process to account for variability in raw materials, guaranteeing constant therapeutic benefits across batches.	For anti-cancer drug paclitaxel extraction, standardized techniques and routine analytical testing ensure every batch meets quality requirements, offering dependable treatment.	[8, 9]
Detection and elimination of contaminants	Essential for identifying and removing contaminants that may originate from raw materials or be introduced during processing.	In *Ginkgo biloba*, QC employs HPLC and GC-MS to check for pesticide residues, ensuring the extract meets safety standards for consumption.	[10, 11]
Optimization of extraction efficiency	Involves the systematic evaluation of parameters to maximize the yield and purity of bioactive compounds.	Optimizing curcumin extraction from turmeric involves systematically varying parameters like temperature and solvent polarity to achieve higher yields of pure curcumin.	[12, 13]

(Table 1) cont.....

Quality Control	Description	Significance	Refs.
Ensuring regulatory compliance	Guarantees that herbal extracts meet legal requirements set by health authorities.	Preparing Echinacea purpurea extract requires QC testing for active substances.	[14, 15]

Methods of Standardization of Crude Dr ugs

Pharmacognosy depends on standardizing extraction techniques to ensure the efficacy, safety, and purity of herbal medications. Standardizing extraction processes is essential to ensuring uniformity and repeatability, since the chemical constituents of crude medicines significantly impact their therapeutic potential. Standardization involves developing and verifying procedures that yield extracts with consistent biological activity and content [16]. This process consists of a number of techniques and strategies meant to optimize the extraction procedure and control the quality of the final product. The process of standardizing crude pharmaceuticals is summarized in Fig. (**1**) below:

Fig. (1). Steps in standardizing crude drug.

Standardization is necessary to ensure herbal products are safe, effective, and consistent. It reduces variation in active substances and ensures consistent treatment results by instituting consistent protocols and quality standards. The standardization procedure, however, might be resource-intensive and cannot always consider the entire spectrum of naturally occurring chemicals present in crude medications [17]. The benefits and drawbacks of standardization are given in Table **2**.

Table 2. Advantages and limitations of standardization for crude drugs.

Advantages of Standardization	Limitations of Standardization
• Improved quality control • Consistent quality assurance • Reproducibility of outcomes • Maximum extraction efficiency	• The complexity of phytochemicals • The variability of plant material • Possibility of standardization errors • The process could be expensive

CHAPTER 9

Future Trends

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Abstract: In this chapter, we delve into the impact of extraction methods by focusing on how changing technological trends and regulations, as well as sustainable efforts, are shaping the landscape. It is becoming increasingly important to have extraction processes that are both effective and eco-friendly and that make sense given the growing global demand for natural resources. Progress in areas like automation, AI, and data analysis is key to managing resources, enforcing safety measures, and streamlining operations. Furthermore, there is an increasing focus on eco-methods, such as reducing waste, incorporating energy into extraction procedures, and embracing principles of a circular economy. The implementation of rules and the integration of environmental and social responsibility criteria are now crucial to ensure that mining operations have minimal negative environmental impacts while also supporting long-term sustainability goals. As the sector adjusts to these transitions, it is well positioned to fulfil existing resource needs while also setting the stage for an eco-conscious and accountable future.

Keywords: Artificial intelligence, Emerging extraction technologies, Environmental, Social governance.

INTRODUCTION

Industries are increasingly extracting valuable bioactive compounds from natural sources to meet the demands of food processing, pharmaceutical, cosmetic, nutraceutical, and personal care sectors. As consumer preference for natural, organic, and green-label products grows rapidly, companies strive to produce extracts that maximize bioactivity, purity, and safety while minimizing their environmental impact [1]. Traditional extraction methods, such as solvent extraction, maceration, and steam distillation, are often inefficient, energy-intensive, and reliant on chemical solvents. These drawbacks prolong processing

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times and degrade heat-sensitive bioactive compounds, thereby reducing their functional value [2, 3].

To overcome these challenges, industries have adopted advanced green extraction technologies, such as Ultrasound-Assisted Extraction (UAE), Microwave-Assisted Extraction (MAE), and Supercritical Fluid Extraction (SFE) [1, 4]. These methods enhance extraction efficiency by up to 40-60%, improve selectivity, and ensure environmental compatibility while preserving the bioactive integrity. The integration of biotechnology, predictive modeling, and Artificial Intelligence (AI) further transforms the extraction processes [5, 6] These tools precisely optimize parameters, enable real-time monitoring, and predict outcomes, thereby driving sustainable, efficient, and high-quality production systems. This shift from traditional to modern extraction approaches reflects a global move toward sustainable manufacturing, superior bioactivity retention, and technology-driven innovations [7].

Emerging Extraction Technologies

Conventional extraction of vegetable and nut oils using mechanical pressing, maceration, and solvent extraction often operates slowly, consumes excessive energy, and applies high temperatures or solvents that degrade the nutritional value, oxidative stability, and flavor. Consumer demand for natural, clean-label products has prompted industries to adopt advanced technologies that improve purity and bioactivity retention and reduce environmental impact [8].

Innovative extraction methods, such as Supercritical Fluid Extraction (SupFE), Subcritical Fluid Extraction (SubFE), Ultrasound-Assisted Extraction (UAE), Microwave-Assisted Extraction (MAE), and Enzyme-Assisted Extraction (EAE), increase efficiency by 30-70% compared to traditional techniques. These methods offer unique advantages but also require careful management of equipment costs, operational complexity, and scalability [9–11].

To provide a clear overview of these modern techniques, Table **1** summarizes their principles, applications, advantages, limitations, and suitability for the extraction of nut and vegetable oils.

To help readers understand how each of these extraction methods progresses step-by-step, Table **2** presents a simplified process flow comparison of single (non-combined) extraction technologies. This table highlights the core stages and key operational parameters that must be controlled during processing [16–18].

Table 1. Comparison of emerging extraction technologies for plant, nut, and vegetable oils [12–15].

Extraction Method	Principle	Key Industry Applications	Advantages	Limitations	Suitability for Vegetable/Nut Oils
Supercritical Fluid Extraction (SupFE)	Utilizes CO_2 in the supercritical state to dissolve target compounds.	Cosmetics, nutraceuticals, pharmaceuticals	High purity, solvent-free extracts; excellent for heat-sensitive compounds.	High equipment cost; requires skilled operation.	Excellent for premium-grade nut oils.
Subcritical Fluid Extraction (SubFE)	Uses CO_2 at subcritical pressure and temperature	Edible oils, herbal extracts	Mild conditions; efficient extraction	Lower solvating power than supercritical CO_2	Very good for edible and specialty oils.
Ultrasound-Assisted Extraction (UAE)	Cavitation disrupts plant tissues, enhancing mass transfer.	Functional foods, cosmetics, antioxidant-rich oils.	Fast; low solvent use; high yield.	Scale-up challenges; potential radical formation at high intensity.	Highly effective for nut oils.
Microwave-Assisted Extraction (MAE)	Rapid microwave heating disrupts cell structure.	Aromatic oils, herbal actives, fragrance industry.	Very short extraction time; energy efficient.	Overheating risk for thermo-labile compounds; specialized reactors needed.	Excellent when temperature is controlled.
Enzyme-Assisted Extraction (EAE)	Enzymes degrade cell walls and release intracellular contents.	Functional foods, skincare formulations.	Eco-friendly; mild temperature; improved clarity.	Requires controlled pH and temperature; enzyme cost is high.	Ideal for cold-processed premium oils.
UAEE	Enzyme pretreatment combined with ultrasound.	Cosmetic oils, nutraceutical oils.	Higher yield; enhanced cell disruption.	More complex and costly setup.	Excellent for maximizing purity and bioactivity.
MAEE	Microwave heating combined with enzymatic.	Phytochemical-rich oils.	Faster extraction; reduced solvent use.	Risk of enzyme deactivation at high temperatures.	Highly efficient with precise control.

SUBJECT INDEX

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