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A review of the most important extraction methods from medicinal plants

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Abstract

The first and most important stage in creating plant compositions is extraction. The development of conventional herbal treatments can be effectively advanced by using contemporary extraction techniques. The creation of contemporary sample preparation methods for the extraction and analysis of medicinal plants that offer notable benefits over traditional approaches is probably going to be crucial to the overall endeavor to guarantee that consumers around the world can obtain high-quality herbal products. The development of analytical techniques for the examination of the components found in botanical and herbal remedies depends critically on sample preparation. The use of medicinal plants in traditional medicine to cure common ailments like colds and fevers, as well as other therapeutic claims, has recently attracted a lot of attention due to solid scientific evidence. The study of medicinal plants began with extraction techniques that are essential to the extraction results (such as yield and phytochemical content) and the ensuing assays carried out. These days, a vast array of technologies with various extraction techniques are accessible. Therefore, in order to assess the methods' applicability and economic viability, this review aims to characterize and contrast the most widely used approaches according to their principles, strengths, and limitations.

Keywords: Efficiency And Effectiveness of Extraction; Soxhlet Extraction; Medicinal Plants

1. Introduction

Humans have been using plant sources to treat or reduce ailments for thousands of years. Novel chemical compounds with potential applications in medicine and other fields can be found in plants. Alkaloids, steroids, tannins, glycosides, volatile and fixed oils, resins, phenols, and flavonoids are among the numerous active substances found in plants. These substances are deposited in various plant parts, including leaves, flowers, bark, seeds, fruits, roots, and so on. When these secondary metabolites are combined, plant materials usually have positive therapeutic effects (Tonthubthimthong et al., 2001). The choice of an appropriate extraction technique is crucial for both qualitative and quantitative investigations of bioactive chemicals derived from plant materials (Smith, 2003; Sasidharan et al., 2011). The following procedures may be included in a phytochemical analysis of a plant: plant material extraction and authentication, constituent separation and isolation, compound characterisation, and quantitative assessment (Evans, 2008). One of the more environmentally friendly methods for isolating biological components is extraction from plants (Jadhav et al., 2009). One must adjust the processes for more efficiency in order to produce higher-quality and more efficient extraction from herbs. Research on plant seed extracts revealed a significant positive linear connection ($r = 0.96$) between extraction efficiency and total antibacterial activity (Kothari, 2010). Although the advent of contemporary chromatographic and spectrometric techniques has made the analysis of bioactive compounds easier than in the past, the precise nature of plant components, extraction processes, and input parameters remain crucial for success (Poole et al., 1990). The plant part's matrix characteristics, solvent, temperature, pressure, and time are the most frequent variables influencing extraction procedures (Hernández et al., 2009). The pre-extraction and extraction processes, which are crucial stages in the production of the bioactive components from plant materials, are where the study of medicinal plants begins. At the Small Manufacturing Enterprise (SME) or small research setting levels,

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traditional techniques like maceration and Soxhlet extraction are frequently employed.Considerable progress has been achieved in the processing of medicinal plants, including the use of contemporary extraction techniques like supercritical fluid extraction (SFE), ultrasound-assisted extraction (UAE), and microwave-assisted extraction (MAE), which are intended to boost output at a reduced cost. Additionally, changes to the techniques are always being created. With so many different approaches available, choosing the best extraction technique requires careful consideration. The advancement of bioactive analysis over the past ten years has been fueled by a greater understanding of the dynamic chemical nature of the various bioactive substances (Torssell, 1997). The pharmaceutical, food additive, and even natural pesticide industries have developed an interest in bioactive compounds derived from natural sources as a result of these significant scientific advancements (Anklam et al., 1998; Ambrosino et al., 1999). Bioactive substances typically coexist with other substances found in plants. The leaves, stem, flower, and fruits of plants are among the portions from which bioactive chemicals can be found and described. Plant materials can be extracted using a variety of extraction techniques. Over the past 50 years, unconventional techniques have been created that are more environmentally friendly since they use fewer synthetic and organic chemicals, require less time to operate, and produce extracts of higher yield and quality. Ultrasound (Vinatoru et al., 1997; Ghafoor et al., 2011), pulsed electric field (Toepfl et al., 2006), enzyme digestion (Gaur et al., 2007), extrusion (Lusas and Watkins, 1988), microwave heating (Kaufmann and Christen, 2002), ohmic heating (Lakkakula et al., 2004), supercritical fluids (Marr and Gamse, 2000; Lang and Wai, 2001; Meireles and Angela, 2003; Wang et al., 2008; Ghafoor et al., 2010, 2012), and accelerated solvents (Kaufmann and Christen, 2002; Smith, 2002) have all been investigated as unconventional techniques to improve the overall yield and selectivity of bioactive components from plant materials.

1.1. The definition and background of bioactive substances

The usage of plants by humans dates back to the dawn of civilization. Plants were first utilized by humans for sustenance, but as their therapeutic qualities were discovered, they were used by many human groups to treat illnesses and promote better health. Through thousands of recipes, Egyptian papyruses demonstrated the therapeutic, cosmetic, and preservation properties of coriander and castor oil (Vinatoru, 2001). Hippocrates, Theophrastus, Celsus, Dioscorides, and numerous other authors documented a thousand medicinal use of herbal plants during the Greek and Roman eras (Paulsen, 2010). The usage of therapeutic herbs by Romanians has a long history. For instance, in his writings from the fifth century B.C., Herodotus stated that the inhabitants north of the Danube River utilized Leonurus cardiaca, also known as mother wort. Herbal products were introduced by Romanian pharmacopoeia in the 19th century, and Cluj City saw the founding of the first Institute of Medicinal Herbs in 1904 (Vinatoru, 2001). The history of bioactive compounds is clearly illustrated by the ancient use of herbal plants. Bioactive chemicals were unknown to people in the past, but their applications were sufficiently varied to cover a wide range of viewpoints. Plants usually create their bioactive chemicals as secondary metabolites (Bernhoft, 2010). For life and sustenance, all living things, from single-celled bacteria to multicellular plants, process a variety of chemical substances. All biological system chemicals fall into one of two major categories. One category is primary metabolites, which include chemicals like proteins, lipids, carbohydrates, and amino acids that are meant to promote growth and development. Another is called secondary metabolites, a class of substances other than primary metabolites that are thought to help plants interact with their environment and improve their overall capacity to survive and overcome local obstacles (Harborne, 1993). Martin and Demain (1978) defined secondary metabolites as those that are often produced in a phase that follows growth, that are produced by specific limited taxonomic groups of microorganisms, that have peculiar chemical structures, that are often formed as mixtures of closely related members of a chemical family, and that have no role in growth (though they may have a survival function). Different species' production of secondary metabolites is mostly chosen based on their unique needs and the evaluation process. For instance, flower species produce scent to draw insects for pollination and fertilization, and they also produce harmful chemicals that are directed toward pathogens and herbivores to inhibit the growth of nearby plants (Dudareva & Pichersky, 2000). Some of these compounds are regarded as bioactive secondary metabolites because of their effects on biological systems. Accordingly, secondary plant metabolites that cause pharmacological or toxicological effects in both humans and animals can be simply defined as bioactive chemicals in plants (Bernhoft, 2010).

2. Methods of advanced extraction

2.1. Extraction Assisted by Microwave (MAE)

Microwave electromagnetic energy is transformed into thermal energy when it is absorbed by a substance. The most often utilized frequency for commercial microwave instruments, with an energy output of 600–700 W, is 2450 MHz (2.45 GHz) (Jain et al., 2009). MAE is a straightforward, cost-effective, and environmentally benign method for removing biologically active substances from various plant materials (Hemwimon et al., 2007). In 1975, Samra et al. treated biological samples for metal analysis using microwave home ovens for the first time (Letellier and Budzinski, 1999).

Ganzler and associates initially documented the use of MAE for plant materials in 1986 (Kaufmann and Christen, 2002). The electric and magnetic fields seen in microwaves are perpendicular to one another. Ionic conduction and dipolar rotation are the two simultaneous processes by which the electric field generates heating. The alignment of molecules with a dipole moment in the solvent and the solid sample on the electric field causes dipolar rotation. Collisions with nearby molecules caused by this oscillation release thermal energy into the medium. This effect happens 4.9×109 times quicker at a frequency of 2.45 GHz, which results in extremely rapid heating. In fact, the heating rate increases with the solvent's dielectric constant. Thus, in contrast to traditional conductive heating techniques, microwaves heat the entire sample at once. The benefit of microwave heating in the extraction process is that it breaks weak hydrogen bonds that are encouraged by the molecules' dipole rotation (Kaufmann and Christen, 2002). According to their respective dielectric constants, the sample's constituents absorb microwave energy (Ahuja and Diehl, 2006). The remaining moisture in plant material is instantly heated when it is submerged in a microwave-transparent solvent because the heat from the microwave radiation reaches the solid directly without being absorbed by the solvent. Heating causes the moisture to evaporate and creates a high vapour pressure that breaks the cell wall of substrate and releases the content into solvent. Solvents employed for most MAE operations are those with a high dielectric constant and capacity to strongly absorb microwave energy, however, the extraction selectivity, and the ability of the medium to interact with microwaves can be modulated by using mixtures of solvents. It is not uncommon to use binary mixture of solvents with only one solvent capable of absorbing microwave (Camel, 2001). "Broken cell-wall theory" places microwave transparent solvents above microwave absorbing ones, despite the general belief that polar solvents are superior to non-polar ones (Jagetia et al., 2005; Kothari et al., 2010; Proestos and Komaitis, 2007). Adding water to the solvent could result in higher yields. Acetone and other microwave-transparent solvents worked best for phenolic compound extraction (Proestos and Komaitis, 2007). Due to its high dissipation factor, the former offers superior overall heating efficiency in the methanol:chloroform mixture. Chloroform is translucent due to its low polarity (Kothari et al., 2009; and Komaitis, 2007). The extraction of thermolabile components is best accomplished with microwave-transparent solvents, such as hexane (Mandal et al., 2008). There are two ways to practice MAE: open vessel operation at atmospheric pressure and closed vessel operation, which is done under controlled (higher) pressure and temperature. According to Chemat and Esveld (2001), these technologies are referred to as focused microwave assisted extraction (FMAE) and pressurized microwave assisted extraction (PMAE), respectively. In a closed vessel setup, the solvent may be heated much above its ambient boiling point. This procedure increases the speed and efficiency of extraction (Kaufmann and Christen, 2002). In closed vessels, the temperature can be raised by applying the appropriate pressure. For volatile compounds, the closed vessel approach is effective. In an open vessel system, the highest temperature is determined by the solvent's boiling point (Camel, 2001).

2.2. Extraction Assisted by Ultrasonication (UAE)

UAE uses high-frequency, high-intensity sound waves and examines how they interact with various materials. UAE is a potentially helpful technique because it is quite inexpensive and doesn't require complicated instruments (Fig. 1). Both local and large-scale applications are possible for it (Dai and Mumper, 2010). UAE uses acoustic cavitations to produce ultrasonic effects. The solute rapidly diffuses out from the solid phase to the solvent due to the acceleration and vibration of solid and liquid particles caused by ultrasonic action (Cares et al., 2009). Numerous likely processes, including cell rupture, enhanced penetration, increased swelling, capillary effect, and hydration process, have been suggested as explanations for ultrasonic enhancement of extraction (Huaneng et al., 2007). Cavitation occurs when the intensity of ultrasonic waves in a liquid increases to a degree where the molecular structure can no longer be held together by intramolecular forces, causing it to break down and produce bubbles (Baig et al., 2010). Bubble collapse can have mechanical, chemical, and physical effects that cause biological membranes to break down, allowing extractable compounds to be released, increasing solvent penetration into cellular materials, and improving mass transfer (Cares et al., 2009; Metherel et al., 2009). The creation and asymmetrical collapse of microcavities near cell walls, which results in the production of microjets that rupture the cells, is thought to be the cause of sound waves' advantageous effects on extraction. Because the skin of the plant cell wall's exterior glands is so thin and easily broken by sonication, essential oil contents can be released into the extraction solvent more quickly, cutting down on extraction time and increasing extraction efficiency (Huie, 2002). Using ultrasonic to extract the tea solids from dried leaves with water increased the extraction yield by 20%. By utilizing several solvents, such as ethanol, ethyl acetate, and butanone, UAE also demonstrated superiority in the extraction of carnosic acid and decreased the extraction time (Baig et al., 2010). The extraction rate and final yield of total isoflavones are generally significantly influenced by the type of solvent used; however, in one study, when UAE was used to extract isoflavones from the stem of Pueraria lobata (Willd.), an increased extraction rate and yield were obtained for all solvent types. The extraction yield was found to increase with increasing electrical power input within the range of 0-650 W (Huaneng et al., 2007). Compared to the Soxhlet approach, UAE offers superior vanillin extraction in a shorter amount of time for various solvents (Jadhav et al., 2009). Applying ultrasound to the pre-leached mixture for a brief length of time could make commercial ultrasonic treatment dependable and easy (Jadhav et al., 2009). The UAE of grape-derived resveratrol was thought to be quite beneficial.

Using UAE may result in little resveratrol degradation from grapes within a specific extraction time frame (Cho et al., 2006). The extraction of pectin and protein is retained by UAE, which enhances the tea's sensory appeal. UAE was determined to be suitable for the extraction of glycosidic aroma precursors and aroma molecules (Xia et al., 2006). Additionally, oil was extracted from rapeseed (Ibiari et al., 2010), soybean (Li et al., 2004), and Monopterus albus (Abdullah et al., 2010) using the UAE. UAE has the potential to increase extraction efficiency and shorten processing times, according to studies on the effects of various solvents and their mixtures, solvent volume, sonication power, and sonication time. Moreover, the use of ultrasound during processing had no effect on the composition of the oil. When compared to maceration and Soxhlet extraction, UAE provides the maximum extraction yield of some flavonoids, including tectoridin, iristectorin B, iristectorin A, tectorigenin, iris-tectorigenin A, and total isoflavones, in a shorter amount of time (Sun et al., 2011). UAE isolated significant functional components from grape seeds. The UAE of total phenolics, antioxidants, and anthocyanins from grape seeds is significantly influenced by extraction parameters, especially extraction duration and temperature (Ghafoor et al., 2009). According to reports, ultrasound-assisted extraction is a quicker and more efficient way to separate ginsenosides (saponins) from different kinds of ginseng than traditional extraction techniques. Ginseng saponin extraction with sonication was around three times quicker than using the conventional extraction technique. For the recovery and purification of the active components, ultrasonic extraction was not only more practical but also more effective. Lower temperatures can be used for sonication-assisted extraction, which is advantageous for thermally unstable chemicals (Wu et al., 2001).

2.3. SFE, or supercritical fluid extraction

Certain chemicals can be extracted from plants using SFE at temperatures close to room temperature, avoiding thermal denaturation. SFE is an ancient solvent extraction method, but because it requires expensive and complex high pressure apparatus and technology, its commercial use has been delayed (Tonthubthimthong et al., 2001). Due to a thorough understanding of its design and operating parameters, SFE is now a widely used extraction and separation technique (Li et al., 2010). Compared to traditional organic solvents, the advantageous transport characteristics of fluids close to their critical points enable deeper penetration into the solid plant matrix and more effective and rapid extraction. The extraction process is carried out either continuously or in batches using high-pressure equipment. In both situations, contact occurs between the substance to be extracted and the supercritical solvent. When preparing samples, cylindrical extraction tubes are frequently utilized (Handa et al., 2008). Solids are put into extraction vessels in batch processing, and supercritical solvent is added until the desired extraction conditions are met. Additionally, in semi-batch processing, a high-pressure pump continually feeds the supercritical solvent at a set flow rate. One or more separation stages are employed to precipitate the solute from the supercritical solution. Today, supercritical fluid technology is acknowledged as a successful analytical procedure with an efficiency level on par with current chemical analysis techniques. SFE works well for both qualitative and quantitative identification of natural product ingredients, including chemicals that are heat-labile (Mohameda and Mansoor, 2002). Caffeine and other volatile or aromatic chemicals, such essential oils, are extracted from plant sources using SFE. During extraction by SFE, a number of variables are crucial, including temperature, pressure, sample volume, cosolvent addition, and flow and pressure control. These supercritical fluids have characteristics halfway between those of the liquid and gaseous phases, and in practice, conditions slightly over the critical temperature and pressure for a given chemical are typically applied (Evans, 2008). By varying the applied pressure and temperature, the fluid's characteristics, which are limited by the extremes of the gaseous and liquid states, can be modified (Kroon and Raynie, 2010). Any fluid can achieve its supercritical state in the right circumstances. The density of supercritical fluids has a direct bearing on their potential for use as extraction solvents. Dense gases, or fluids above their critical temperature (TC) and critical pressure (PC) to a certain degree, are known as supercritical fluids. While the reduced pressure Pr (i.e., P/PC) may be as high as permitted by technological constraints, the lowered temperature Tr (i.e., T/TC) must not be greater than 1.2 or 1.3 in order to be considered supercritical (Handa et al., 2008).

According to Evans (2008), the critical parameters for carbon dioxide are 30.9ºC and 73.8 atm, while the critical conditions for water are 374ºC and 220 atmosphere, respectively. Hexane, pentane, butane, nitrous oxide, sulfur hexafluoride, and fluorinated hydrocarbons are among the solvents that can be utilized for SFE (Reverchon and Marco, 2006). The most widely utilized extraction solvent in SFE is carbon dioxide (CO2) (Handa et al., 2008). Although CO2 is not selective on its own, a co-solvent or modifier can increase the extraction's capacity and selectivity. It is simple to remove the co-solvent after extraction. Due to its low critical temperature of 304 K, CO2 is typically the most preferred solvent in SFE and is hence appealing for the extraction of heat-labile chemicals. Furthermore, CO2 is a non-toxic, safe (non-flammable, non-explosive), affordable, noncorrosive, colorless, odorless, and clean solvent that leaves no solvent residue in the final product. It is also widely acknowledged as a safe component of food and medicine, and it can be readily separated from the extracted oil by simple expansion. Additionally, carbon dioxide is a desirable supercritical solvent due to its high diffusivity, low surface tension, and viscosity (Handa et al., 2008; Tothubthimthong et al., 2001).

2.4. Extraction using a pulsed electric field (PEF)

Over the past ten years, the pressing, drying, extraction, and diffusion processes have all been found to benefit from the pulsed electric field (PEF) treatment (Barsotti and Cheftel, 1998; Angersbach et al., 2000; Vorobiev et al., 2005; Vorobiev and Lebovka, 2006). PEF works on the premise of breaking down cell membrane structure in order to increase extraction. An electric potential flows through a live cell's membrane when it is suspended in an electric field. Electric potential divides molecules based on their charge in the cell membrane, which is based on the dipole nature of membrane molecules. Repulsion between the charge-carrying molecules that create pores in weak regions of the membrane happens after the transmembrane potential reaches a critical value of about 1 V. This results in a sharp rise in permeability (Bryant and Wolfe, 1987). For PEF treatment of plant materials, a straightforward circuit with exponential decay pulses is typically employed. Plant materials are positioned in a treatment chamber with two electrodes. The PEF process can run in batch or continuous mode, depending on the treatment chamber design (Puértolas et al., 2010). Heinz et al. (2003) state that the effectiveness of PEF therapy depends on the process parameters, including the properties of the materials to be treated, the specific energy input, the pulse number, the treatment temperature, and the field strength. By breaking down the plant materials' membrane structure, PEF can improve extraction and shorten extraction times while increasing mass transfer. PEF has been used to increase cell membrane permeability and enhance the release of intracellular chemicals from plant tissue (Toepfl et al., 2006). Plant tissue cell membranes are shown to be damaged by PEF treatment at moderate electric fields (500 and 1000 V/cm; for 10^4–10^2 s) with minimal temperature increase (Fincan and Dejmek, 2002; Lebovka et al., 2002). PEF can thereby reduce the rate at which heat-sensitive chemicals degrade (Ade-Omowaye et al., 2001). In order to reduce extraction effort, PEF can also be used on plant materials as a pretreatment procedure before traditional extraction (López et al., 2009).

2.5. Enzyme-assisted extraction (EAE)

Certain compounds in the plant matrix are kept in the polysaccharide-lignin network by hydrogen or hydrophobic bonding, while other phytochemicals are distributed throughout the cytoplasm of the cells. These compounds cannot be accessed with a solvent during a standard extraction procedure. According to Rosenthal et al. (1996), enzymatic pre-treatment has been regarded as a new and efficient method of releasing confined chemicals and boosting total yield. By dissolving the cell wall and hydrolyzing the structural polysaccharides and lipid bodies, the addition of particular enzymes during extraction, such as cellulase, a-amylase, and pectinase, improves recovery (Rosenthal et al., 1996; Singh et al., 1999). According to Latif and Anwar (2009), there are two methods for enzyme-assisted extraction: (1) enzyme-assisted aqueous extraction (EAAE) and (2) enzyme-assisted cold pressing (EACP). EAAE techniques were often created primarily for the purpose of extracting oils from different seeds (Hanmoungjai et al., 2001; Rosenthal et al., 1996, 2001; Sharma et al., 2002). Since polysaccharide-protein colloid, which is evident in EAAE, is not present in the EACP approach, enzymes are utilized to hydrolyze the seed cell wall (Concha et al., 2004). According to Niranjan and Hanmoungjai (2004), a number of variables are known to be important for extraction, including the concentration and composition of enzymes, the size of plant material particles, the solid to water ratio, and the duration of hydrolysis. According to Dominguez et al. (1995), another crucial element for enzymatic hydrolysis is the moisture level of plant materials. EACP's nontoxic and nonflammable qualities make it a perfect substitute for removing bioactive ingredients from oilseeds, according to Bhattacharjee et al. (2006). It was discovered that the oil extracted using enzyme-assisted techniques had greater levels of phosphorus and free fatty acids than conventional hexane-extracted oil (Dominguez et al., 1995). Since the EAE uses water as a solvent rather than organic chemicals, it is acknowledged as an environmentally benign method for extracting oil and bioactive substances (Puri et al., 2012). Meyer et al. (1998) studied the EAE of phenolic antioxidants from grape pomace during wine production and discovered a relationship between the yield of total phenols and the degree of enzyme-mediated plant cell wall disintegration. Using a variety of enzymes, Landbo and Meyer (2001) demonstrated enhanced phenolic component release from Ribes nigrum pomace. Li et al. (2006) used various enzymes to extract the total phenolic contents from five citrus peels (grapefruit, orange, mandarin, Meyer lemon, and Yen Ben lemon) using EAAE; celluzyme MX produced the best recovery.

2.6. Liquid extraction under pressure (PLE)

Richter et al. initially described PLE in 1996. According to Nieto et al. (2010), this technique is currently referred to by a number of names, including high pressure solvent extraction (HSPE), improved solvent extraction (ESE), accelerated fluid extraction (ASE), and pressurized fluid extraction (PFE) .Applying high pressure to keep a liquid solvent over its typical boiling point is the idea behind PLE. The extraction process is facilitated by high pressure. The primary driver behind the increased advancement of PLE-based methods, as well as the reduction in extraction time and solvent requirements, is automation approaches. Because the PLE technique combines high pressure and temperatures to produce faster extraction, it uses less solvents. By boosting solubility and mass transfer rate, as well as by lowering solvent viscosity and surface tension, a higher extraction temperature can increase analyte solubility and improve

extraction rate (Ibañez et al., 2012). PLE was shown to significantly reduce solvent usage and time consumption when compared to conventional soxhlet extraction (Richter et al., 1996). These days, PLE is being explored as a possible substitute for supercritical fluid extraction in the extraction of polar chemicals (Kaufmann and Christen, 2002). According to Wang and Weller (2006), PLE is also helpful for removing organic contaminants from environmental matrices that remain stable at high temperatures. Additionally, bioactive chemicals from marine sponges have been extracted using PLE (Ibañez et al., 2012). There are many examples in the literature of using the PLE technique to obtain natural products (Kaufmann and Christen, 2002). Furthermore, PLE is widely considered as a green extraction technique because it uses a small amount of organic solvent (Ibañez et al., 2012).

3. Conclusion

The identification and discovery of novel therapeutic chemicals depends on medicinal plants. The extraction procedure is crucial for separating and characterizing the many phytochemicals found in herbs as well as for searching for new leads in plant extracts. Compared to their contemporary counterparts, conventional procedures are more labor-intensive, time-consuming, power-intensive, and solvent-intensive. Choosing a better technique can also enhance the extract's stability, recovery, and general quality. The constant search for practical extraction techniques is fueled by the increasing desire to extract plant bioactive components. Two key elements in the development of the majority of unconventional extraction techniques are environmental consciousness and advancements in chromatography. However, since the majority of these techniques are founded on distinct mechanisms and extraction enhancement is the outcome of distinct processes, it is imperative to comprehend every facet of non-conventional extraction processes. Taking into account the properties of plant materials and compound selection, hybrid method creation and incorporation should also be examined. Some of the current approaches still lack adequate experimental data. The measurement of extraction efficiency is also impacted by the appropriate selection of standard procedures. However, the growing economic importance of bioactive substances and goods containing them could eventually lead to the development of more advanced extraction techniques.

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