Conventional and non-conventional approaches for extraction of medicinal plant

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**Abstract**

The extraction of medicinal plants is a crucial process to harness their therapeutic potential. Conventional methods, including maceration, percolation, and Soxhlet extraction, have been widely employed for their simplicity and reproducibility. However, these methods often involve prolonged processing times and the use of organic solvents, raising environmental and safety concerns. In contrast, non-conventional approaches offer innovative alternatives. Supercritical fluid extraction and ultrasound-assisted extraction are gaining prominence due to their efficiency in obtaining bioactive compounds while minimizing solvent usage and extraction time. Microwave-assisted extraction and enzyme-assisted extraction further enhance yield and bioactivity. This review explores the landscape of both conventional and non-conventional extraction techniques, highlighting their principles, advantages, and limitations in the context of medicinal plant extraction. By synergizing traditional wisdom with modern innovation, these approaches contribute to unlocking the full therapeutic potential of medicinal plants while addressing sustainability and safety challenges.

**Keywords**: Medicinal plants, Extraction methods, Conventional approaches, Non-conventional methods, Bioactive compounds, Supercritical fluid extraction, Sustainable extraction.

# Introduction

In the past 2000 years of the history of medicine we can imagine for most of the period, mankind had no other major source of medicine than plants, either fresh or dried. Over 248,000 species of higher plants have been identified and from these 12,000 plants are known to have medicinal plants engaged with a multi-dimensional role in therapeutic values. However, less than 10% of all plants have been investigated from a phytochemical and pharmacological point of view. The importance of medicinal plants is demonstrated by the fact for their quality, safety, and efficacy not only in developed countries even in developing countries [1–3]. According to the World Health Organization (WHO), in India, 65% of the population in rural areas uses Ayurveda or traditional medicines as an alternative and complementary medicine for treating various disorders [4]. The aims of medicinal plant research can be summarized as

* Qualitative and quantitative analysis of the constituents of
medicinal plants
* Isolation of plant-originated, biologically active, purified
fractions and molecules with new structures.
* Optimization of the amount and/or ratio of medicinal plant
compounds responsible for therapeutic effects.

As it is known with the complexity of phytochemicals in medicinal plants, evaluation of therapeutic potential concerning the phytochemical specification is one of the challenging endeavors to validate the medicinal plants for their regulatory purpose. Several conventional and nonconventional extraction techniques are strongly hyphenated for the establishment of targeted and non-targeted plant matrices based on successive extraction, target-based bio-guided fraction, or phytochemical enrichment extraction methods [2].

Chromatographic techniques are liable for the separation of phytochemicals from a complex plant matrix using suitable mobile and stationary phases. Besides the chromatographic separation, the selection of appropriate stationary and mobile phase provides robustness in chromatographic separation. Optimization of targeted bioactive phytoconstituents from herbal medicine is one of the important steps from separation science to biological science [5]. Chromatography and spectroscopy techniques such as thin layer chromatography (TLC), high performance thin layer chromatography (HPTLC), high performance liquid chromatography (HPLC), Ultra performance liquid chromatography (UPLC), liquid chromatography and mass spectroscopy (LC-MS), gas chromatography and mass spectroscopy (GC-MS), nuclear magnetic resonance (NMR) etc are mainly hyphenated with target-based isolation, identification and quantitation of phytoconstituents from a huge diversity of phytoconstituents as well as help us to optimized and evaluate single constituents than the complexity of phytoconstituents [6,7]. This chapter includes a comprehensive review concerning modern methods of extraction and the techniques (chromatographic and spectroscopic) used for isolation, purification and identification of crude drugs from the medicinal plants.

# Selection of extraction approaches

The fundamental steps in the analysis of medicinal plants are the selection of extraction method, as it is essential to extract the desired phytoconstituents from the plant materials for further chromatographic and spectroscopic identification or even characterization. The extraction method generally depends upon several factors

* Type of plant, part of the plant to be extracted, availability of solvent and nature of the bioactive compounds
* Pre-washing, drying or freeze-drying and grinding of crude plant material are often improving the analytic extraction kinetics with increased contact of the sample surface with the solvent system
* During extraction, it should be highly identifiable that potential active constituents are not lost, degraded during the extract preparation. Generally, extraction methods, such as decoction/boiling under reflux, sonification, soxhlation etc results in degradation of thermolabile phytoconstituents such as carotenoids, terpenoids etc and drops unfavorable conditions to reach out successive extraction.
* If the selection of plants was made based on ethnobotanicals perspective, then it is necessary to prepare the extract as described in traditional literature in order to mimic unfavorable conditions.

For example, if indigenous people approach a specific extraction method or use water, alcohol/alcoholic water as extracting solvent with heat or without heat, then a similar method should be approached in the laboratory to mimic the loss of molecular integrity so that same natural product can be extracted [8].

# Selection of solvent for extraction

The selection of solvent for the extraction of phytoconstituents depends on the target-based isolation of phytoconstituents. Besides, polarity-based extraction and isolation of phytoconstituents are one of the necessities concerning their ethnobotanical purpose. In case, if the extraction method is not directly used for the ethnobotanical perspective, target-based isolation is the main perspective, the selection of solvent system mostly is influenced by the specific nature of the targeted bioactive compound [8]. Verities of solvent systems are accessible to extract the bioactive compound from the plant material and it largely depends upon the polarity index of acting solvent.

* The extraction of hydrophilic phytoconstituents uses semi-polar/polar solvents such as ethyl-acetate, ethanol, methanol, n-butanol, water etc.
* Extraction for lipophilic compounds, dichloromethane or dichloromethane: methanol (1:1), chloroform etc. used as the universal and more compatible solvents
* Extraction using hexane is purposed only to remove chlorophyll [9].

For example, extraction of non-polar compounds such as carotenoids, terpenoids, steroids, etc dichloromethane can be used as the extracting solvent using any specified extraction method without application of heat as it can cause degradation of desired components in the crude plant matrix.

# Modern methods of extraction

## Extraction

Extraction is a process to separate the targeted or untargeted classes of phytoconstituents from herbal/crude plant material when it is brought into contact of a solvent in which the substance of interest is soluble, but the other substances present areinsoluble. The selection of the solvent is crucial for solvent extraction. Selectivity, solubility, cost and safety should be considered in the selection of solvents. The constituents that pose a similar polarity value near to the polarity of the solvent are likely to perform better miscibility and vice versa. Alcohols (ethanol and methanol) and water are being considered as universal solvents for the extraction of phytochemicals and their investigation [10].

The extraction of natural products progresses through the following stages:

* The solvent penetrates into the solid matrix.
* The solute dissolves in the solvents.
* The solute is diffused out of the solid matrix.
* The extracted solutes are collected.

Generally, the finer the particle size is better the result for extraction can be achieved. The extraction efficiency will be enhanced by the small particle size due to the enhanced penetration of solvents and diffusion of solutes, however, too fine a particle size will cost the excessive absorption of solute in solid and may cause difficulty in subsequent filtration [11].

During liquid-liquid extraction, the conventional way is to select two miscible solvents such as water–dichloromethane, water–ether, and water–hexane. In all the combinations, water is present because of its high polarity and miscibility with an organic solvent. The compound to be extracted using liquid-liquid extraction should be soluble in an organic solvent but not in water to ease the separation. Furthermore, the solvent used in extraction is classified according to its polarity, from n-hexane which is the least polar to water the most polar [8].

## Methods of extraction

There are various types of conventional and non-conventional methods which are widely used for the extraction of targeted and untargeted metabolites from natural or crude plant material [1,3,12], [9].

**Methods of extraction**

**Conventional methods**

1. Infusion
2. Decoction
3. Digestion
4. Maceration
5. Percolation

**Non-Conventional methods**

1. Reflux method
2. Soxhelation method
3. Ultrasonic Assisted Extraction (UAE)
4. Microwave Assisted Extraction (MAE)
5. Pressurized liquid extraction (PLE)
6. Supercritical fluid extraction (SFE)
7. Pulsed electric field (PEF) extraction
8. Enzyme assisted extraction (EAE)
9. Hydro distillation and steam distillation

Figure 1: Enlisted of extraction methods used in herbal industries

## Conventional methods of extraction

### Infusion:

**Infusion** is the process of extracting chemical compounds from plant material in a solvent such as water by allowing the material to remain suspended in the solvent over a short period of time.

**Principle**

The drug material is grinded into a fine powder and then placed inside a clean container. The extraction solvent hot or cold is then poured on top of the drug material, soaked, and kept for a short period of time. This method is suitable for the extraction of bioactive constituents that are readily soluble. In addition, it is an appropriate method for the preparation of fresh extract before use. The solvent to sample ratio is usually 4:1 or 16:1 depending on the intended use.

**Advantages**

* No degradation of phytoconstituents
* Safe in consumption if used as medicinal purpose
* Economic and easy establishment

**Disadvantages**

* Less extractive yield
* Solvent restricted metabolites achievement

### Decoction

A process of extracting chemical compounds from crude material boiled with a specified volume of water for a defined time at atmospheric temperature.

**Principle**

A dried, grinded, and powdered plant material is placed into a clean container. Water is then poured and stirred. Heat is then applied throughout the process to hasten the extraction [13]. The process has lasted for a short duration usually about 15min. The ratio of solvent to the crude drug is usually 4:1 or 16:1. It is used for the extraction of water-soluble and heat-stable plant material

**Advantages**

* More efficient than infusion
* High extraction yield
* Safe in consumption if used as medicinal purpose
* Economic and easy establishment

**Disadvantages**

* Decoction contains a large amount of water-soluble impurities.
* Decoction cannot be used for the extraction of thermolabile or volatile components.

**Example:** Preparation of green tea, ordinary tea etc.

### Digestion

It is a form of maceration where gentle heat is needed during the process of extraction. It is used when the moderately elevated temperature is not objectionable. The solvent efficiency of menstruum is thereby increased.

**Principle**

The solvent of extraction is poured into a clean container followed by powdered drug material. The mixture is placed over a water bath or in an oven at a temperature of about 50o C. Heat was applied throughout the extraction process to decrease the viscosity of the extraction solvent and enhance the removal of secondary metabolites.

Eg. Extraction of morphine through digestion extract**.**

**Advantages**

* More efficient than infusion and decoction
* High extraction yield
* Suitable for readily soluble plant materials.

**Disadvantages**.

* This method cannot be used for the extraction of thermolabile or volatile components.

### Maceration

Maceration is a simple extraction process in which consistent maintenance of direct contact between the crude material and distilled water or another extracting solvent (depends on the polarity and targeted natural products) is being processed for a period of time at room temperature.

**Principle**

In this method, coarsely powdered drug material either leaves or stems bark or root bark is placed inside a container; the menstruum is poured on top until completely covered the drug material. The container is then closed and kept for at least three days. The content is stirred periodically, and if placed inside the bottle it should be shaken from time to time to ensure complete extraction. At the end of extraction, the micelle is separated from marc by filtration or decantation. Subsequently, the micelle is then separated from the menstruum by evaporation in an oven or on top of a water bath.

Eg- Extraction of total phenols and total anthocyanins from chokeberry fruit

**Advantages**

* Majorly hyphenated for the extraction of thermolabile components from natural sources
* Economic and easy establishment

**Disadvantages**

* Long extraction time and low extraction efficiency
* High consumption of extraction solvent
* The process is labor-intensive

### Percolation

Percolation, it is a continuous process in which the saturated solvent is constantly being replaced by fresh solvent and the extracted contents being collected. This method is more efficient than maceration because of its continuous process. This process is performed at room temperature and occasionally under heat.

**Principle**

The apparatus used in this process is called a percolator. It is a narrow-cone-shaped glass vessel with an opening at both ends. A dried, grinded, and finely powdered plant material is moistened with the solvent of extraction in a clean container. More quantity of solvent is added, and the mixture is kept for a period of 4h. Subsequently, the content is then transferred into a percolator with the lower end closed and allow to stand for a period of 24h. The solvent of extraction is then poured from the top until the drug material is completely saturated. The lower part of the percolator is then opened, and the liquid is allowed to drip slowly. Some quantity of solvent was added continuously, and the extraction has taken place by gravitational force, pushing the solvent through the drug material downward. The addition of solvent stopped when the volume of solvent added reached 75% of the intended quantity of the entire preparations. The extract is separated by filtration followed by decantation. The marc is then expressed and the final amount of solvent is added to get the required volume.

**Advantages**

* Higher extraction efficiency and less time required than maceration.
* It can be used for tinctures and resinous drugs
* Economic and easy establishment

**Disadvantages**

* There may be chances of blasts due to over swelling of drugs
* Restricted to tinctures and resinous drugs only

## Non-Conventional methods

### Reflux extraction

Reflux extraction is a solid-liquid extraction process at a constant temperature with repeatable solvent evaporation and condensation for a particular period of time without the loss of solvent. It involves the technique of condensation of vapors and the return of this condensate to the system from which it originated.

**Principle**

A coarsely powdered drug was placed to the round bottom flask (RBF) with the extracting solvent in 1:8 ratio (drug : solvent) for proper extraction. A condenser is placed to the RBF which condenses the solvent vapors thus mimic the loss of solvent during extraction. This process is performed continuously for 8-10 hrs to achieve proper extraction and high extractive yield. After the extraction process, the extract is filtered, concentrated and stored at room temperature for further use.

Example: Refluxing with 70% ethanol provided the highest yield or good extraction efficiency of active ingredients. The reflux method was found to be better than the decoction method.

**Advantage**

* Required moderate solvent consumption with high extraction efficacy and yield
* Reflux extraction is more efficient than percolation or maceration and requires less extraction time and solvent

**Disadvantage:** It can not be used for the extraction of thermolabile natural products.

### Soxhlet extraction method

The Soxhlet extraction method integrates the advantages of reflux extraction and percolation. It is an automatic continuous extraction method with high extraction efficiency that requires less time and solvent consumption than maceration or percolation. The process utilizes the principle of reflux and siphoning to continuously extract the herb with fresh solvent [14].

**Principle**

 The coursly powdered biomass of dried plant material is placed in a soxhlet thimble constructed of filter paper, through which solvent is continuously refluxed. After reaching a level of soxhlet thimble with the extracting solvent, it empty its content into the RBF. Further, the fresh solvents enter into the soxhlet thimble by the reflux condenser. The cycle of up and down enter of extracting solvent from RBF to soxhlet thimble is continuously processed till the complete extraction can not be achieved. this process takes a minimum 10-15 hrs to complete the extraction process. After reaching the complete extraction, the extract is filtered through the Whatman's filter paper and concentrated for further use.

**For example,** in a study, ursolic acid was isolated from the Cynomorium (*Cynomorii Herba*) extract obtained through the soxhlet method, the yield of ursolic acid was found as 38.21 mg/g. Besides, using the same method for extraction, the degradation of catechins in tea was also observed in Soxhlet extraction due to the high extraction temperature applied. The concentrations of both total polyphenols and total alkaloids from the Soxhlet extraction method at 70 °C decreased compared to those from the maceration method applied under 40 °C.

**Advantages**:

1. Integrates the advantages of the reflux extraction and percolation.
2. High extraction efficiency.
3. Less time and solvent consumption

**Disadvantages:**

1. The high temperature and long extraction time will increase the possibilities of thermal degradation.

### Supercritical fluid extraction (SFE)

Supercritical fluid extraction (SFE) uses supercritical fluid (SF) as the extraction solvent. SF has similar solubility to liquid and similar diffusivity to gas, and can dissolve a wide variety of phytoconstituents. The solvating properties dramatically changed near their critical points due to small pressure and temperature changes. Supercritical carbon dioxide (S-CO2) was widely used in SFE because of its attractive merits such as low critical temperature (31°C), selectivity, inertness, low cost, non-toxicity, and capability to extract thermally labile compounds.

Furthermore, in working principle of SFE, there are main there steps that are associated with the extraction phenomenon.

#### Maximizing diffusion

This can be achieved by increasing the temperature, swelling the matrix, or reducing the particle size. Matrix swelling can sometimes be increased in proportion to the acting solvent pressure, and by adding modifiers to the solvent it can be regulated to achieve the successive extraction. Some polymers and elastomers, in particular, are swelled dramatically by CO2, with diffusion being increased by several orders of magnitude in some cases.

#### Maximizing solubility

Generally, optimized pressure and temperature will increase the solubility or dissolving power of phytoconstituents with no loss of their chemical integrity. At pressures well above the critical pressure, solubility is likely to increase with temperature. Besides, the addition of low levels of modifiers (sometimes called entrainers), such as methanol and ethanol, can also significantly increase solubility, particularly of more polar compounds.

#### Optimizing flow rate

Flow rate must therefore be determined depending on the competing factors of time and solvent costs, and also capital costs of pumps, heaters and heat exchangers. The optimum flow rate will probably be somewhere in the region where both solubility and diffusion are significant factors.

For example, in a study, Conde-Hernández extracted the essential oil of rosemary (Rosmarinus officinalis) by three methods such as S-CO2 extraction, hydro distillation and steam distillation. He found that both yields of essential oil and the antioxidant activity of SFC extract were higher than those from the other two methods. S-CO2 modified with 2% ethanol at 300 bar and 40 °C gave higher extracting selectivity of vinblastine (an antineoplastic drug) from Catharanthus roseus, which is 92% more efficient for vinblastine extraction compared to traditional extraction methods [15].

**Advantage**

* The process can facilitate the collection of pure CO2 solvent (gas), such that it can be recirculated into storage for re-use, thus reducing total energy costs (less CO2 collection required) thereby reducing energy consumption and increasing the overall sustainability of SCF-based extractions.
* Precise and rapid extraction
* Selectivity of this method beings this into a more considerable instrument for the extraction of non-polar constituents. As the properties of the supercritical fluid can be altered by varying the pressure and temperature, allowing selective extraction.

**Disadvantage**

Unfortunately, SFE-based methods are not without their own shortcomings; two major ones being are associated with the same as

* The high establishment cost; and
* The selective solvent nature of CO2, i.e., that CO2 only dissolves small non-polar molecules

### Ultrasound-assisted extraction (UAE)

Ultrasonic-assisted extraction (UAE), also called ultrasonic extraction or sonication, uses ultrasonic wave energy in the extraction. Ultrasound in the solvent-producing cavitation accelerates the dissolution and diffusion of the solute as well as the heat transfer. Acoustic cavitation generated by UAE destroys the cell wall and reduces the particle size, thereby enhancing the contact between the solvents used in UAE.

**Working principle**

A coarsely powdered drug was placed in the conical flask with the extracting solvent in 1:8 ratio (drug : solvent) for proper extraction. The container is placed to the sonicator at the optimized extraction condition. This process is performed continuously for 5-8hrs to achieve proper extraction and high extractive yield. After the extraction process, the extract is filtered, concentrated and stored at room temperature for further use.

**For example,** a higher yield of polyphenols from Thymus serpyllum L. by UAE at an optimized condition (50% ethanol as solvent; 1:30 solid-to-solvent ratio; 0.3 mm particle size and 15 min time) than other extraction methods such as maceration and heat-assisted extraction methods. Hence, it is reported that the reflux method and UAE had the advantages of time-saving, convenient operation and high extract yield and that UAE is relatively better than reflux methods for TCM Dichroae Radix using the extract yield and content of febrifuge as the indexes [16].

**Advantage:**

* UAE improves the extraction efficiency with low solvent and energy consumption, and the reduction of extraction temperature and time.
* UAE increases the yield of the extract with short extraction times.
* UAE is applicable for the extraction of thermolabile and unstable compounds.
* In addition, there are some other advantages to this method, such as simplicity, speed, and low energy consumption, compared with traditional extraction methods.

**Disadvantage:**

* Associated demerits such as their time consumption, inefficiency, and uneconomical nature.

### Microwave-assisted extraction (MAE)

This is one of the advanced extraction procedures which involves the mechanism of dipole rotation and ionic transfer by displacement of charged ions present in the solvent and drug material.

**Principle**

It involves the application of electromagnetic radiation in frequencies between 300 MHz and 300 GHz and wavelengths between 1cm and 1 m. The microwaves applied at a frequency of 2450 Hz yielded energy between 600 and 700 W. The technique uses microwave radiation to bombard an object, which can absorb electromagnetic energy and convert it into heat. Subsequently, the heat produced facilitates the movement of solvent into the drug matrix.

When the polar solvent is used, dipole rotation and migration of ions occur, increase solvent penetration, and assist the extraction process. However, when the non-polar solvent is used, the microwave radiation released will produce only small heat; hence, this method does not favor use of nonpolar solvents. Microwaves generate heat by interacting with polar compounds such as water and some organic components in the plant matrix following the ionic conduction and dipole rotation mechanisms. The MAE is based on the assistance of electromagnetic radiation with frequencies from 0.3 to 300 GHz, which induce heat inside the material via dipolar rotation and ionic conduction of the molecules [17]. The activation of these molecules and the heat generated in this process may weaken or break the cell walls thereby the bioactive compounds can be released more easily from material matrix to the extraction solvent[18].

**Advantages:**

* The application of MAE provides many advantages, such as increasing the extract yield, decreasing the thermal degradation and selective heating of vegetal material.
* MAE is also regarded as a green technology because it reduces the usage of organic solvents.
* MAE method for the extraction of polar and non-polar constituents

**Disadvantages**

This method is suitable only for phenolic compounds and flavonoids. Compounds such as tannins and anthocyanins may be degraded because of high temperature involved.

### Hydro distillation and steam distillation

Essential oils are extracted from natural resources especially plant resources which contain hundreds of constituents belongs to the group of terpenes and phenylpropenes. Hydro distillation (HD) and steam distillation (SD) are commonly used methods for the extraction of volatile oil/essential oil in a Clevenger apparatus.

**Principle**

Hydro distillation (HD) and steam distillation (SD) are commonly used methods for the extraction of volatile oil. In brief, the crude material is placed to the RBF on which the Clevenger apparatus is attached. After providing the optimized temperature to RBF through the heating source, essential oil or volatile oils is convert in vapors and condensed along with the vapors of water which is collected in the graduated cylinder reservoir. In this reservoir, the condensed liquid contains two phases, the upper phase represents the essential oil and other represents to hydrosol (water contains some of the most polar volatile constituents).

**Application:** Extraction and purification of essential/volatile oils.

# Separation method

The components in the extract from the above methods are complex and contain a variety of natural products that require further separation and purification to obtain the active fraction or purely natural products. The separation depends on the physical or chemical difference of the individual natural product. Chromatography, especially column chromatography, is the main method used to obtain pure natural products from a complex mixture.

## Fraction and purification methods

Fractionation is a process of separation of plant extracts into various fractions. It further segregates the fractions into portions comprising a number of compounds. The process continues until the pure compound is isolated [19]. When several solvents are required for the fractionation, they should be added according to the order of increasing polarity. Fractionation techniques are classified into the physical or chemical methods.

## Physical methods

Physical methods used in the separation of compounds from mixtures include the separation funnel method, chromatographic techniques, fractional distillation, fractional crystallization, fractional liberation, and sublimation [20]

## Separation funnel method

When four different solvents (n-hexane, chloroform, acetone, and n-butanol) are selected, fractionation begins by moistening or complete dissolution of the crude extract with 250mL of water. This is followed by transfer into a separating funnel, shaken, and allowed to settle. Furthermore, to 250mL of n-hexane, the least polar solvent was added and shaken. The content can settle, and the bottom of the separating funnel opened to remove the aqueous layer. The remaining content in the separating funnel was poured into a clean container to get n-hexane fraction. An equal volume of n-hexane was added again, shaken, and separated. The addition continued until after adding n-hexane and shaken no reasonable quantity of extract appeared to move into the n-hexane portion. A similar cycle was performed for chloroform, acetone, n-butanol to get chloroform, acetone, and n-butanol fractions. The remaining portion left after the fractionation is termed as a residual aqueous fraction (RAF) as the crude extract was first dissolved in water.

## Fractional distillation

This is the process of separating or purifying compounds from a mixture. It is usually used in the separation of hydrocarbons such as crude oil, citral, and eucalyptol. Purification is achieved based on the differences in their boiling points. The fractional distillation apparatus is constructed in such a manner that when heat is applied each compound will evaporate and separates at its boiling point. Consequently, each compound fractionated will condense and be collected as a separate entity through several siphons attached to the fractional distillation apparatus.

## Fractional crystallization

Large numbers of compounds that exist naturally in plant extracts are crystal in nature. Separation is achieved via the formation of crystals during the concentration of an extract using heat or refrigeration. Hence, the process of chemical crystallization from the fraction called Fractional crystallization

## Fractional liberation

This method is suitable for separating compounds that can easily form precipitates from the mixture. The precipitate is usually formed by changing the compounds into their salt form or treating the sample (containing a large amount of single compound) to the solvent pose opposite polarity nature. Fractional liberation is commonly applicable in the separation or purification of natural products from rich fractions [20].

## Sublimation

This method involves changing from solid to gaseous state without passing through the liquid state. Substances such as camphor and volatile oils when heated get separated and converted directly into a gas.

# Conclusion

In conclusion, the extraction of bioactive compounds from medicinal plants is a fundamental process in modern herbal medicine. While conventional methods have proven their reliability, the emergence of non-conventional approaches offers promising alternatives that are more efficient, environmentally friendly, and yield compounds of higher bioactivity. Integrating these innovative techniques with traditional knowledge bridges the gap between ancient wisdom and contemporary science. This synthesis not only enhances the therapeutic potential of medicinal plants but also aligns with sustainability goals and safety considerations. As research continues to evolve, a holistic approach that embraces both conventional and non-conventional extraction methods will undoubtedly shape the future of medicinal plant utilization and its contributions to human well-being.

**Conflict of interest**

Authors declare no conflict of interest.

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