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Extraction of Natural Products Using Microwaves as a Heat Source

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Microwave-assisted extraction is the process of using microwave energy to heat the moisture present in the plant material or solvents in contact in order to extract natural products from the plant materials. A typical microwave-assisted extraction is completed within few minutes with higher yield and less solvent consumption. This review gives a brief theoretical background of microwave heating along with the mechanism involved for extraction and influence of parameters is discussed. Finally, a comparison of microwave-assisted extraction with other extraction techniques is given which enables the readers to appreciate microwave-assisted extraction as energy efficient, environment friendly and rapid method available today.

KEYWORDS Microwave, extraction, natural products, parameters, comparison

INTRODUCTION

Natural products, known as phytochemicals, are a group of nutritive compounds found in herbs, fruits, vegetables and spices. Plants synthesize thousands of these metabolites for their growth and development, reproduction, defense against attack by many different kinds of organisms, and survival in often harsh and ever changing environments. The synthesis of the various metabolites proceeds along metabolic pathways located in one or more cell

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compartments (e.g., cell walls, membrane systems, the cytosol, and various cellular organelles) within tissues that are often specialized for particular tasks as shown in Figure 1.

Each individual biosynthetic pathway is regulated by a vast array of environmental, biotic, biochemical, and molecular factors. It is these factors that allow for the incredible variety of metabolite activities that control the overall growth, development, and environmental interactions of each plant. Thus, each plant constituents of medicinal importance form an extensively diverse group of chemical compounds showing greater variation in solubility and stability. They can be broadly classified as: lipids (fixed oils, fats, and waxes); phenols; tannins; proteins; alkaloids; carbohydrates; glycosides; essential oils and resins and resin combinations. Some of the major components like linalool and citral are shown in the Figure 2a and 2b, respectively. A brief list of various medicinal plants and natural products with their major applications is given in Table 1. Considering the usefulness in medicinal field, various compounds are often derived from the plant source rather than being produced synthetically. Also, these compounds are used quite

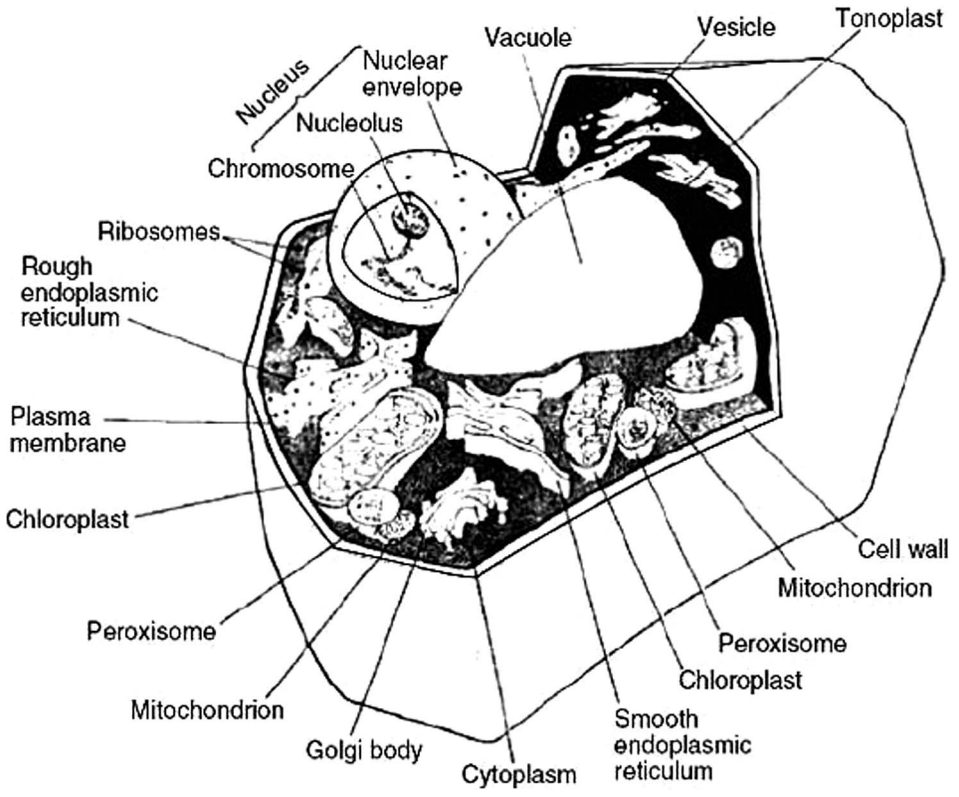

FIGURE 1 A plant cell and its organelles. Adapted from Ref. 1.

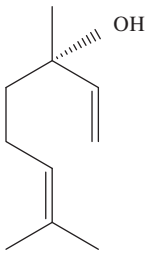

FIGURE 2a Chemical structure of linalool.

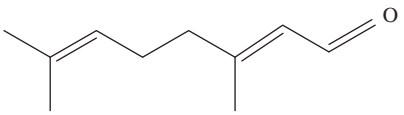

FIGURE 2b Chemical structure of citral.

extensively in the food, cosmetic, pharmaceutical, oleochemical and other industries (1, 4, 5).

For extraction of the natural products, selection of extraction methods depends on solubility, volatility and stability of these compounds, and interaction of other compounds present. Usually, extraction of natural products from various plants uses various techniques like steam distillation (SD) (6), Soxhlet extraction (SE) (7), and so on. These techniques consume more energy, take long time for extraction and use large amount of solvents creating the environmental issue. Keeping in mind these problems, there has been an increasing demand for new sustainable extraction techniques that lead to shortened extraction time, reduced solvent consumption, automation and energy saving. Driven by these purposes, a number of techniques such as supercritical fluid extraction (SFE) (8), pressurized fluid extraction (PFE) (9), pressurized hot water extraction (PHWE) (10), microwave-assisted extraction (MAE) (11) and ultrasound-assisted extraction (UAE) (12) have been developed. Among them, microwave heating offers various processing advantages over the conventional heating methods:

1. In microwave processing, for the material having high microwave absorbing capacity, the heat is generated inside the material and then comes out ward, known as volumetric heating, whereas in conventional heating the surface is heated first. Thus, the microwave heating is rapid and effective as heat is transferred directly to the material (13).
2. For most materials, especially biological tissues, the maximum penetration of the electromagnetic energy occurs in microwave range (14).
3. In organic synthesis, microwave radiation is very well exploited. Many solvent free reactions using microwave irradiation showed enhanced

TABLE 1 A List of Various Medicinal Plants and Compounds with Their Major Applications

Sr. no.	Plant name	Useful part	Natural compound	Applications	Ref.
1.	*Eucalyptus globulus*	Leaves	Essential oil containing cineole	Flavoring, antiseptic, aromatherapy	2
2.	*Lavandula angustifolia*	Stem, flower	Essential oil containing linalyl acetate, linalool, camphor, borneol	Sedative, carminative, antispasmodic, cough suppressant, skin freshener, perfumeries	2, 3
3.	*Morinda citrifolia*	Root, leaves, heartwood	Morindone, Morindin, Ursolic acid, β-Sitosterol, Citric acid	Treatment of gout and ulcer, cathartic, deobstruent,	3
4.	*Ocimum basilicum* L.	Root, leaves, flower, seed	Essential oil containing α-pinene, limonene, 1,8-cineole, thymol.	Diaphoretic, carminative, stimulant	3
5.	*Origanum majorana*	Flower	Essential oil containing terpinines, terpineol, tannins, carotenes	Stomachic, carminative, antispasmodic	3
6.	*Pinus palustris*	Needles, twigs	α-Terpineol	Antiseptic, disinfectant, aromatherapy	2
7.	*Rosmarinus officinalis*	Leaves	Carnosolic acid, Essential oil containing cineole, camphor, borneol	Anti HIV activity, rubefacient action	3, 4
8.	*Taxus baccata* L.	Wood, bark, leaves, fruit	Taxine, Vitamin C	Treatment of gout, rheumatism, arthritis, urinary tract infections, heart and level condition, antitumor activity	3
9.	*Zingiber officinale*	Rhizome	Essential oil containing Zingiberene, β-sesquiphellandrene, β-phellandrene, β-bisabolene, Resins, Starch	Flavoring, stomachic, carminative, stimulant, atherosclerosis reducer	2–4

reaction rates, greater selectivity and experimental ease to manipulation (15, 16).

Apart from heating, microwave processing has an edge over other extraction techniques as described next:

1. Compared to other solvent extraction techniques like Soxhlet and sonication extraction, amount of solvent used is very less (13).
2. It allows full control of extraction parameters like time, power and temperature (13).

3. It reduces extraction time to the great extent (11, 17–20).
4. It is energy efficient method with enhanced extraction efficiency and environment friendly nature (21–23).
5. MAE leads to improved yield, quality of the extract, reduced production costs and reduced process-related hazards compared to the conventional extraction processes (11).
6. Use of microwave in essential oil extraction causes fewer chemical changes of original plant components like rearrangement, dehydration and isomerization compared to hydro distillation (HD) (24, 25). Also, it provides a more valuable essential oil with higher amounts of oxygenated compounds (21, 23–29). In the case of thermosensitive compounds, degradation can be prevented or reduced upon application of microwave irradiation under vacuum (30).
7. Essential oil obtained by microwave irradiation has increased antimicrobial as well as antioxidant activities compared to oil obtained by HD (29).

There have been a few review articles on novel extraction techniques including MAE in recent years (31–35). The review papers involved extraction of environmental contaminants (31, 32) and phytochemicals (33), features of various microwave systems for intensification of sorption and extraction concentration operation (34), application of MAE in analysis of medicines, vitamins and drugs of abuse, present in pharmaceutical, environmental and biological samples (35). Major review papers focus either on the various techniques available or application of MAE in the field of environment at analytical level. During the literature search, it was found that no review paper has discussed the extraction of natural products for preparation purpose towards various applications. The main application of MAE is to obtain a specified compound in a desired form.

In this context, the objective of this review is to provide a short theoretical background of microwave heating and the basic principles of using microwave energy for extraction. The influence of parameters such as solvent choice, solvent volume, temperature, time and matrix characteristics on the yield of product is, also, discussed. This paper attempts to summarize all studies performed after the year 1999 and comparison with other extraction techniques will provide importance of microwave as a significant heat source to carry out cost effective, energy efficient, environment friendly and rapid extraction.

HISTORY

The microwave region of the electromagnetic field lies in the frequency range of 300 MHz to 300 GHz or between wavelengths of 1 mm and 1 m (31).

For microwave power applications, the frequency band at 915 MHz and 2.45 GHz are used. Almost all domestic ovens operate at 2.45 GHz (14). The use of microwave energy as a heating source in analytical laboratories started in the late 1970s and was applied to acid digestions (36). The development of MAE was first reported by Ganzler and co-workers (37). First patent for extraction of natural products using microwave was developed by Pare (11).

Advancements in this process were achieved by eliminating use of solvents in the system (38, 39), by providing wave-guides for focusing the microwave in confined volume to accelerate the rate of extraction (40) and by applying reduced pressure in the enclosure during the microwave radiation stage and heating the enclosure to compensate for the temperature drop resulting from water evaporation from the biological material (41). In recent years, hydrodistillation was modified by applying microwave as a heat source instead of conventional heating (42) and microwave heating along with earth gravity was utilized for extraction of essential oil (43).

Constructional Features

The microwave vessel is comprised of four major units: (a) Magnetron, which generates microwave energy; (b) Wave guide, which transmits the microwave from the source to the microwave cavity; (c) The applicator where the sample is placed; and, d) Circulators used for reflection and homogenization of radiation.

Two types of extraction vessels are commercially available: closed extraction vessel (Figure 3) and open extraction vessel (Figure 4). The former performs extraction under controlled pressure and temperature where temperature can be increased by simply applying the correct pressure. The latter is operated at atmospheric pressure; hence, the temperature is limited by the boiling point of the solvent or the polar compounds present. Additional stages of cooling and filtration are required when closed extraction vessel is used. Regarding safety of the personnel working with the vessel and the vessel itself, numerous emergency systems such as rupture membranes, solvent vapor detector and exhaust fan to evacuate air from the cavity are available with commercial microwave vessels dedicated for the extraction purpose. The features of both the systems and different accessories for convenience of operation are discussed at length in the review paper by Kubrakova and Toropchenova (34). On comparing the extraction efficiencies, both the systems have shown similar performances (32). For operating the system, the personnel must be acquainted with know how of the system, i.e., standard operating procedure should be established to avoid any mishap.

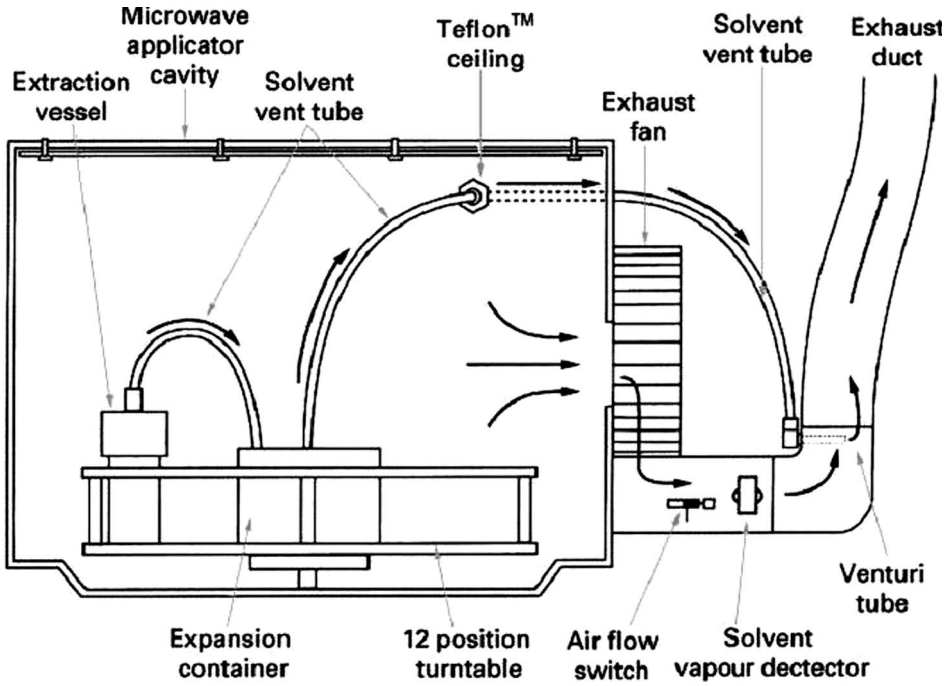

FIGURE 3 Schematic figure showing a closed vessel of a microwave-assisted extraction system. Adapted from Ref. 13. Reprinted with permission of Elsevier.

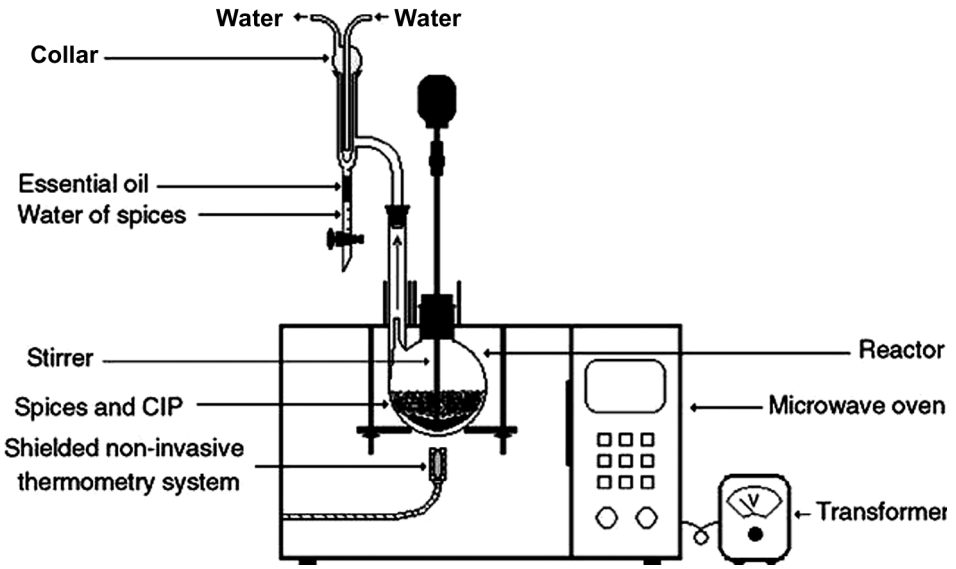

FIGURE 4 Schematic of an open vessel microwave-assisted extraction system. Adapted from Ref. 25.

BASIC PRINCIPLES

Microwave as a Source of Heat

The mechanism of microwave heating is different from that of conventional heating. In conventional heating, thermal energy is transferred from the source to the object through conduction and convection. Here, microwaves penetrate into the pores (13) and then electromagnetic energy is transformed into heat through ionic conduction and dipole rotation. Ionic conduction refers to the movement of ions in a solution under an electromagnetic field. The friction between the solution and the ions generates heat. Dipole rotation is the reorientation of dipoles under microwave radiation. A polarized molecule rotates to align itself with the electromagnetic field at a rate of 4.9 X 10^9 times per second (44, 45). The larger the dipole moment of a molecule, the more vigorous is the oscillation in the microwave field (45).

The parameters defining the dielectric properties of the materials are dielectric constant (ε') and loss factor (ε''). The dielectric constant gives the idea about the ability of a molecule to be polarized by the applied field while the loss factor measures the efficiency with which the microwave energy can be converted into heat. These two parameters depend on the frequency of the microwave. The energy dissipation factor or loss tangent ($\tan\delta = \varepsilon''/\varepsilon'$) combines these two parameters and gives idea of different materials to convert microwave energy into thermal energy at given frequency (45, 46). The higher the dissipation factor, the higher will be the thermal energy. Polar solvents such as water, methanol and ethanol have high loss tangent, indicating rapid heating. Nonpolar solvents such as hexane cannot be heated because of very low dielectric constant; hence, they are termed as microwave transparent solvents. Physical parameters of some important solvents are listed in Table 2. As water is the predominant component of biological materials, its presence directly enhances heating.

TABLE 2 Physical Parameters of Some Solvents Commonly used in Microwave Applications (45, 47, 48)

Sr. No.	Solvent	Dipole moment at 20°C (debye)	Dielectric constant at 20°C	Dissipation factor at 2.45 GHz
1	Acetonitrile (ACN)	3.44	37.5	–
2	Ethyl acetate	1.88	6.02	–
3	Water	1.84	80.4	0.123
4	Methanol	1.70	33.7	0.659
5	Ethanol	1.69	25.7	0.941
6	1-Butanol	1.66	–	0.571
7	Acetone	–	21.4	–
8	Diethyl ether	–	4.389*	–
9	Chloroform	–	4.8	–
10	Hexane	< 0.1	1.88	

*at 18°C.

Extraction by Microwave Energy

In MAE of biological active compounds from plant materials, the microwaves reach the inner glandular, trichomes and vascular systems of the biological material and are absorbed by the polar molecules present or added absorbing component generating the sudden rise in temperature inside the material. This causes vaporization of volatile materials, increasing the internal pressure of the cell and finally rupturing of the cell as shown in Figure 5a and 5b. The substances that were located in the cells are then free to flow out of the cells. They migrate to the surrounding medium that, in turn, is relatively cold and that can trap them and dissolve them (11, 18, 49, 50).

PARAMETERS AFFECTING MICROWAVE-ASSISTED EXTRACTION

Optimization of extraction conditions has been reported in the literature. Factorial (51, 52) and central composite (26, 53, 54) designs have also been

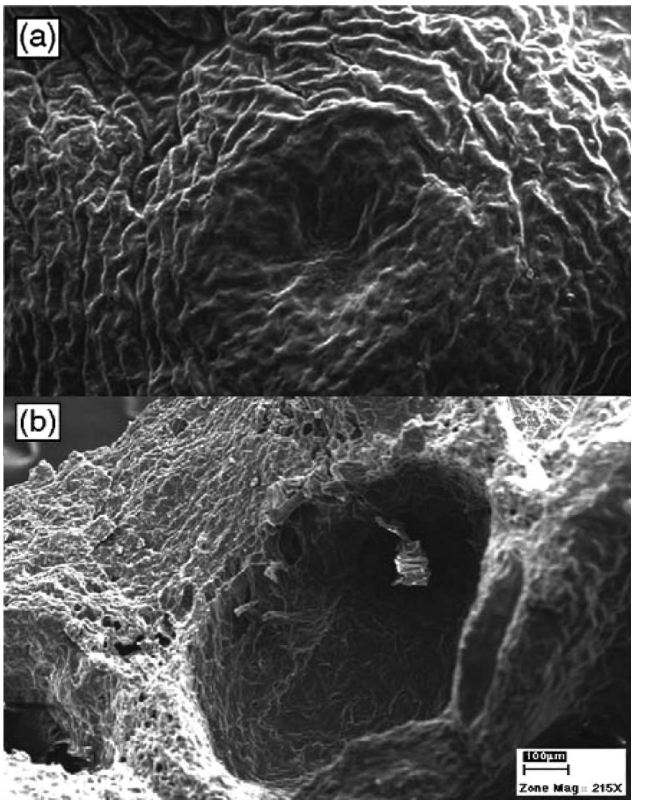

FIGURE 5 Electron micrograph of orange peels. (a): top, untreated orange peel; (b): bottom, orange peel after 30 min microwave irradiation. Adapted from Ref. 49.

used to find optimal conditions. The parameters that influence the extraction technique are choice of solvent or solvent composition, solvent volume or solid loading, power applied or extraction temperature, extraction time and size of plant material. The selection of parameters and their values depend on solubility, volatility and stability of these compounds. It will also depend on the interaction of other compounds present in the parent material as well as the type of solvent used with the target compound.

Choice of Solvent

A correct choice of solvent is very important for obtaining an optimal extraction yield. In the case of extraction from plant tissues, the desired compound or the group of compounds is present in various cells in different parts of the raw material. In the process of extracting these compounds, the solvent has to reach and dissolve them. Solvent usually attacks the cell wall of raw material and penetrates it to reach the compounds. It also dissolves various other impurities in the process. Solvent selection, therefore, should be such that it extracts only targeted compound efficiently. Various selection methods are available to carry out effective extraction processes which are as follows: 1. Use of microwave transparent solvent. 2. Use of single solvent or mixture of solvents that absorb microwave energy strongly. 3. Use of combined solvent containing solvents with both high and low dielectric losses in various proportions to vary dielectric properties. In case of microwave transparent solvent, the heat resulting from the interaction of the microwaves with the matrix contributes to the temperature increase of the system. On the other hand, for solvents absorbing microwave energy strongly, the heating takes place from the interaction of microwaves with the solvent and with the matrix, which in turn provides very rapid heating compared to microwave transparent solvents.

The increased rate of extraction and selectivity were observed when microwave transparent solvent, petroleum ether, was used to extract piperine from *Piper nigrum* (pepper) compared to dichloromethane and ethanol (18). Ethanol gave better result for extraction from dried *Zingiber officinale* (ginger) compared to hexane (19), for isolation of total triterpenoid saponin from dried *Ganoderma atrum* compared to chloroform, ethyl acetate, n-butanol, acetone and methylene chloride: methanol (1:1) (52). Also, for vanillin extraction from *Vanilla planifolia*, dehydrated ethanol proved to be a better solvent compared to hexane, chloroform, acetonitrile, 40% methanol and 40% ethanol (55). Rose red pigments (RRP) were efficiently extracted from yannan highland rose using 40% ethanol compared to 30% and 50% ethanol (56). For extraction of glycyrrhizic acid from the roots of *Glycyrrhizae radix* (licorice), the experiments were optimized at 50–60% ethanol with 2% ammonia (v/v) (57).

Higher extraction of polyphenols and caffeine from *Thea sinensis* L. (green tea) leaves was obtained using 50% ethanol compared to acetone, absolute methanol, absolute ethanol, water, 50% acetone and 50% methanol (58). In comparison with acetone, absolute ethanol and acetonitrile, 80% ethanol and methanol gave higher recovery for extracting anthraquinones from dried roots of *Morinda citrifolia* (59). In extraction of pigments namely alizarin and purpurin from dried *Rubuaceae tinctorum* roots, 50% methanol was found to be superior to 50 % ethanol, absolute methanol and absolute ethanol (53).

Better extraction was achieved for polyphenols from grape seeds in case of 90% methanol compared to pure methanol (60). Methanol gave good results for withanolides extraction from the leaves of *Iochroma gesnerioides* compared to ethanol, hexane and dichloromethane (61). The maximum extraction of stevioside and rebaudioside-A, major low-calorie diterpene steviol glycosides, from leaves of *Stevia rebaudiana* Bertoni was achieved in methanol: water (80:20, v/v) when extracted with methanol, ethanol, water and their binary mixtures (62). For extraction of curcuminoids from *Curcuma longa* (turmeric), acetone gave the best result among dichloromethane, isopropyl alcohol and 95% ethanol (50).

Fat contents were found to be higher in extract from cocoa powder when extracted with hexane/isopropanol compared to hexane and ethanol (63). MAE using 60% acetone gave better yield compared to 60% methanol, water and ethyl acetate: water (60:30, v/v) for extracting phenolic compounds from *Rosmarinus officinalis, Origanum dictamnus, Origanum majorana, Teucrium polium* (all belonging to *Labiatae), Vitex agnus–cactus (Verbenaceae)* and *Styrax officinalis* (*Styracaceae*) (64). Non-ionic surfactant, as a biodegradable micellar media, was used as an alternative and effective solvent for the extraction of glycyrrhizic acid and liquiritin from licorice root (65).

Even distillation using microwave gave comparable yield with reduced time and energy for extraction of essential oil from *Lavandula angustifolia* M. (lavender) flowers (22), *Rosmarinus officinalis* L. (rosemary) leaves (23, 66), *Laurus nobilis* L. leaves (28), *Lippia alba* leaves and stems (42), *Foeniculum vulgare* M. (67) and *Cinnnamomum iners Reinw. ex* Bl. leaves (68).

Also, the concept of solvent-free microwave extraction (SFME) was generated where either dried raw material was rehydrated and then it was used for the extraction without any aid of solvent or fresh raw material was used directly. This technique has been used to obtain essential oil from *Ocimum basilicum* L. (basil), *Mentha crispa* L. (garden mint), *Thymus vulgaris* L. (thyme) (21), *Elletaria cardamomum* L. (cardamom) seed (26), *Citrus sinensis* L. (orange) peels (49) and *Origanum vulgare* L. (oregano) (69). In the improved solvent-free microwave extraction, a microwave absorption solid medium, such as carbonyl iron powders, was added and mixed with the sample for the extraction of essential oil from the dried plant materials

(*Cuminum cyminum* L. and *Zanthoxylum bungeanum* Maxim) without any pretreatment (25).

In microwave hydrodiffusion and gravity (MHG), fresh plant material is utilized for extraction of essential oil without addition of water or solvent. Extraction of essential oil from *Mentha spicata* L. and *Mentha pulegium* L. (43); leaves of *Rosmarinus officinalis* L. (29) and peels of various *Citrus* fruits (70) were carried out using MHG.

Solvent Volume/Solid Loading

The amount of solvent needed must be sufficient to ensure that the sample is immersed so that materials can be swelled during extraction. With increase in solvent volume, percentage extraction was also increased but with more time and energy (57, 58), because higher volume required higher power or more time to achieve required temperature. For extraction of triterpenoid saponins, the yield increased up to 75 ml of ethanol for 3 g of plant material, after which a decreased trend in yield was observed because of inadequate stirring of solvent during irradiation (52). No influence on recovery of withanolides was observed with increase in methanol volume from 5 to 30 ml for 100 mg of plant material (61).

Also, the effect of solid loading on extraction of the product can be studied to have a higher yield. Six different solid loading viz. 1, 2, 4, 5, 10 and 15% (w/v) were studied for piperine extraction. With increased solid loading, a decrease in yield was observed (18). Similar result was obtained for curcuminoids extraction when solid loading was increased from 1 to 5% (w/v) (50). The reason for decreased yield could be the incident microwave radiation per particle decreased with the increased solid loading at a given power. This should give a relatively low dielectric heating effect, and thus a reduced effect of microwave radiation. The absorption of microwave radiation by plant material near the surface of vessel reduces the penetration depth of microwave radiation into the suspension (71). Therefore, the raw material in the interior part of vessel will not have the same level of microwave radiation which is the case with the raw materials nearer the vessel surface. For RRP, the optimum ratio was found to be 1:5 (56).

Usually, plant material is dried at room temperature, crushed and stored in a desiccator to keep it free from moisture when extraction is to be done for dried material. The dried raw material is, then, pretreated prior to loading into the extraction vessel to increase the extraction rate by changing its dielectric properties. Since polar compounds are affected the most by microwave radiation, raw material is soaked with water for different period of time. The rehydration caused improvement in extraction efficiency (18, 26, 27, 50, 51, 61, 63, 66, 69, 72). The soaking time varied from 10 minutes to 24 hours and with increase in soaking time, enhanced extraction rate was observed. Also, pre-leaching with solvent to be used (57, 58) or addition of

strongly microwave absorbing solvent (19) influenced the percentage extraction. For fresh materials, no pretreatment is given.

After extraction is complete, compound collected is dried using anhydrous sodium sulfate and stored at 4°C or lower temperature until used in case of essential oil extracted using open vessel system (21, 22, 27, 29, 49, 69, 70, 72). Also, the essential oil–water mixture was washed with n-pentane and organic phase was evaporated at 35°C in argon environment at atmospheric pressure and dried over anhydrous sodium sulfate and stored at 4°C (24). Extract was centrifuged and filtered through 0.45 μm membrane when material was extracted with surfactant (65). In closed vessel system, extracts after cooling are either filtered and evaporated to dryness or centrifuged and filtered. Supernatant of *Stevia rebaudiana* Bertoni extract was filtered and dried under vacuum which was, then, defatted with hexane. Residual matter was dried in vacuum after discarding the supernatant (62). For fat extraction from cocoa nibs and powder, the extracts were washed with solvent and acetone for purification and vacuum evaporated (63).

Power Applied/Temperature

With increase in power level, the intracellular water and polar constituents within the plant cells are heated rapidly, which enhances the extraction rate. The solvent heating is also rapid and relatively hot solvent dissolves more products as well as the impurities. However, increased power with longer irradiation time may cause solvent loss. Higher microwave power viz. 450 W, gave more extraction of piperine when plant material was irradiated with 150, 300 and 450 W (18). In case of curcuminoids extraction, higher power level (60% i.e., microwave delivered full power for 60% time and for remaining 40%, no power was delivered) among 20, 40 and 60% power level, gave better results with decreased purity (50). In both the case, the higher yield was achieved in lesser time and with increased solvent loss.

The maximum yield for ginger extract (19) and essential oil (69) was obtained with higher power magnitude of 300 W compared to 150 W and 622 W among 249, 373, 498 and 622 W, respectively. Also, Hydrodistillation with 300 W microwave power gave higher yield for extraction of essential oil in comparison with 150 W power (28). For red dye extraction, the product yield increased with increase in radiation power up to 540 W and at higher power the product was charred (73). In the case of withanolides extraction, power variation at 25 and 250 W showed not much effect (61). Higher extraction of RRP was obtained by applying higher microwave power (56). A microwave irradiation of 500 W was found to be optimum value in the range of 200–1000 W for extraction of essential oil (29). Yield of stevioside and rebaudioside-A reached maximum at 80 W and 50°C upon irradiating the power in the range of 20–160 W and varying the temperature in the range of 10 to 90°C (62).

In theory, when MAE is conducted in closed vessels, the temperature may well reach above the boiling point of the solvent. These elevated temperatures result in improved extraction efficiencies, since desorption of analytes from active sites in the matrix will increase. Additionally, solvents have higher capacity to solubilize analytes at higher temperatures, while surface tension and solvent viscosity decrease with temperature, which will improve sample wetting and matrix penetration, respectively (52, 59). The extraction of triterpenoid saponins increased up to 78°C after which the yield decreased because other compounds were also extracted at elevated temperature (52). For anthraquinones extraction, efficiency increased with increasing temperature from 60°C to 120°C (59).

MAE of thermosensitive polyphenolic compounds in vacuum obtained higher extraction yields than that normal air pressure at the same extraction temperature. It may be because the boiling point of the solvent was lower in vacuum and the extraction temperature of 70 or 60°C was high enough to cause the solvent refluxing continuously. However, thermostable compounds showed no difference in extraction yields (30).

Extraction Time

The extraction time is varied to observe the effect of radiation for different duration and in turn to observe an impact on mechanism of interaction between microwaves and various materials like plant cells, desired products and impurities. But longer extraction time is not studied because it may not have further effects or have negative effects due to degradation or conversion of products. For ginger extract, the relative yield increased with time at 150 W and 300 W using hexane and ethanol with 1–2 ml of water and hexane with 1–2 ml of ethanol except using hexane with 1–2 ml of ethanol at 150 W (19).

Percentage extraction of triterpenoid saponins (52), glycyrrhizic acid (57), polyphenols and caffeine (58), anthraquinones (59) and red dye (73) increased with increase in extraction time. After 4 minutes no further extraction was observed in the case of glycyrrhizic acid and polyphenols and same result was observed for anthraquinones at 80°C, 100°C and 120°C after 20 minutes. But at 60°C, anthraquinones recovery was increased. This is so, because at lower temperature more microwave absorption is required for rupture or release of products from the plant cells. For caffeine extraction, yield was decreased after 4 minutes, while in the case of red dye and triterpenoid saponins, it was decreased after 20 minutes. Higher RRP was obtained for processing time of 35 s compared to 40 s and 45 s (56). MAE of stevioside and rebaudioside-A was carried out for duration ranging from 30 s to 5 min and higher yield was achieved for time of 1 min (62).

Size of Plant Material

Size of raw material is also an important parameter affecting the percentage extraction. To have higher yield, powdered raw material is preferred for the extraction. Fine samples gave a higher extraction of withanolides compared to a coarse sample (61). The yield of glycyrrhizic acid increased from large pieces and 5–10 mesh unrefined powder to 50 mesh powder of roots of *Glycyrrhizae radix* (licorice) (57). Higher yield is observed in case of powdered raw material because smaller size materials have less penetration depth that leads to uniform microwave exposure.

COMPARISON OF DIFERENT EXTRACTION TECHNIQUES

The selection of any extraction method mainly depends on factors such as extraction yield, complexity, production cost, environmental friendliness and safety. In general, steam distillation, soxhlet extraction, shaking extraction and heat reflux extraction (HRE) are the most frequently used extraction methods. They are definitely very user-friendly. The drawbacks of soxhlet, shaking and heat reflux extraction are the large amount of solvent and long extraction time needed to achieve desired yield. Considering the expensive solvent consumption and the long extraction period, these extraction methods are not favorable from a commercial perspective. Though steam distillation is the option available, it requires high energy and longer extraction time to achieve desired extraction. Also, for all these methods, close control of operating parameters particularly temperature is difficult because heat is first transferred to the vessel and then to plant material, creating a temperature gradient, which is not the case with MAE.

The supercritical fluid extraction (SFE) technique, using CO_2 as a solvent, is a widely accepted alternative extraction technique for conventional extraction. The extraction characteristics are determined by the pressure and temperature of the supercritical carbon dioxide used. Compared to classic extraction methods, the SFE method has the advantages based on gentle extraction conditions with relatively low extraction temperature, short time and easy recovery of product from solvent. However, CO_2 is also non-polar, so this method has some limitations, particularly for the extraction of polar compounds. Addition of co-solvents to increase recovery of polar compounds is the alternative available. However, this approach negates the biggest advantage of this method in terms of ease of solvent removal (74).

Ultrasound assisted extraction (UAE) mainly depends on the ultrasonic effects of acoustic cavitations. Because of rupture of matrix caused by ultrasonic irradiation, the solute quickly diffuses from solid phase to the solvent. In general, UAE is rapid and inexpensive. But the positions of the extraction vessels have to be carefully chosen and fixed during extraction, since generally

the ultrasonic energy is not homogeneously distributed, which will induce the low precision of ultrasonic extraction. Even extraction with probe system may cause loss of volatile component due to degassing effect of the ultrasound power (13).

Pressurized fluid extraction (PFE) involves extraction of compounds at elevated temperature and pressure. The solubility of the target compound is enhanced by decreased viscosity of solvents at higher temperature. The higher temperature also encourages the diffusion of the compound to the matrix surface. Under these conditions, solvents have enhanced solvation power and increased extraction rates (9). Similar efficiencies were reported for extraction of flavonoids from *Allium cepa* var. *zittauer* (onion) using PFE, UAE and MAE (75). Water, which is both harmless and widely available, can be used effectively as a solvent in PFE because its physicochemical properties can be readily altered at higher temperature and pressure. This technique is better known as pressurized hot water extraction (PHWE). Good extraction efficiency and selectivity can be obtained by temperature and pressure tuning. The main application of PHWE is the extraction of essential oils from various plant materials (9). The most serious problems with PHWE equipment relate to materials and the possibility of corrosion inside the tubes and the extraction chamber. Also, PHWE may not be the best choice for compounds that are both non-polar and temperature sensitive (76).

Microwave-assisted extraction (MAE) is a relatively new method, which has received increasing attention as an alternative method. The principle of heating during microwave irradiation is based on the direct effect of microwaves on molecules by ionic conduction and dipole rotation (44, 45). Based on that mechanism, either polar samples or polar extraction solvents are required for efficient heating. The use of polar solvents could be a drawback of this method, since polar matrix compounds are co-extracted, which could interfere during the following analytical steps. Also, cooling and filtration are required after extraction stage in case of closed vessel extraction. For heat sensitive compounds, extraction should be carried out under vacuum to reduce or prevent degradation. Also, for operating the system, the personnel must be acquainted with knowhow of the system, i.e., standard operating procedure should be established to avoid any mishap.

However, compared with the conventional extraction methods, UAE and SFE, MAE showed evident advantages with strong penetration force, high selectivity, high extraction efficiency and better products with lower cost. These obvious advantages over other extraction techniques have been supported by the results reported by various researchers as shown in Table 3. The comparison shows that microwave yields better extraction in less time. Also, SFE and PFE require need higher investment compared to the moderate of MAE.

TABLE 3 Comparison of Microwave-assisted Extraction with Other Techniques

Sr. no.	Plant material	Compound extracted	Extraction methods	Solvent	Extraction time	Yield (%)	Ref.
1	*Glycyrrhiza uralensis Fisch.* (Licorice) root (3 g for ERT; 10 g for the other methods)	Glycyrrhizic acid	HRE at boiling point	50–60% Ethanol with 2% (v/v) ammonia (260 ml)	4.5 h	2.80	57
			UAE	50–60% Ethanol with 2% (v/v) ammonia (100 ml)	20.5 h	2.80	
			SE	50–60% Ethanol with 2% (v/v) ammonia (200 ml)	10 h	3.0	
			Soxhlet-MAE	50–60% Ethanol with 2% (v/v) ammonia (300 ml)	5.07 h	3.1	
			Extraction at room temperature (ERT)	50–60% Ethanol with 2% (v/v) ammonia (100 ml)	20 h	2.85	
			MAE at 85–90°C Power: 700 W	50–60% Ethanol with 2% (v/v) ammonia (100 ml)	4 min	2.75	
2	*Zingiber officinale* (ginger) (5 g)	Essential oil	SE	1. Ethanol (70 ml) 2. Hexane (70 ml)	2 h	1.13 (1) 1.00 (2)	19
			Microwave Assisted Process (MAP) Power: 300 W	1. Ethanol (30 ml) 2. Hexane (30 ml)	0.5 min	1.28 (1) 0.92 (2)	
3	*Thea sinensis L.* (green tea) leaves (5 g)	Polyphenols and Caffeine	HRE at boiling point about 85°C	50 % Ethanol (100 ml)	45 min	28 & 3.6	58
			UAE at 20–40°C	50 % Ethanol (100 ml)	1.5 h	28 & 3.6	
			ERT of 20°C	50 % Ethanol (100 ml)	20 h	28 & 3.6	
			MAE at 85–90°C Power: 700 W	50 % Ethanol (100 ml)	4 min	30 & 4	
4	*Ocimum basilicum* L. (basil) (500 g for HD; 250 g for SFME)	Essential oil	HD at boiling point	Water (6 L)	4.5 h	0.028	21
			SFME at 100°C Power: 500 W	–	30 min	0.029	

(*Continued*)

TABLE 3 (*Continued*)

Sr. no.	Plant material	Compound extracted	Extraction methods	Solvent	Extraction time	Yield (%)	Ref.
5	*Mentha crispa* L. (garden mint) (500 g for HD; 250 g for SFME)	Essential oil	HD at boiling point SFME at 100°C Power: 500 W	Water (6 L) -	4.5 h 30 min	0.095 0.095	21
6	*Thymus vulgaris* L. (thyme) (500 g for HD; 250 g for SFME)	Essential oil	HD at boiling point SFME at 100°C Power: 500 W	Water (6 L) -	4.5 h 30 min	0.16 0.161	21
7	*Lippia alba* (Mill.) N.E. Brown. (100 g for HD and MAHD; 10 g for SDSE and SFE)	Essential oil	HD at boiling point Simultaneous distillation solvent extraction (SDSE) SFE Microwave accelerated hydrodistillation (MAHD) at boiling point Power: 800 W	Water (1 L) Dichloromethane CO_2 Water (1 L)	2 h 2 h 2 h 30 min	0.70 – – 0.69	42
8	*Taxus baccata* L. (4 g for Extraction at ambient temperature; 1.5 g for MAE)	Paclitaxel	Extraction at ambient temperature MAE at 95°C Power: 1200 W (max)	Methanol (150 ml) 90% Methanol (20 ml)	17 h 15 min	0.0059 0.00622	51
9	*Nothapodytes foetida* (Slemure) Wight (5 g)	Camptothecin	Stirring Extraction at 60°C Speed: 150 x *g* SE at 70°C UAE Frequency: 33 kHz MAE Power: 100 W	90% Methanol (100 ml) 90% Methanol (100 ml) 90% Methanol (100 ml) 90 % Methanol (100 ml)	30 min 2 h 30 min 3 min	2.36 2.5 1.67 2.67	77

10	Flowers of *Lavandula angustifolia* Mill. (lavender) (50 g)	Essential oil	SD at 100°C Microwave accelerated steam distillation (MASD) at 100°C Power: 500 W	Water (200 ml) Water (200 ml)	1.5 h 10 min	8.75 8.86	22
11	*Citrus sinesis* L. (200 g)	Essential oil	HD Microwave accelerated distillation (MAD) at 100°C Power: 200 W	Water (2 L) –	3 h 30 min	0.39 0.42	49
12	*Allium sativum* (garlic) (100 g blended with 20 ml deionized water for 2 min)	Essential oil	SDSE	1. Diethyl ether-Deionized water (1:10) 2. Hexane-Deionized water (1:10) 3. Ethyl acetate- Deionized water (1:10) (110 ml each)	2 h	0.23(1) 0.22(2) 0.24(3)	78
			UAE at 25°C Frequency: 35 kHz	1. Diethyl ether 2. Hexane 3. Ethyl acetate (50 ml each)	30 min	0.13(1) 0.12(2) 0.17(3)	
			MAHD Power: 700 W (max)	1. Diethyl ether-Deionized water (1:2) 2. Hexane-Deionized water (1:2) 3. Ethyl acetate- Deionized water (1:2) (150 ml each)	30 min	0.22(1) 0.22(2) 0.23(3)	
13	*Rosmarinus officinalis* L. (Rosemary) (200 g)	Edible essential oil	HD MAD at 100°C Power: 200 W	Water (2 L) –	3 h 30 min	0.6 0.6	23

(*Continued*)

TABLE 3 (*Continued*)

Sr. no.	Plant material	Compound extracted	Extraction methods	Solvent	Extraction time	Yield (%)	Ref.
14	*Vanilla planifolia* (vanilla) pods (5 g)	Vanillin	ERT	1. Hexane	24 h	0.08 (1)	55
				2. Chloroform		0.27 (2)	
				3. ACN		0.34 (3)	
				4. Ethanol, dehydrated		1.25 (4)	
				5. 40% Methanol		0.72 (5)	
				6. 40% Ethanol (45 ml each)		0.68 (6)	
			UAE Power: 500–750 W Frequency: 20 kHz	1. Hexane	2 min	0.35 (1)	
				2. Chloroform		0.43 (2)	
				3. ACN		0.60 (3)	
				4. Ethanol, dehydrated		0.99 (4)	
				5. 40% Methanol		0.64 (5)	
				6. 40% Ethanol (45 ml each)		0.67 (6)	
			MAE Power: 900 W	1. Hexane	2 min	0.51 (1)	
				2. Chloroform		1.08 (2)	
				3. ACN		1.04 (3)	
				4. Ethanol, dehydrated		1.86 (4)	
				5. 40% Methanol		1.69 (5)	
				6. 40% Ethanol (45 ml each)		1.58 (6)	
15	*Caesalpinia sappan* heartwood (10 g)	Red dye	Extraction with reflux	Distilled water (400 ml)	2 h	6.56	73
			MAE Power: 540 W	Distilled water (400 ml)	20 min	7.47	
16	*Ganoderma atrum* (10 g for Shaking extraction; 4 g for UAE and HRE, 80 g for SFE; 3 g for MAE)	Triterpenoid saponins	Shaking ERT	95% Ethanol (40 ml/g)	12 h	2.58	52
			UAE at room temperature Frequency: 33 kHz	95% Ethanol (60 ml/g)	30 min	1.72	
			HRE at 95°C	95% Ethanol (40 ml/g)	2 h	2.22	
			SFE Pressure: 25 MPa Temperature: 55°C Flow rate: 30 l/h (liquid)	CO_2 + 95% Ethanol (60 ml ethanol)	3 h	1.52	
			MAE at 78°C Power: 800 W	95% Ethanol (25 ml/g)	5 min	5.11	

17	*Laurus nobilis* L. (30 g)	Essential oil	HD	Tap water (650 ml)	1 h	0.784	28
			HD with a 300 W microwave system	Tap water (650 ml)	1 h	1.132	
18	Crude extract of *Dictyopteris membranacea* (brown alga) (266 mg for HD; 300 mg for SFE; 56 mg for Focused MAHD)	Essential oil	HD	Water (300 ml)	1 h	12.9	79
			SFE Pressure: 90 bar Temperature: 40°C Flow rate: 1 ml/min	CO_2	30 min	15.4	
			Focused MAHD Power: 180 W	Water (50 ml)	10 min	13.0	
19	Roots of *Morinda citrifolia* (0.1 g for Maceration, UAE and MAE; 2 g for SE)	Anthraquinones	Maceration at 60°C	Ethanol (10 ml)	1 h	52.20*	59
			Maceration at ambient temperature	Ethanol (10 ml)	1 h	38.12*	
			Maceration at ambient temperature	Ethanol (10 ml)	3 days	63.33*	
			SE at boiling temperature	Ethanol (200 ml)	4 h	97.74*	
			UAE at 60°C Power: 270 W Frequency: 2 No. of transducers, 38.5 kHz each	Ethanol (10 ml)	1 h	62.23*	
			MAE at 60°C Power: 1200 W	Ethanol (10 ml)	30 min	65.88*	
			MAE at 60°C Power: 1200 W	Ethanol: Water (80:20) (10 ml)	15 min	95.91*	
20	Leaves of *Cinnamomum iners Reinw. ex* Bl. (700 g for HD; 200 g for MAHD)	Essential oil	HD	Water	5 h	0.12	68
			MAHD Power: 800 W	Water	30 min	0.12	

(*Continued*)

TABLE 3 (*Continued*)

Sr. no.	Plant material	Compound extracted	Extraction methods	Solvent	Extraction time	Yield (%)	Ref.
21	*Rubus idaeus* L. var. Heritage (red raspberry) (60 g)	Anthocyanins	Extraction at 55°C	1.5N HCl – 95% ethanol (15:85) (240 ml)	1 h	0.03415	54
			MAE Power: 366 W	1.5M HCl – 95% ethanol (15:85) (240 ml)	12 min	0.03905	
22	Leaves of *Origanum vulgare* L. (material: water = 1:10 for HD; 50 g for SFME)	Essential oil	HD	Water	3 h	0.048 ml/g	69
			SFME Power: 622 W	–	35 min	0.054 ml/g	
23	*Origanum glandulosum* D. (25 g for MAE and SFME)	Essential oil	HD	Water	3 h	4.8	27
			MAE at 60 – 80 °C Power: 850 W	Hexane (200 ml)	2 min	1.0	
			SFME Power: 850 W	–	20 min	3.3	
24	*Styrax officinalis* (1 g)	Total phenolic compounds	Conventional Extraction with reflux at 90 °C	1. Methanol: Water (60:40)	2 h	1.84 (1)	64
				2. Acetone: Water (60:40)		1.82 (2)	
				3. Water		2.01 (3)	
				4. Ethyl acetate: Water (60:30) 40 ml each		0.48 (4)	
			MAE Power: 650 W	1. Methanol: Water (60:40)	4 min	1.87 (1)	
				2. Acetone: Water (60:40)		1.89 (2)	
				3. Water		1.84 (3)	
				4. Ethyl acetate: Water (60:30) 20 ml each		0.49 (4)	

25	*Origanum dictamnus* (1 g)	Total phenolic compounds	Conventional Extraction with reflux at 90 °C	1. Methanol: Water (60:40) 2. Acetone: Water (60:40) 3. Water 4. Ethyl acetate: Water (60:30) 40 ml each.	2 h	1.36 (1) 0.95 (2) 1.56 (3) 0.36 (4)	64
			MAE Power: 650 W	1. Methanol: Water (60:40) 2. Acetone: Water (60:40) 3. Water 4. Ethyl acetate: Water (60:30) 20 ml each	4 min	1.43 (1) 1.46 (2) 1.41 (3) 0.38 (4)	
26	*Rosmarinus officinalis* (1 g)	Total phenolic compounds	Conventional Extraction with reflux at 90°C	1. Methanol: Water (60:40) 2. Acetone: Water (60:40) 3. Water 4. Ethyl acetate: Water (60:30) 40 ml each	2 h	2.11 (1) 1.78 (2) 2.67 (3) 0.83 (4)	64
			MAE Power: 650 W	1. Methanol: Water (60:40) 2. Acetone: Water (60:40) 3. Water 4. Ethyl acetate: Water (60:30) 20 ml each	4 min	2.12 (1) 2.38 (2) 2.03 (3) 0.87 (4)	
27	*Origanum majorana* (1 g)	Total phenolic compounds	Conventional Extraction with reflux at 90°C	1. Methanol: Water (60:40) 2. Acetone: Water (60:40) 3. Water 4. Ethyl acetate: Water (60:30) 40 ml each	2 h	1.69 (1) 1.39 (2) 1.92 (3) 0.72 (4)	64
			MAE Power: 650 W	1. Methanol: Water (60:40) 2. Acetone: Water (60:40) 3. Water 4. Ethyl acetate: Water (60:30) 20 ml each	4 min	1.78 (1) 1.83 (2) 1.72 (3) 0.72 (4)	

(*Continued*)

TABLE 3 (*Continued*)

Sr. no.	Plant material	Compound extracted	Extraction methods	Solvent	Extraction time	Yield (%)	Ref.
28	*Teucrium polium* (1 g)	Total phenolic compounds	Conventional Extraction with reflux at 90°C	1. Methanol: Water (60:40) 2. Acetone: Water (60:40) 3. Water 4. Ethyl acetate: Water (60:30) 40 ml each	2 h	0.92 (1) 0.88 (2) 1.08 (3) 0.27 (4)	64
			MAE Power: 650 W	1. Methanol: Water (60:40) 2. Acetone: Water (60:40) 3. Water 4. Ethyl acetate: Water (60:30) 20 ml each	4 min	1.03 (1) 1.12 (2) 0.98 (3) 0.29 (4)	
29	*Vitex agnus–cactus* (1 g)	Total phenolic compounds	Conventional Extraction with reflux at 90°C	1. Methanol: Water (60:40) 2. Acetone: Water (60:40) 3. Water 4. Ethyl acetate: Water (60:30) 40 ml each	2 h	1.14 (1) 1.09 (2) 1.52 (3) 0.3 (4)	64
			MAE Power: 650 W	1. Methanol: Water (60:40) 2. Acetone: Water (60:40) 3. Water 4. Ethyl acetate: Water (60:30) 20 ml each	4 min	1.16 (1) 1.22 (2) 1.11 (3) 0.34 (4)	
30	*Mentha spicata* L. (spearmint) (500 g)	Essential oil	HD MHG Power: 500 W	Water (3 L) –	1.5 h 20 min	0.59 0.60	43
31	*Mentha pulegium* L. (pennyroyal) (500 g)	Essential oil	HD MHG Power: 500 W	Water (3 L) –	1.5 h 20 min	0.90 0.95	43

32	Leaves of *Rosmarinus officinalis* L. (rosemary) (500 g)	Essential oil	HD MHG Power: 500 W	Water (3 L) –	1.5 h 15 min	0.35 0.33	29
33	Yunnan Highland Rose	Rose red pigments	Solvent leaching at 70°C MAE High Power	70% Ethanol (material to liquid ratio is 1:10) 40% Ethanol (material to liquid ratio is 1:5)	3 h 35 s	73.5 81.6	56
34	Leaves of *Stevia rebaudiana* (100 mg for conventional extraction and MAE; 500 mg for UAE)	Stevioside and Rebaudioside-A	Conventional Extraction at room temperature UAE at 35 ± 5 °C MAE at 50 °C Power: 80 W	Methanol: water (80:20, v/v) (10 ml) Methanol: water (80:20, v/v) (50 ml) Methanol: water (80:20, v/v) (10 ml)	12 h 30 min 1 min	6.54 & 1.20 4.20 & 1.98 8.64 & 2.34	62
35	*Citrus limon* L. (eureka) (1 kg fruit for CP; 500 g peels for HD and MHG)	Essential oil	Cold pressing (CP) HD MHG Power: 500 W	– Water (3 L) –	1 h 3 h 15 min	0.1 0.8 0.7	70
36	*Citrus limon* L. (villa franca) (1 kg fruit for CP; 500 g peels for HD and MHG)	Essential oil	CP HD MHG Power: 500 W	– Water (3 L) –	1 h 3 h 15 min	0.2 1.7 1.6	70
37	*Citrus aurantifolia* (Chrism.) Swing (lime) (1 kg fruit for CP; 500 g peels for HD and MHG)	Essential oil	CP HD MHG Power: 500 W	– Water (3 L) –	1 h 3 h 15 min	0.2 0.8 0.8	70

(*Continued*)

TABLE 3 (*Continued*)

Sr. no.	Plant material	Compound extracted	Extraction methods	Solvent	Extraction time	Yield (%)	Ref.
38	*Citrus paradisi* L. (marsh seedless) (1 kg fruit for CP; 500 g peels for HD and MHG)	Essential oil	CP HD MHG Power: 500 W	– Water (3 L) –	1 h 3 h 15 min	0.2 1.1 1.0	70
39	*Citrus sinensis* L. (tarocco) (1 kg fruit for CP; 500 g peels for HD and MHG)	Essential oil	CP HD MHG Power: 500 W	– Water (3 L) –	1 h 3 h 15 min	0.3 1.3 1.2	70
40	*Citrus sinensis* L. (valencia late) (1 kg fruit for CP; 500 g peels for HD and MHG)	Essential oil	CP HD MHG Power: 500 W	– Water (3 L) –	1 h 3 h 15 min	0.2 1.1 1.0	70
41	*Citrus sinensis* L. (washington naval) (1 kg fruit for CP; 500 g peels for HD and MHG)	Essential oil	CP HD MHG Power: 500 W	– Water (3 L) –	1 h 3 h 15 min	0.2 1.0 0.9	70
42	*Citrus paradisi* Macf. (tengelo seminole) (1 kg fruit for CP; 500 g peels for HD and MHG)	Essential oil	CP HD MHG Power: 500 W	– Water (3 L) –	1 h 3 h 15 min	0.3 1.3 1.2	70

*Percentage recovery = amount of anthraquinones extracted / amount of anthraquinones present in the material.

CONCLUSION

MAE is found to be more effective compared to traditional extraction techniques such as steam distillation, soxhlet extraction, extraction under reflux and ultrasonic extraction. Initially employed as a digestion method for different sample types such as environmental, biological and geological matrixes, MAE is now widely accepted for extracting natural products from plant materials. The main advantage of this technique resides in volumetric heating of the material. Rapid heating results in decreased extraction time (up to 30 minutes), reduced solvent consumption (up to 200 ml), less energy consumption and increased sample throughput. Extraction and reproducibility of products are improved by using microwave as a heat source.

However, effect of inert atmosphere on extraction of oxidizable compounds should be carried out in order to study degradation behavior of such compounds. The technique is easy to use and cheaper compared to modern techniques like SFE and PFE. Clean-up is an additional step required in MAE, which is the disadvantage compared to SFE and PFE. Also, careful method optimization is required for selective extraction because increase in microwave power or extraction time and improper selection of solvent may lead to decomposition of the compounds or extraction of other compounds. Person working with the MAE system must acquire the know-how about the system to avoid any hazard. Although microwave-assisted extraction has these drawbacks, it is a strong competitor to the other recent extraction techniques and provides a great potential for the extraction of natural products.

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ABBREVIATIONS

ACN:	Acetonitrile
CP:	Cold Pressing
ERT:	Extraction at Room Temperature
HD:	Hydrodistillation
HRE:	Heat Reflux Extraction
MAD:	Microwave-Accelerated Distillation
MAE:	Microwave-Assisted Extraction
MAHD:	Microwave-Assisted Hydrodistillation
MAP:	Microwave-Assisted Process
MASD:	Microwave-Accelerated Steam Distillation
MHG:	Microwave Hydrodiffusion and Gravity
PFE:	Pressurized Fluid Extraction
PHWE:	Pressurized Hot Water Extraction
RRP:	Rose Red Pigments
SD:	Steam Distillation
SDSE:	Simultaneous Distillation Solvent Extraction
SE:	Soxhlet Extraction
SFE:	Supercritical Fluid Extraction
SFME:	Solvent Free Microwave Extraction
UAE:	Ultrasound-Assisted Extraction