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Microwave-Assisted Extraction of Bioactive Compounds (Review)

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Abstract

In recent times, bioactive compounds from plant samples are extracted using a microwave extractor. This is because traditional methods of extraction are need of higher volume of solvents, degrade thermal-sensitive bioactive compounds, and consume much time of extraction. Hence, this chapter unveils the importance of the microwave-assisted extraction (MAE) technique in the recovery of bioactive compounds from plants. The involving extraction steps need to recover higher yields, faster, consumption of lesser extracting solvents, and ensure stable heat-sensitive bioactive compounds. The factors affecting MAE in the recovery of bioactive compounds from plant materials are as well discussed. Additionally, some of the previously reported bioactive compounds from plant samples using MAE are highlighted.

Keywords: extraction, microwave heating, microwave-assisted extraction, bioactive compounds, solvents, plants

1. Introduction

Extraction involves separating dissolvable substances from non-dissolvable residues using solvent(s); it can be in form of liquid or solid [1]. There are two categories of extraction which are traditional and modern; the former includes Soxhlet, soaking, maceration, ultra-sonication, turbo-fast blending, and solvent permeation; the latter includes ultrasonic-assisted, subcritical, supercritical CO₂, enzyme-assisted, pressure-assisted, and microwave-assisted methods [2–6]. The traditional methods are mainly associated with an extended time of extraction, destruction of heat-sensitive bioactive compounds, and enormous consumption of solvents [3, 7]. It is then important to explore modern methods of extraction to overcome the setbacks associated with the traditional methods. Out of all the modern methods of extraction, microwave-assisted extraction (MAE) has received the greatest attention due to its reduced consumption of solvent, shorter operation time, reproducibility, improved recovery yield, good selectivity, and reduced sample manipulation [8, 9]. Gedye et al. and Giguere et al. were groups that first described the usage of microwave energy in 1986, it was employed in organic synthesis; microwave energy was also employed in the extraction of biological samples for analyzing organic compounds [10–12].

MAE method is being used in different kinds of samples which include geological, environmental, and biological matrices. In recent times, MAE is generally used

Solvent	Dielectric loss	Dielectric constant	Loss tangent
Chloroform	0.437	4.8	0.091
Dimethyl sulfoxide	37.125	45.0	0.825
Dimethylformamide	6.079	37.7	0.161
Ethanol	22.866	24.3	0.941
Ethylene glycol	49.950	37.0	1.350
Hexane	0.038	1.9	0.020
Toluene	0.096	2.4	0.040
Water	12.3	80.4	9.889

Table 1.
Solvents with their corresponding dielectric losses, dielectric constants, and loss tangents.

in obtaining bioactive compounds from plant samples, this has greatly improved the total interest in development and research areas. This method allows for faster recovery of solutes from plant samples with appreciable extraction efficiency as compared to traditional techniques. MAE is one of the modern methods, and employed shortened time of extraction, minimal solvent consumptions, and secure thermolabile compounds. It is a green technology that is effective for extracting bioactive compounds from plant samples [13]. Based on the importance of MAE, this method has provided two sub-classes which are microwave solvent-free extraction (MSFE) and microwave-assisted solvent extraction (MASE).

Microwave irradiation employs a specific frequency of electromagnetic field in a way closely to photochemical-activated reaction; the frequency falls between 300 MHz and 300 GHz [14]. Nevertheless, few frequencies are allowed for medical, scientific and industrial usages; this falls within 0.915 and 2.45 GHz worldwide. Dielectric heating from MAE is appropriate for heat-sensitive bioactive compounds [15]. It had been provided that the used water for extracting phenolic compounds is not effective compared to traditional techniques due to reduced dissipation factor and higher dielectric constant associated with water relative to other solvents; hence, using solvents that possess higher dissipation and dielectric factors is advisable in MAE. Furthermore, extractability is proportional to the solvent used in extracting bioactive compounds from plants and kind of plant sample [16]. **Table 1** presents the dielectric losses, dielectric constants, and loss tangents for different solvents used in MAE. Rapid heating is generated in MAE when ionic species or polar molecules are used, this heating generates collisions with molecules from surrounding which do not require higher pressure. In most cases, the extraction time and microwave power fall within 30 s to 10 min and 25 to 750 W, respectively [17]. Several studies had reported the use of MAE for recovering phenolics from plant samples including bitter leaf, purple fleabane, roselle, tea leaf, vanilla, radix, flax seeds, scent leaf, siam weed, and among others [6, 8, 9, 18–22].

Thus, the chapter presents the working principle, factors influencing this method, and previously reported bioactive compounds extracted through MAE.

2. Operating principle and working mechanism of MAE

2.1 Operating principle of MAE

The fundamental of MAE technique is different compared to traditional techniques, this is because MAE happens based on electromagnetic waves that causes

the cell structure to change. Microwave-assisted extraction works with a principle by which polarizable materials and dipoles of polar solvent interact with microwave radiation whereby the forces between magnetic and electric components change direction rapidly. The molecules of polar solvent get heated when they orient in the changing field direction. In the case of non-polar solvents that do not have polarizable groups, the heating is poor. This thermal effect at the molecular level is rapid but limited to the depth near the surface and a small portion of the samples. The remaining part of the samples is heated up by conduction. Therefore, this is the major drawback of the MAE because large samples or agglomerates of small samples cannot be heated uniformly. There is a possibility of using high power sources in order to enhance the depth of penetration but microwave radiation involves an exponential decay once inside a microwave-absorbing solid [23].

2.2 Working mechanism of MAE

The mechanism at which microwave-assisted extraction works is different from other types of extraction methods because the extraction occurs as a result of changes in the cell structure caused by electromagnetic waves [3]. As provided in **Figure 1**, this process of extraction involves a synergistic combination of mass and heat transfers working in the same direction whereas the mass transfer in conventional methods occurs from inside to outside of the substrates and heat transfer occurs from the outside to inside of the substrate [13]. The series of phenomenological steps that occur during the microwave-assisted extraction (MAE) are as follows:

- a. The irradiation heat from a microwave is transferred to the solid through the microwave-transparent solvent without absorption;
- b. The intense heating of the (a) above results in residual microwave-absorbing in the solid being heated up;
- c. The heated moisture evaporates and creates a high vapor pressure;
- d. The high vapor pressure breaks the cell of the substrate; and
- e. Cell wall breakage enhances the releases of the extract from the samples [13].

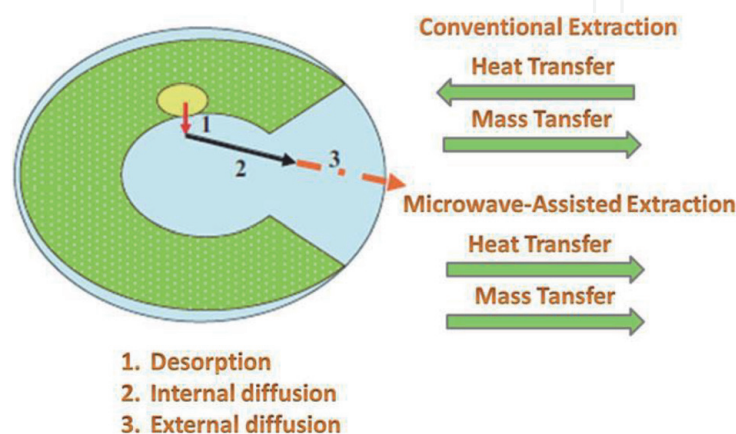


Figure 1.
Heat and mass transfer mechanisms in conventional and microwave extraction [13].

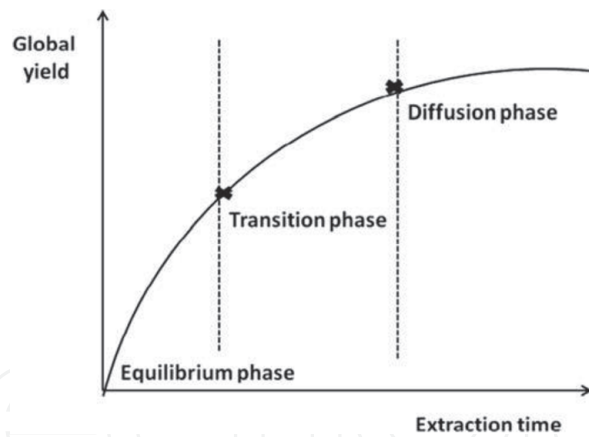


Figure 2.
Pictorial diagram of yield against time in the extraction [14].

Additionally, the extracting solvent is absorbed into the plant sample through diffusion, causing the dissolution of solutes into the solvent until saturation. This solution diffuses to the plant surface through effective diffusion and then transfer to the bulk solution (**Figure 2**). Several forces that include physicochemical relations and interactions can be seen during the process (chemical interactions, driving forces, interstitial diffusion, and dispersion forces), and the strength and persistence of properties can be related to the characteristics of the extraction solvent (polarity, solubility in water, purity, solubilization, and among others) [4].

3. Essential factors influencing MAE and mechanism of action

Several studies had been done on optimizing MAE factors to achieve optimal yields from the considered plant samples. The operative parameters influencing MAE include solvent-to-feed ratio, solvent composition, characteristic of the plant sample and its water content, microwave power, irradiation time, stirring effect, microwave energy density, and extraction temperature. These operative parameters determine the efficiency of MAE. Hence, understanding the influences and interactions of these parameters on the extraction process is paramount.

3.1 Solvent-to-feed ratio

The selection of solvent is the most significant factor that affects microwave-assisted extraction. Adequate solvent selection will produce an efficient extraction process. The solubility of the compound of interest, mass transfer kinetics of the process, and solvent penetration that occurs from the interaction between the dielectric effect and sample matrix are inevitable parameters [24, 25]. Chan et al. reported that the selection of extraction solvent depends on the capacity of that solvent to absorb microwave energy [26]. If the solvent has a high dielectric constant and dielectric loss, the solvent capacity to absorb microwave energy will be high [25]. Tatke and Jaiswal reported that solvents such as methanol, ethanol, and water are excellent microwave-absorbing solvents which possess sufficient polarity to be heated up through microwave power [27]. Studies had shown that the addition of a small quantity of water to polar solvent resulted in higher diffusion of water into the cells of the matrix, leading to effective heating and thus facilitating the transport of compounds into the solvent at higher mass transfer rates [24, 26, 28].

Veggi et al. had reported that the extraction solution must not exceed 30–34% (w/v) [29]. In the past studies, the solvent-to-feed ratio between 10:1 (mL/g) and 20:1 (mL/g) had been reported to give optimal yields [29, 30]. The volume of extracting solvent is another important factor, a large volume of solvent requires more energy and time to condense extraction solution in the purification process. MAE may give lower recoveries because of non-uniform distribution and exposure to microwave [29].

3.2 Irradiation time

The irradiation time is another important factor that affects microwave-assisted extraction. One of the importance of MAE over conventional methods is that the extraction time is very short. The usual time ranges from a few minutes to half an hour depending on the plant matrix so as to avoid possible oxidation and thermal degradation [13, 25, 27]. The irradiation time is affected by the dielectric property of solvent used. Solvents such as ethanol, water, and methanol may heat up rapidly on longer exposure which can result in degradation of thermolabile compounds in the extracts [4, 26]. Increased time of irradiation can improve the recovery yield; nevertheless, the increased yield can decline at prolonged irradiation time [21].

Sometimes, if the extraction will take a longer time, the plant materials are extracted through multiple stages by utilizing consecutive extraction cycle. Here, a new solvent is introduced to the residues, the procedure is then repeated to ensure exhaustion of the plant sample. The use of this process helps higher recovery yield with no excessive heating [26, 31]. The nature of plant sample and solute determines the number of extraction cycles. A study presented that 3 cycles of 7 min were adequate in extracting triterpene saponins from yellow horn through MAE [32]. The optimization MAE to obtain triterpenoids saponins from *Ganoderma atrum* yielded 5 min for each cycle [33].

3.3 Effect of stirring

Mass transfer processes in the solvent phase are usually enhanced by stirring. The equilibrium between the vapor and aqueous phases is achieved more rapidly. The use of a stirrer in MAE accelerates the extraction process by increasing the dissolution and desorption of bioactive compounds in the sample matrix [13, 27]. Thorough stirring can reduce the drawbacks possess when using a low solvent-to-solid ratio and minimized the mass transfer barrier [13].

3.4 Microwave power and temperature

Microwave power and temperature are important factors that affect the extraction yield when using MAE. The higher microwave power can lead to an increase in the temperature of the system resulting in the increase of the extraction yield until it becomes insignificant or declines [13, 25, 34]. An increase in temperature can result in solvent power increase because of a drop in surface tension and viscosity, enhancing the solvent to solubilize solutes, improving matrix wetting and penetration [13]. However, Spigno and De Faveri reported that the efficiency of MAE increases with the increase in temperature until an optimum temperature is reached [25]. Microwave power is also related to the quantity of sample and the extraction time required. However, the power provides localized heating in the plant matrix acts as a driving force for MAE to destroy the plant matrix so that the solute can diffuse and dissolve in the solvent. Therefore, increasing the microwave power will

generally improve the extraction yield and result in a shorter extraction time [13, 29, 35]. On the other hand, if microwave power is too high, it can result in poor extraction yield leading to the degradation of thermally sensitive compounds in the plant matrix [29]. It is then important to select the appropriate microwave power to reduce the extraction time required to reach the set temperature and avoid a “bumping” phenomenon [13].

3.5 Characteristic of plant sample and its water content

The characteristic of the plant sample and its water content can influence MAE. The extraction efficiency improves as the contact surface area of the plant sample increases. Moreover, finer samples give room for deeper penetration of microwave irradiation [36]. Nevertheless, too much finest of the plant sample may generate some technical difficulties; hence, filtration or centrifugation is employed in the preparation of the plant samples [27, 37]. During the sample preparation, the grinded sample is homogenized to improve contact between the solvent and the plant matrix. The plant particle sizes mostly fall within 2 and 100 μm [31]. Sometimes, the plant matrix is soaked before extraction to improve the yield; this is known as pre-leaching [37].

Mostly, the recovery of bioactive compounds from the plant matrix tends to increase through its moisture that acts as a solvent. This moisture is heated up, evaporated, causes pressure within the cell, and dispenses the solutes through rupturing of the cell wall; thus, increase the yield of bioactive compounds [38]. An increase in the polarity of solvent causes the addition of water to have a positive influence on microwave-absorbing capability; thus, encourages the heating procedure [26]. Extra water generates hydrolyzation and reduces the oxidation of bioactive compounds.

3.6 Microwave energy density

There are three heating operational modes employed in the performance evaluation of microwave-assisted extraction [28]. These include the constant-power heating mode, intermittent heating mode, and the constant temperature heating mode. Terigar et al. reported that the constant power heating mode presents the standard practice in the extraction of thermally sensitive active constituents of the plant matrix [35]. It is worthy to note that the microwave power alone does not provide an adequate explanation as to how energy is being absorbed in the extraction of the biological medium. Li et al. therefore studied the interrelationship between the microwave energy density and the extraction yield, it was concluded that for a unit of extracting solvent, microwave energy density is the most important factor affecting the extraction efficiency in a microwave-assisted extraction [39].

Gao et al. reported an accelerated effect on the ionic conduction and dipole rotation which in turn leads to an increase in the extraction yield [40]. This is due to the release of more microwave energy to the biological medium as the microwave power increases. Polar solvents rates of absorption improve with increasing power and ultimately resulting in higher heating and extraction rate [41]. Li et al. in [39] described the energy density of microwave heating as the power per unit quantity of sample under extraction as shown in Eq. (1).

$$\text{Energy density (W/mL)} = \frac{\text{Microwave power (W)}}{\text{Volume of extracting solvent (mL)}} \quad (1)$$

Number	Plant sample	Results obtained	Bioactive compounds	Remarks	Reference
1.	<i>Artemisia annua</i> L.	<p>MAE: Microwave power = 650 W; Solvent/feed ratio = 15; Temperature = ambient; Extraction time = 12 min</p> <p>SFE: Pressure = 30 MPa; solvent = CO₂; Solvent/feed ratio = 6; Temperature = 35 °C; Extraction time = 2.5 h</p> <p>Soxhlet: Solvent oil; S/F = 11.67; T = 35 C; t = 6 h</p>	<p>Artemisinin (92.1% db)</p> <p>Artemisinin (33.2% db)</p> <p>Artemisinin (60.4% db a)</p>	High yields and selectivity compared to other extraction methods.	[43]
2.	Sweet grass leaves	<p>MAE: Microwave power = 200 W; solvent used = acetone; Solvent/feed ratio = 10; Temperature = 80 °C; Extraction time = 15 min; one-step extraction</p> <p>SFE: Two-step: 1. Pressure = 35 MPa; Temperature = 40 °C 2. Pressure = 25Mpa; Temperature = 40 °C; Solvent = 20% of ethanol; Extraction time = 2 h; Flowrate = 0.5 L/min</p> <p>Soxhlet: Solvent/feed ratio = 50; Solvent = acetone; Extraction time = 6 h</p>	<p>5,8-Dihydroxycoumarin (0.42% db)</p> <p>5-Hydroxy-8-O-β-D-glucopyranosyl-benzopyranone (0.11% db)</p> <p>5,8-Dihydroxycoumarin (0.49% db)</p> <p>5-Hydroxy-8-O-β-D-glucopyranosyl-benzopyranone (0.06% db)</p> <p>5,8-Dihydroxycoumarin (0.46% db)</p> <p>5-Hydroxy-8-O-β-D-glucopyranosyl-benzopyranone (0.08% db)</p>	High yields and selectivity compared to other extraction methods.	[44]
3	Licorice roots	<p>MAE: Microwave power = 700 W; Solvent = ethanol; Solvent/feed ratio = 10; Temperature = 85–90 °C; Extraction time = 4 min</p> <p>Ultrasonic: Solvent = ethanol; Solvent/feed ratio = 10; Extraction time = 20.5 h</p> <p>Soxhlet:</p>	<p>Glycyrrhizic acid–GA (2.26%)</p> <p>Glycyrrhizic acid–GA (2.26%)</p> <p>Glycyrrhizic acid–GA (2.5%)</p>	It recovered a higher yield in reduced time.	[45]

Number	Plant sample	Results obtained	Bioactive compounds	Remarks	Reference
		Solvent = ethanol; Solvent/feed ratio = 10; Extraction time = 10 h			
4.	Green tea leaves	MAE: Microwave power = 700 W; Solvent = ethanol/ water (1:1 v/v); Solvent/feed ratio = 20; Temperature = 20 °C; Extraction time = 4 min UAE: Solvent = ethanol/water (1:1 v/v); Solvent/ feed = 20; Temperature = 20–40 °C; Extraction time = 90 min Heat reflux extraction: Solvent = ethanol/water (1:1 v/v); Solvent/ feed = 20; Temperature = 85 °C; Extraction time = 45 min	Tea polyphenols (30%), Tea caffeine (4%) Tea polyphenols (28%), Tea caffeine (3.6%) Tea polyphenols (28%), Tea caffeine (3.6%)	High yields and selectivity compared to other extraction methods.	[18]
5.	Grape fruit	MAE: Microwave power = 0.9 kW; Solvent = water; Solvent/feed ratio = 30; T = 20 °C; Extraction time = 6 min UAE: Solvent = water; Solvent/feed ratio = 30; T = 70 °C; Extraction time = 25 min UAE + MAE: Microwave power = 0.45 kW; Solvent/ feed = 30; Extraction time = 30 min for UAE and 10 min for MAE Heat batch: Solvent = water; Solvent/feed = 30; T = 90 °C; Extraction time = 90 min	Pectin (27.81%) Pectin (17.92%) Pectin (31.88%) Pectin (19.16%)	High yields compared to other extraction methods.	[46]
6.	<i>Ganoderma atrum</i>	MAE: Solvent = ethanol/water (9.5:0.5 v/v); Solvent/ feed ratio = 25; Temperature = 90 °C; Extraction time = 5 min	Global yield (5.11% db)	High yields compared to other extraction methods.	[47]

Number	Plant sample	Results obtained	Bioactive compounds	Remarks	Reference
		UAE: Solvent = ethanol/water (9.5:0.5 v/v); Solvent/ feed ratio = 25; Extraction time = 30 min; Frequency = 33 kHz	Global yield (1.72% db)		
		SFE: Pressure = 25 MPa; Temperature = 55 °C; Solvent = CO ₂ + ethanol; Extraction time = 3 h	Global yield (1.52% db)		
		Shaking: Solvent = ethanol/water (9.5:0.5 v/v); Extraction time = 3 h	Global yield (2.58% db)		
		HRE: Solvent = ethanol/water (9.5:0.5 v/v); Solvent/ feed ratio = 25; Temperature = 95 °C; Extraction time = 1 h	Global yield (2.22% db)		
7.	Yellow horn	MAE: Microwave power = 900 W; Solvent = ethanol/ water (40:60 v/v); Solvent/feed = 30; Temperature = 50 °C; Extraction time = 7 min × 3 cycles	Global yield (11.62%)	High yields compared to other extraction methods.	[48]
		UAE: Microwave power = 250 W; Solvent = ethanol/ water (40:60 v/v); Solvent/feed ratio = 30; Temperature = 50 °C; Extraction time = 60 min × 3 cycles	Global yield (6.78% db)		
		HRE: Microwave power = 800 W; Solvent = ethanol/ water (40: 60 v/v); Solvent/feed ratio = 30; Temperature = 50 °C; Extraction time = 90 min × 3 cycles	Global yield (10.82% db)		
8.	Turmeric plant	MAE: Microwave power = 60 W; Solvent = acetone; Solvent/feed = 3; Temperature = 50 °C; Extraction time = 5 min	Curcumin (90.47% db)	High yields compared to other extraction methods.	[49]

Number	Plant sample	Results obtained	Bioactive compounds	Remarks	Reference
		UAE: Microwave power = 150 W; Solvent = acetone; Solvent/feed = 3; Temperature = 21 °C; Extraction time = 5 min	Curcumin (71.42% db)		
		Soxhlet: Solvent = acetone; Solvent = 5; Extraction time = 8 h	Curcumin (2.10% db)		
		SFE: Pressure = 30 MPa; Solvent = CO ₂ + ethanol (10%); Temperature = 50 °C; Extraction time = 240 min; flowrate = 5 mL/ min	Curcumin (69.36% db)		
9.	<i>Silybum marianum</i> (L.) (milk thistle)	MAE: Microwave power = 600 W; Solvent = ethanol/ water (80:20 v/v); Solvent/feed = 25; Extraction time = 2 min × 6 cycles	Silybinin (1.37 db)	High yields compared to other extraction methods.	[50]
		Soxhlet: Solvent = ethanol/water (80:20 v/v); Solvent/ feed = 100; Extraction time = 12 h	Silybinin (1.09 db)		
		Stirring: Solvent = ethanol/water (80:20 v/v); Solvent/ feed ratio = 100; Extraction time = 24 h	Silybinin (0.48% db)		
		Maceration: Solvent = ethanol/water (80:20 v/v); Solvent/ feed ratio = 100; Extraction time = 24 h	Silybinin (0.36 db)		
10.	<i>Coriandrum sativum</i>	MAE: Microwave power = 200 W; Solvent = ethanol/ water (50:50 v/v); Solvent/feed = 20; Temperature = 50 °C, Extraction time = 18 min	Phenolics content (0.082% db)	The recovery of phenolic compounds was higher in MAE compare to other techniques.	[51]
		UAE: Solvent = ethanol/water (50:50 v/v), Solvent/ feed ratio = 10; Extraction time = 30 min	Phenolics content (0.041% db)		

Number	Plant sample	Results obtained	Bioactive compounds	Remarks	Reference
11.	<i>Cinnamomum zeylanicum</i>	MAE: Microwave power = 200 W; Solvent = ethanol/water (50:50 v/v); Solvent/feed ratio = 20; Temperature = 50 °C, Extraction time = 18 min UAE: Solvent = ethanol/water (50:50 v/v), Solvent/feed ratio = 10; Extraction time = 30 min	Phenolics content (1.679% db) Phenolics content (0.506% db)	The recovery of phenolic compounds was higher in MAE compare to other techniques.	[51]
12.	<i>Cuminum cyminum</i>	MAE: Microwave power = 200 W; Temperature = 50 °C, Solvent = ethanol/water (50:50 v/v); Solvent/feed ratio = 20; Extraction time = 18 min UAE: Solvent = ethanol/water (50:50 v/v), Solvent/feed ratio = 10; Extraction time = 30 min	Phenolics content (1.159% db) Phenolics content (0.290% db)	The recovery of phenolic compounds was higher in MAE compare to other techniques.	[51]
13.	<i>Crocus sativus</i>	MAE: Microwave power = 200 W; Temperature = 50 °C, Solvent = ethanol/water (50:50 v/v); Solvent/feed ratio = 20; Extraction time = 18 min UAE: Solvent = ethanol:water (50:50 v/v), Solvent/feed ratio = 10; Extraction time = 30 min	Phenolics content (2.939% db) Phenolics content (0.500% db)	The recovery of phenolic compounds was higher in MAE compare to other techniques.	[51]
14.	Sea buckthorn	MHG: Microwave power = 400 W; Extraction time = 15 min; Humidity = 57% Agitated: Solvent = methanol/water (80:20 v/v);	Isorhamnetin 3- <i>O</i> -rutinoside (0.123% db) Isorhamnetin 3- <i>O</i> -glucoside (0.097% db) Quercetin 3- <i>O</i> -Glucoside (0.025% db) Isorhamnetin (0.00084% db) Isorhamnetin 3- <i>O</i> -rutinoside (0.187% db)	Recovery of higher yields of bioactive compound compared to other extraction techniques.	[52]

Number	Plant sample	Results obtained	Bioactive compounds	Remarks	Reference
		Solvent/feed ratio = 10; Extraction time = 8 min	Isorhamnetin 3- O -glucoside (0.162% db) Quercetin 3- O -Glucoside (0.016% db) Isorhamnetin (0.00064% db)		
15.	Cranberry press cake	MAE: Solvent = ethanol; Solvent/feed ratio = 5.7; Temperature = 125 °C; Extraction time = 10 min Stirring: Solvent = ethanol; Solvent/feed ratio = 5; Extraction time = 2 h	Quercetin (0.1537% db) Quercetin (0.1272% db)	Recovery of higher yields of bioactive compound in lesser time compared to other extraction techniques.	[53]
16.	<i>Morinda citriflora</i> (roots)	MAE: Microwave power = 720 W; Solvent = ethanol/water (80:20 v/v); Solvent/feed ratio = 100; Temperature = 60 °C; Extraction time = 15 min UAE: Solvent = ethanol; Solvent/feed ratio = 100; Temperature = 60 °C; Extraction time = 60 min Maceration: Solvent = ethanol; Solvent/feed ratio = 100; Extraction time = 3 days Soxhlet: Solvent = ethanol; Solvent/feed ratio = 100; Temperature = 100 °C; Extraction time = 4 h	Global yield (95.91% db) Global yield (62.23% db) Global yield (63.33% db) Global yield (97.74% db)	High yields compared to other extraction methods.	[54]
17.	Soybean germ	MAE: Solvent/feed ratio = 17.5; Temperature = 120 °C; Extraction time = 0.5 h MAE + UAE: Microwave power = 60 W for UAE and 100 W for MAE; Solvent/feed ratio = 5;	Global yield (16.5% wb) Global yield (14.1% wb)	High yields compared to other extraction methods.	[55]

Number	Plant sample	Results obtained	Bioactive compounds	Remarks	Reference
		Temperature = 45 °C; Extraction time = 1 h Soxhlet: Solvent = hexane; Solvent/feed ratio = 6.67; Extraction time = 4 h	Global yield (8.65% wb)		
18.	<i>Lavandula angustifolia</i> Mill., Lamiaceae (lavender flowers)	MASD: Microwave power = 500 W; Solvent = water; Solvent/feed ratio = 4; Extraction time = 10 min SD: s = water; S/F = 4; t = 90 min	Monoterpenes (3.45% db) Oxygenated monoterpenes (78.29% db) Sesquiterpenes (2.77% db) Global yield (8.86% db) Monoterpenes (4.92% db) Oxygenated monoterpenes (75.14% db) Sesquiterpenes (2.87% db) Global yield (2.59% db)	Recovery of higher yields of a bioactive compound in lesser time compared to other extraction techniques.	[56]
19.	Caraway (<i>Carum carvi</i> L.)	MDG: Microwave power = 100 W; Extraction time = 45 min Hydrodistillation: Solvent/feed ratio = 5; Extraction time = 300 min	Global yield (2.59% db) Carvone (67.59% db) Limonene (30.10% db) Global yield (2.54% db) Carvone (66.89% db) Limonene (30.30% db)	High yields compared to other extraction methods.	[57]
20.	Tomato	MAE: Microwave power = 100 W; Solvent = methanol; Solvent/feed ratio = 50; Extraction time = 45 min Shaker: Solvent = ethanol/water (60:40 v/v); Solvent/ feed ratio = 50; Temperature = 45 °C; Revolution = 400 rpm; Extraction time = 15 h	Total phenolic contents (0.646% db) Total phenolic contents (0.603% db)	The recovery of phenolic compounds was higher in MAE compare to other technique.	[58]
21.	<i>Foeniculum vulgare</i> Miller (seeds)	MWHD: Microwave power = 300 W; Solvent = water; Solvent/feed ratio = 2; Temperature = 100 °C; Extraction time = 200 s	Global yield (1.14% db)	High yields compared to other extraction methods.	[59]

Number	Plant sample	Results obtained	Bioactive compounds	Remarks	Reference
		HD: Microwave power = 300 W; Solvent = water; Solvent/feed ratio = 8; Extraction time = 319 s; Temperature = 100 °C; Revolution = 50 rpm	Global yield (0.265% db)		
22.	<i>Iochroma gesnerioides</i> (leaves)	MAE: Microwave power = 25 W; Solvent = methanol; Solvent/feed ratio = 50; Extraction time = 40 s Soxhlet: Withaferin A (0.41% db a) 1. Solvent = water; Solvent/feed ratio = 6; Extraction time = 15 min 2. Solvent = methanol; Solvent/feed ratio = 100; Extraction time = 6 h	Withaferin A (0.48% db) Iochromolide (0.85% db) Withacnistin (0.39% db) Withaferin A (0.41% db) Iochromolide (0.81% db) Withacnistin (0.38% db)	Recovery of higher yields of bioactive compound compared to other extraction techniques.	[60]
23.	<i>Xanthoceras sorbifolia</i> Bunge. (yellow horn)	Microwave power = 900 W; Solvent = ethanol: water (40: 60 v/v); Solvent/feed ratio = 30; Temperature = 50 °C; Extraction time = 7 min × 3 cycles UAE: Microwave power = 250 W; Solvent = ethanol: water (40:60 v/v); Solvent/feed ratio = 30; Temperature = 50 °C; t = 60 min × 3 cycles Reflux: Microwave power = 800 W; Solvent = ethanol: water (40:60 v/v); Solvent/feed = 30; Temperature = 50 °C; Extraction time = 90 min × 3 cycles	Triterpene saponins (11.62% wb) Triterpene saponins (6.78% wb) Triterpene saponins (10.82% wb)	Recovery of higher yields of bioactive compound compared to other extraction techniques.	[48]
24.	<i>Ocimum basilicum</i> L. (basil)	SFME: Microwave power = 500 W; Temperature = 100 °C; Extraction time = 30 min	Eugenol (43.2% wb) Linalool (25.3% wb) Global yield (0.029% wb)	Recovery of higher yields of bioactive compound compared to other extraction techniques.	[61]

Number	Plant sample	Results obtained	Bioactive compounds	Remarks	Reference
		HD: Eugenol (11.0% wb a) s = water; S/F = 12; T = 100 C; t = 4.5 h	Eugenol (11.0% wb) Linalool (39.1% wb) Global yield (0.028% wb)		
25.	<i>Mentha crispa</i> L. (gardenmint)	SFME: Microwave power = 500 W; Temperature = 100 °C; Extraction time = 30 min HD: Solvent = water; Solvent/feed ratio = 12; Temperature = 100 °C; Extraction time = 4.5 h	Limonene (9.7% wb) Carvone (64.9% wb) Global yield (0.095% wb) Limonene (20.2% wb) Carvone (52.3% wb) Global yield (0.095% wb)	Recovery of higher yields of bioactive compound compared to other extraction techniques.	[61]
26.	<i>Thymus vulgaris</i> L. (thyme)	SFME: Microwave power = 500 W; Temperature = 100 C; Extraction = 30 min HD: γ -Terpinene (22.8% wb a) s = water; S/F = 12; T = 100 C; t = 4.5 h	γ -Terpinene (17.1% wb) Eugenol (51.0% wb) Global yield 0.160% wb) γ -Terpinene (22.8% wb) Eugenol (40.5% wb) Global yield 0.161% wb) Global yield (2.70% db)	Recovery of higher yields of bioactive compound compared to other extraction techniques.	[61]
27.	<i>Elletaria cardamomum</i> L. (cardamom)	SFME: Microwave power = 390 W; Temperature = 100 °C; Humidity = 67%; Extraction time = 75 min HD: Solvent = water; Solvent/feed ratio = 10; Temperature = 100 °C; Extraction time = 6 h	1,8-Cineole (26.23% db) Linalool (5.29% db) Terpin-4-ol (2.60% db) α -terpineol (3.88% db) Linalyl acetate (3.63% db) α -terpinyl acetate (45.45% db) 1,8-Cineole (26.23% db)	Recovery of higher yields of bioactive compound compared to other extraction techniques.	[62]
28.	<i>Gymnema sylvestre</i> R. Br.	MAE: Microwave power = 280 W; Solvent = methanol:water (85:15 v/v); Solvent/feed ratio = 25; Extraction time = 6 min Reflux:	Gymnemagenin (4.3% db) Gymnemagenin (3.3% db)	Recovery of higher yields of bioactive compound compared to other extraction techniques.	[63]

Number	Plant sample	Results obtained	Bioactive compounds	Remarks	Reference
		Solvent = methanol:water (85:15 v/v); Solvent/feed ratio = 100; T = 95 °C; Extraction time = 6 h Maceration: Solvent = methanol:water (85:15 v/v); Solvent/feed ratio = 100; Extraction time = 24 h Stirring: Solvent = methanol:water (85:15 v/v); Solvent/feed ratio = 100; Extraction time = 24 h	Gymnemagenin (1.7% db) Gymnemagenin (2.2% db)		
29.	<i>Melilotus officinalis</i> (L.) Pallas) (yellow sweet clover)	MAE: Microwave power = 100 W; Solvent = water:ethanol (50:50 v/v); Solvent/feed ratio = 20; Temperature = 50 °C; Extraction time = 5 min × 2 cycles USAE: Solvent = water:ethanol (50:50 v/v); Solvent/feed ratio = 20; Extraction time = 60 min Soxhlet: Solvent = ethanol:water (95:5 v/v); Solvent/feed ratio = 16.67; Extraction time = 8 h	Coumarin (0.3978% db) O-coumaric acid (0.1257% db) Melilotic acid (0.9052% db) Coumarin (0.3569% db) O-coumaric acid (0.1269% db) Melilotic acid (0.8092% db) Coumarin (0.2156% db) O-coumaric acid (0.0708% db) Melilotic acid (0.6314% db)	Recovery of higher yields of bioactive compound compared to other extraction techniques.	[20]
30.	<i>Salvia miltiorrhiza</i> Bunge. (dried root)	MAE: Solvent = ethanol:water (95:5 v/v); Solvent/feed ratio = 10; T = 80 °C; Extraction time = 2 min Reflux: Solvent = ethanol:water (95:5 v/v); Solvent/feed ratio = 10; Extraction time = 45 min UAE: Solvent = ethanol:water (95:5 v/v); Solvent/feed ratio = 10; Extraction time = 75 min Soxhlet: Tanshinone IIA (0.33% db a) Solvent = ethanol:water (95:5 v/v); Solvent/feed ratio = 10; Extraction time = 95 min	Tanshinone IIA (0.29% db) Cryptotanshinone (0.23% db) Tanshinone I (0.11% db) Tanshinone IIA (0.25% db) Cryptotanshinone (0.24% db) Tanshinone I (0.11% db) Tanshinone IIA (0.28% db) Cryptotanshinone (0.25% db) Tanshinone I (0.10% db) Tanshinone IIA (0.33% db) Cryptotanshinone (0.25% db) Tanshinone I (0.33% db)	Recovery of higher yields of bioactive compound compare to other extraction techniques.	[64]

Number	Plant sample	Results obtained	Bioactive compounds	Remarks	Reference
31.	<i>Radix astragali</i> (dried root)	<p>MAE: Microwave power = 700 W; Solvent = ethanol: water (80:20 v/v); Solvent/feed ratio = 25; Temperature = 70 °C; Extraction time = 5 min × 3 cycles</p> <p>Soxhlet: Solvent = ethanol:water (80:20 v/v); Solvent/feed ratio = 20; Temperature = 90 °C; Extraction time = 4 h</p> <p>Reflux: Solvent = ethanol:water (80:20 v/v); Solvent/feed ratio = 20; Temperature = 90 °C; Extraction time = 1 h</p> <p>UAE: Power = 100 W; Solvent = ethanol:water (80:20 v/v); Solvent/feed ratio = 20; Extraction time = 40 min</p> <p>Maceration: Solvent = ethanol:water (80:20 v/v); Solvent/feed ratio = 20; Extraction time = 12 h</p>	<p>Astragalosides I (0.788% db) Astragalosides II (0.351% db) Astragalosides III (0.206% db) Astragalosides IV (0.278% db) Astragalosides I (0.770% db) Astragalosides II (0.347% db) Astragalosides III (0.193% db) Astragalosides IV (0.242% db) Astragalosides I (0.761% db) Astragalosides II (0.352% db) Astragalosides III (0.203% db) Astragalosides IV (0.257% db) Astragalosides I (0.519% db) Astragalosides II (0.302% db) Astragalosides III (0.190% db) Astragalosides IV (0.225% db) Astragalosides I (0.411% db) Astragalosides II (0.299% db) Astragalosides III (0.166% db) Astragalosides IV (0.206% db)</p>	<p>Recovery of higher yields of bioactive compound compare to other extraction techniques.</p>	[65]
32.	Sweet potato [<i>Ipomoea batatas</i> (L.) Lam.]	<p>MAE: Microwave power = 123 W; Solvent = ethanol: water (53:47 v/v); Solvent/feed ratio = 25; Extraction time = 2 min</p> <p>CSE:</p>	<p>Total phenolics (6.115% db) Total phenolics (5.969% db)</p>	<p>The recovery of phenolic compounds was higher in MAE compare to other techniques.</p>	[66]

Number	Plant sample	Results obtained	Bioactive compounds	Remarks	Reference
		Solvent = ethanol:water (60:40 v/v); Solvent/feed ratio = 30; Extraction time = 120 min			
33.	Tobacco leaves	MAE: Microwave power = 700 W; Solvent = hexane:ethanol (1:3 v/v) + NaOH (0.05 mol/L); Solvent/feed ratio = 10; Extraction time = 40 min HRE: Solvent = hexane:ethanol (1:3 v/v) + NaOH (0.02 mol/L); Solvent/feed ratio = 10; Temperature = 60 °C; Extraction time = 180 min	Solanesol (0.91% db) Solanesol (0.87% db)	The recovery of phenolic compounds was higher in MAE compare to other techniques.	[67]
34.	<i>Lavandula angustifolia</i> Mill., Lamiaceae (lavender flowers)	MSD: Microwave power = 200 W; flowrate = 8 g/min; Extraction time = 6 min	1,8-Cineole (14.40% db) Linalool (42.52% db) Global yield (2.7% db)	Recovery of higher yields of bioactive compound	[68]
35.	<i>Radix astragali</i> (root of <i>Astragalus</i> ; Huangqi)	MAE: Solvent = ethanol:water (95:5 v/v); Solvent/feed ratio = 25; Temperature = 110 °C; Extraction time = 25 min × 2 cycles Soxhlet: Solvent = methanol; Solvent/feed ratio = 25; Temperature = 85 °C; Extraction time = 4 h UAE: Solvent = methanol; Solvent/feed ratio = 20; Temperature = 60 °C; Extraction time = 30 min × 2 cycles HRE: Solvent = ethanol:water (90:10% v/v); Solvent/feed ratio = 25; Temperature = 75 °C; Extraction time = 2 h × 2 cycles	Flavonoids (0.1292%) Flavonoids (0.1190%) Flavonoids (0.0736%) Flavonoids (0.0934%)	Recovery of higher yields of bioactive compound compares to other extraction techniques.	[69]

Number	Plant sample	Results obtained	Bioactive compounds	Remarks	Reference
36.	Yellow onion	VMHG: Microwave power = 500 W; Pressure = 700 mbar; Power/feed = 1 W/g; Temperature = 81 °C; Extraction time = 26 min; Moisture content = 84.5% MHG: Pressure = 1 bar; Temperature = 100 °C; Extraction time = 23 min; Moisture content = 84.5% CSE: Solvent = methanol:water (80:20 v/v); Solvent/feed ratio = 10; Revolution = 8,000 rpm; Extraction time = 5 min	Quercetin (0.662% db) Global yield (3.18% db) Quercetin (0.283% db) Quercetin (0.890% db)	Recovery of higher yields of bioactive compound compares to other extraction techniques.	[70]
37.	Yellow soybeans (finely ground)	MAE: Microwave power = 600 W, Solvent = acetonitrile/water (2 mL, 80:20 v/v), sonicated with HCl 15 min, 1 min MAE. (sample, solvent, time)	Isoflavoids	Excellent efficiency and low consumption of solvent, sample, and time.	[71]
38.	Soybeans	MAE: Microwave power = 500 W, Temperature = 50 °C, Solvent = 25 mL of ethanol (50%), Extraction time = 20 min	Isoflavones (75%)	High reproducibility without degradation.	[72]
39.	Green tea leaves (<i>Camellia sinensis</i> L.)	MWE: Microwave power = 600 W, Temperature = 80 °C or 100 °C, Solvent = 120 mL of milli-Q water, Extraction time = 60 min	Flavanols	The yield of flavanol extract is higher compared to CWE, especially EGCG (<i>Epigallocatechin gallate</i>) concentration. More efficient at both 80 and 100 °C.	[73]
40.	Dried <i>Saussurea medusa</i> cells	MAE: Microwave power = 460 W, Solvent = 10 mL of	Flavonoids (4.1%)	High selectivity compared to other extraction methods.	[74]

Number	Plant sample	Results obtained	Bioactive compounds	Remarks	Reference
		ethanol (80%), Extraction time = 6 min with 15 s power-on and 30s power-off			
41.	<i>Radix astragali</i>	MAE: Microwave power = 1,000 W, Temperature = 110 °C, Solvent = Ethanol (90%), Solvent/feed ratio = 25, Extraction time = 25 min	Flavonoids	The yield of flavonoids was closer to that of SOX with methanol and higher than that of UAE with methanol.	[32]
42.	<i>Platycladus orientalis</i> (book-leaf pine)	DMAE: Microwave power = 80 W, Solvent = 5 mL methanol (80%), Solvent/feed ratio = 500:1, Extraction time = 5 min	Flavonoids (1.72%)	Very short time and little solvent quantity required.	[75]
43.	<i>Saussurea medusa</i> Maxim	DMAE: Microwave power = 1200 W, Solvent = 2 L of ethanol (80%), Solvent/feed ratio = 50, Extraction time = 60 min	Flavonoids (4.97%)	In comparison with the same dynamic system without a microwave, it showed significant improvement.	[40]
44.	Longan peel	MAE: Microwave power = 500 W, Temperature = 80 °C, Solvent = 50 mL of ethanol (95%), Solvent/feed ratio = 10, Extraction time = 30 min	Total phenolic content (TPC = 96.78 mg/g), excellent scavenging ability comparing to synthetic antioxidant BHT	Very short time and little solvent quantity required.	[76]
45.	Plants of Labiatae, Verbenaceae, and Styracaceae	MAE: Microwave power = 750 W, Solvent = 20 ml of acetone (60%), Solvent/feed ratio = 20:1, Extraction time = 4 min	Total phenolic content (TPC = 23.8 mg GAE/g) in <i>Rosmarinus officinalis</i>	Higher yield in little time of extraction.	[16]
46.	Dried roots of <i>Rhodiola</i> L.	MAE: Microwave power = 400 W, Solvent = 5 mL of methanol (50%), Solvent/feed ratio = 5, Extraction time = 5 min	Salidroside and tyrosol (94.4–123%)	Good recoveries.	[77]

Number	Plant sample	Results obtained	Bioactive compounds	Remarks	Reference
47.	<i>Herba epimedii</i>	DMAE: Microwave power = 80 W, Solvent = ethanol (60%), Extraction time = 6 min	Flavonoids	The extraction yield of flavonoids obtained through DMAE was more compared to SOX, HRE, UE, and PMAE. Microwave saves time and generates lesser decomposition.	[78]
48.	Onion (<i>Allium cepa</i> L.)	MHG: Microwave power = 500 W, Extraction time = 23 min	Total phenolic content (58.29 mg GAE/DW) Yield (81.5%) Flavonol (41.9%)	Shorter extraction time.	[79]
49.	Red, yellow, white, and grelot onion (<i>Allium cepa</i>)	MHG: Microwave power = 500 W, Extraction time = 23 min	Flavonol	MHG remains the preferred method for the extraction of flavonoids compared to CSE.	[70]
50.	Sea buckthorn (<i>Hippophae rhamnoides</i>) by-product	MHG: Microwave power = 400 W, Extraction time = 23 min	Flavonoids	MHG showed much higher phenolic content with greater antioxidant activity in comparison to CSE.	[52]
51.	Onion by-product	VMHG: Pressure = 0.7 bar, Microwave power = 500 W, Extraction time = 26 min	Flavonoids	More antioxidants (total quercetin content) was extracted compared to MHG and CSE; an efficient procedure for extraction of heat-sensitive plant components.	[80]
52.	Olive leaves	MAE: Microwave power = 200 W, Solvent = 8 mL ethanol (80%), Solvent/feed ratio = 8:1, Extraction time = 8 min	Biophenols	The main compounds ranged from 631 (verbacoside) to 23,200 mg/kg (oleuropein).	[81]
53.	Grape skin and seeds	MAE: Pressure = 1–10 atm, Microwave power = 500 W, Temperature = 65–140 °C, Solvent = 20 mL of methanol (100%), Extraction time = 20 min	Phenolic compounds	Flavanols were mostly found in skin but absent in grape seeds; catechin was abundant in seeds.	[82]

Number	Plant sample	Results obtained	Bioactive compounds	Remarks	Reference
54.	Purple corn (<i>Zea mays</i> L.) cob	MAE: Microwave power = 555 W, Solvent = of 1.5 M HCl-ethanol (95%), Solvent/feed ratio = 20, Extraction time = 19 min	Anthocyanins (185.1 mg/100 g)	More efficient and rapid than CSE.	[83]
55.	Tomato paste	UMAE: Microwave power = 98 W, Frequency = 40 KHz of ultrasonic processing, Solvent/feed ratio = 10.6, Extraction time = 367 s	Lycopene (97.4%)	More efficient and rapid than UAE.	[84]
56.	Noni plant roots (<i>Morinda citrifolia</i>)	MAE: Microwave power = 720 W, Temperature = 60 °C, Solvent = 10 mL of ethanol (80%), Solvent/feed ratio = 100, Extraction time = 15 min	Anthraquinones (95.91%)	A higher yield has been obtained with higher antioxidant activity.	[54]
57.	Seeds, leaves, pulp, and fruits of sea buckthorn (<i>Hippophae rhamnoides</i>)	MAE: Microwave power = 150 W, Temperature = 60 °C, Solvent = 50 mL of ethanol, Solvent/feed ratio = 10, Extraction time = 20 min	Phenolic constituents (9.3–23.5 mg GAE/g) Rutin compound (365 mg/g)	Higher yields.	[85]
58.	Aloe (Liliaceae)	MAE: Microwave power = 340 W, Solvent = ethanol/water (20 mL, 80/20, v/v), Solvent/feed ratio = 15, Extraction time = 3 min	Aloe-emodin	Higher yield compared to other extraction methods.	[86]
59.	Bitter leaves	MAE: Microwave power = 558 W, Solvent = ethanol/water (76/24% v/v), Temperature = 70 °C, Solvent/feed ratio = 10, Extraction time = 4 min	Polyphenolic compounds	Several phenolic compounds were extracted.	[87]
60.	Purple fleabane	MAE: Microwave power = 444 W, Solvent = ethanol/water (47/53% v/v), Solvent/feed ratio = 14, Extraction time = 2 min	Total phenolic content = 85.64 ± 0.52 mg GAE/g d.w. Total flavonoid	Recovery of higher yield in a shorter time compared to Soxhlet extraction technique.	[21]

Number	Plant sample	Results obtained	Bioactive compounds	Remarks	Reference
			content = 52.72 ± 0.93 mg QE/g d.w.		
61.	Scent leaves	MAE: Microwave power = 553 W, Solvent = water, Solvent/feed ratio = 10, Extraction time = 3 min	Total phenolic content = 184.99 ± 3.05 mg GAE/g extract Total flavonoid content = 68.78 ± 2.07 mg QE/g extract	Recovery of higher yield in a shorter time.	[22]
62.	<i>Hibiscus sabdariffa</i>	MAE: Microwave power = 450 W, Solvent = ethanol/water (52/48%, v/v), Solvent/feed ratio = 15, Extraction time = 4 min	Total flavonoid content = 94.32 mg QE/g extract	Recovery of higher yield in a shorter time.	[6]
63.	<i>Chromolaena odorata</i> leaves	MAE: Microwave power = 493 W, Solvent = ethanol/water (51/49%, v/v), Extraction time = 3 min	Total phenolic content = 88.52 mg _{GAEgDW} ⁻¹ Total flavonoid content = 68.84 mg _{QEgDW} ⁻¹	Recovery of higher yield in a shorter time.	[9]

HRE: Heat reflux extraction, MHG: Microwave hydro-diffusion and gravity, MASD: Microwave-accelerated steam distillation, SD steam distillation, SFME: Solvent-free microwave extraction, MDG: Microwave dry-diffusion and gravity, MWHD: Microwave-assisted hydrodistillation; HD: Hydrodistillation, USAE: Soxhlet extraction, ultrasound-assisted extraction, MSD: Microwave steam distillation, VMHG: Vacuum microwave hydro-diffusion and gravity, CSE: Conventional solvent extraction.

Table 2.
Bioactive compounds extracted through MAE from different plant samples.

3.7 Influence of stirring

The influence of stirring can be linked to the mass transfer procedure in a solvent that causes convection. Hence, stability between vapor and aqueous phases can be obtained quickly. The process tends to accelerate through agitation, this enhances the dissolution and desorption of bioactive components in the plant sample [42]. Using a low solvent-to-feed ratio can be reduced as well as a reduction in the mass transfer barrier from solutes in a localized area emanating from inadequate solvent [26].

4. Previously extracted bioactive compounds from plants using MAE technique

MAE has been employed in several ways to extract bioactive compounds from different plant samples; the isolates from these plant samples are being used in nutraceutical and pharmaceutical applications. Microwave irradiation is mostly used to resolve some of the drawbacks associated with traditional methods. **Table 2** presents some of the previous studies that employed MAE to extract bioactive compounds from plant samples. In the presented results obtained from previous studies as presented in **Table 2**, it can be seen the use of microwave-assisted extraction technique recover improved quantities of global yields, different phenolic compounds, and bioactive compounds. These indicated the efficacy of MAE over other methods of extractions.

5. Conclusions

This chapter outlines the studies and many advances in development in the MAE of a number of plant compounds. The factors that influence the performance of MAE technique have been extensively discussed as well as some of the bioactive compounds previously reported from plant samples using the MAE. The previously reported results showed that MAE can recover higher yields of bioactive compounds relative to other extraction methods. Thus, MAE is a promising method in achieving substantial bioactive compounds from plant materials due to its importance over other techniques.

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Conflict of interest

The authors declare that there is no conflict of interest.

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