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Microwave assisted extraction of bioactive compounds: A Review

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ABSTRACT
Microwave assisted extraction is rapidly growing and flourished extraction technology. It is a process which extracts a specific element from a specific substance at a given condition. Mainly, these conditions include solvent type, solvent volume, solvent concentration, time of process, temperature of process & required power. In recent years, the need of microwave assisted extraction, in the field of extraction of bioactive compounds has been increased due to its efficient operational conditions. This paper shows the past research on microwave assisted extraction of bioactive compounds from plant and various modified microwave assisted extraction.
Keywords: Microwave heating; phytochemicals; dielectric properties; MAE

1. INTRODUCTION

Definition of bioactive compounds is ambivalent. Some theories prove that these are non-nutritional compounds and body can function properly without them. While some theories say that these are essential and non-essential compounds which can affect the human health (Biesalski H-K et al. 2009). This second phenomena is treated as consensus. Proper quantity of bioactive compounds in dietary may lead the human health in positive way and on other hand deficiency of these may cause the cardiovascular diseases and cancer. Generally these are found in plant species (polyphenol, carotenoids etc.) but some of the living organism (mushroom), micro-organism (bacteria) and animals (fatty acids) also have the bioactive compounds and also can be manufactured by artificial manner. Bioactive compounds are flavor substances, plant volatiles, insect anti-feed ants, natural sweeteners, plant toxins, carcinogens, coloring matters, mycotoxins, pharmaceuticals, phytoalexins and allelochemicals (Sasidharan et al., 2011). Extraction of bioactive compound requires methodical techniques such as conventional methods (soxhlet method) & non-conventional methods (ultrasound extraction, super critical fluid extraction, enzymatic digestion, pulse electric light extraction, microwave assisted extraction, ohmic heating assisted extraction, extrusion pressurized liquid extraction). Conventional method is used as standard method for newly flourished processes. Most common problematic term for conventional method is time consuming process even it takes 8, 16, 24 hours or more which increases the labor requirement and reduces space for other experiments. Soxhlet extrction consumes more solvent 75:1 (ml/g) then the non-conventional methods which mushrooms the cost of experiment. Conventional approach also consumes more power (De Castro and Priego-Capote, 2010).
Microwave assisted extraction process fulfills all these drawbacks of conventional methods. This method consumes low volume of solvent as 1:12 (g/ml) as solid/liquid ratio. This procedure utilizes less time (within few minutes) as compare to soxhlet method (Wang et al., 2010). In some cases MAE took 40 sec for optimum recovery. Time and power factors are interweaved with each other as by elevation of power this process uses less time and vice versa. Aforementioned process is also anti-thermolabile process. It preserves the properties of compound which get lost during long heating of compound in conventional method (Mandal et al., 2007).

2. MAE EXTRACTION MECHANISM

Microwaves are electromagnetic waves which fall in between infrared and radio waves with the wavelength of 1 meter to 1 millimeter and frequency lies between 300MHz to 300GHz (Kumar and Shukla 2014). For microwave heating of sample, dipole moment and ionic conduction play an important role (Jain et al. 2009). At low frequency, dipoles easily get arranged along with change in electric field. When frequency of waves is high then speed of rearrangement is also increased. If the frequency is very high like THz then dipoles are not able to realign themselves (Vollmer, 2004). At GHZ frequency, a phase lag is generated due to late response of dipole moment to the changing electric field during realignment of dipoles. Thus, during rearrangement, frictional force is generated which produces heat (Mandal et al. 2007; Robinson et al. 2010). The heat is transferred by the ions or dipoles to the next molecule. This heat transfer process is called ionic conduction (Anwar et al. 2015). Quantity of heat utilization depends upon dissipation factor (tanδ) which indicates the energy absorbed by dipolar molecule (or solvent) and transfers it to surrounding molecules. It is a combination of absorption of microwave energy by the solvent and transfer of produced heat to the surrounding molecules. There is an energy lag between amount of heat produced and amount of heat transferred because a part of energy utilizes by the molecules to be in excited state, an another part of energy is lost during friction force, a part of energy is absorbed by dipoles to overcome the lag phase (Mandal et al. 2007). So, the energy given to the food material is not equal to the heat generated. Dissipation factor is calculated by

$$\tan\delta = \varepsilon''/\varepsilon'$$

Here, ε'' is the dielectric loss, which is measure of efficiency of converting microwave energy into heat. ε' is dielectric constant of solvent which quantifies the ability of solvent to absorb energy. Thus, tanδ depends upon dielectric constant and dielectric loss. Therefore, selection of proper solvent is a function of dielectric constant and dielectric loss. A solvent having high dielectric loss (ε'') and low dielectric constant (ε') is suitable for microwave heating (Chan et al. 2011; Chemat and Cravotto 2012). MAE apparatus mainly consists of a microwave oven, an extraction flask and a cooling assembly or condenser (Gharekhani et al. 2012). The solvent micelle is put under microwave heating and solute comes into the solvent from sample matrix (Eskilsson and Bjorklund, 2000). After required time of heating, the extract is sent for further analysis. A soluble compound can be extracted from complex material via MAE with high grade of yield efficiency by using microwave heat.

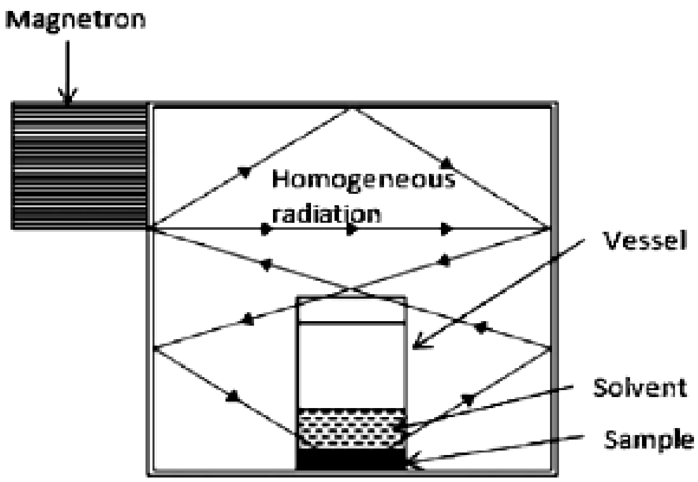

Fig 1: Microwave assisted extraction (Mandal et al., 2007)

3. TYPES OF MAE PROCESSES RESULTS

3.1 Open vessel/ focused MAE

This process is done at atmospheric pressure so it is called as Open Vessel MAE. It can be done in mono mode or multi-mode microwave oven. Multi-mode microwave oven refers even dispersion of waves inside the oven cavity so it gives a homogenous radiation distribution to the sample and sample can be kept anywhere inside the cavity. Mono-mode oven provides a focused radiation generally at the center of cavity where sample is kept. Open vessel MAE have main advantage as due to atmospheric pressure applied so sample preparation is easy and more feasible for thermolabile sample because it uses low temperature than the closed vessel MAE. It attains low maximum temperature as compare to closed vessel MAE so limited compounds can be extracted by this process (Tatke and Jaiswal, 2011).

3.2 Closed vessel/ dynamic MAE process (DMAE)

Dynamic microwave-assisted extraction (DMAE) is a combined technique for extraction as well as analytical analysis. It provides rapid extraction with low solvent consumption. This is improved by modifying the extraction process in a continuous and automatic manner and coupling on-line with analytical step. Due to the fluidized state of extraction solvent-sample system, DMAE promotes rapid transfer of microwave energy to the extraction solvent and the sample. The need of extraction cycle is eliminated and replaced by continuous extraction. Thus, the overall extraction time is reduced. Besides, the risks of analyte loss and contamination can also be minimized as the system runs continuously in a closed and automated manner. DMAE proceeded without causing an increase or decrease in pressure (Chen et al., 2011).

3.3 Solvent free MAE (SFMAE) process

As its name indicate that solvent is not used in this kind of MAE process. This is not a modified MAE but it is a MAE process which has eliminated solvent or water consumption during extraction process. SFME is the combination of microwave heating and dry distillation which is performed at atmospheric pressure. In situ water plays most important role for microwave heating. Due to microwaves, in situ water gets heated and pressurized so it breaks the plant cell. Therefore, compounds are naturally diffused into in situ water and travel with it (in situ water) thus compounds come out from the microwave heating medium. Generally, Clevenger assembly is attached with the volumetric flask for extraction of essential oil. When essential oil travels with in situ water then due to water cooled condenser, vapor is collected and the extra water is automatically transferred back to the volumetric flask. After completion of process, essential oil is collected and is sent for the analysis (Lucchesi et al., 2004).

3.4 Vacuum MAE (VMAE) Process

An MAE process in which vacuum or negative pressure is used for extraction of compounds. Vacuum is created by removal of air from inside of sample-solvent flask up-to a predetermined degree. Vacuum helps the extraction process to complete at lower temperature. At low pressure, boiling point of solvent decreases therefore experiment is performed at low temperature which helps to stop degradation of thermolabile compounds. In VMAE, air is pumped out so oxygen is also removed which helps to prevent oxidation process during extraction process (Chan et al., 2011). Extraction of compounds by VMAE is similar to that of the focused MAE but an extra step is added in the form of vacuum or pumping out of air. Xiao et al. (2009) had compared VMAE or air-MAE for extraction of vitamin c from guava and green pepper and vitamin E from soybean and tea leaves. They found increment in yields by using VMAE that shows that the sample matrix is also a considering factor because thermolabile and oxygen sensitive compounds get degraded during extraction process. VMAE gives higher yield than the focused MAE (Wang et al., 2008).

3.5 Ultrasonic MAE process (UMAE)

Ultrasonic waves along with microwaves provide additional mass transfer to the solute from solid matrix into solvent. In this process both the radiations together furnishes high momentum and energy to the solute. The additional attachment to MAE reduces extraction time as well as solvent volume. Zhang et al. (2010) extracted lycopene from tomato using UMAE with 97.4 % yield within 6 min whereas ultrasonic assisted extraction process completed in 29 min with 89.4 % yield recovery for the same. UMAE is being used for extraction of variety of bioactive components such as vegetable oil, polysaccharides etc. (Chen et al., 2011). Wang and his team (2018) extracted essential oil from white and black peppers using ultrasonic microwave assisted extraction, microwave assisted extraction and ultrasonic assisted extraction and found that ultrasonic microwave extraction provided highest yield recovery.

Table 1: List of bioactive compounds which are extracted by using MAE

S. No.	Compound	Source	Optimum Conditions	Reference
1.	Quercetin	Onion skin	117 s, 69.7% ethanol	Jin et al., 2011
2.	Quercetin	Solid Onion	150s, pH 6.25, methanol	Kumar et al., 2014
3.	Polyphenols	Apple pomace	650W, 53.7s, 62.1% ethanol, 22.9:1 solvent to sample ratio	Rezaei et al. 2013
4.	Green coffee oil	Green coffee beans	10 min, 45°C	Tsukui et al., 2014
5.	Cotton seed oil	Cotton seed	3.57 min, 1:4(sample:solvent),	Taghvaei et al., 2014
6.	Polysaccharides	Mulberry Leaves	170W, 10 min, 20g sample,	Thirugnanasambandham et al., 2015
7.	Polyphenols	Mytrus Communis L. leaves	42% ethanol, 500W, 62s, 32:1 (solvent : material)	Dahmoune et al., 2014
8.	Phenolic compound	Rice grains	185°C, 1000W, 20min, 100% methanol, 10:1 solvent sample ration	Setyaningsih et al., 2015
9.	Phenolic compounds	Almond skin	100W, 60s, 4g sample, 60ml of 70% ethanol	Valdes et al., 2015

10.	Lycopene	Tomato peels	1600w, 15s	Ho et al., 2015
11.	Phenolics	Pomegranate peels	50% aqueous ethanol; solvent/solid ratio, 60/1 mL/g; power, 600 W	Kaderides et al., 2019
12.	Polyphenols	*Quercus* Bark	Power 45 W and irradiation time 60 min, pH 10.75, Solvent - 33% of ethanol and 0.38% of methanol	Bouras et al., 2015
13.	Phenolic compounds	Chardonnay grape	48% ethanol, 10 min extraction time, and 1.77 g solid mass	Garrido et al., 2019

4. CONCLUSIONS

Microwave assisted extraction technologies have gained remarkable research interest to evacuate bioactive components from food matrix. MAE process facilitates faster extraction as compare to traditional process with lower consumption of extraction solvent. Combination of ultrasonication with microwave amplifies the efficiency of extraction process. Modified MAE processes fulfill drawbacks of MAE as well as add additional features to the process such as higher extraction yield, less or no consumption of solvent, minimal degradation of components, rapidity and energy efficient. Hence, appropriate MAE technique can be used with specific operating conditions for extraction of bioactive compounds.

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