Chapter 9

Microwave-Assisted Green Extraction Technology for Sustainable Food Processing

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Additional information is available at the end of the chapter

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Abstract

Today, the relationship between the concepts of environment, food, society, and health are frequently examined. It is necessary for people to understand the process consciously from the time when the foodstuffs are procured to reach their hands in order to prepare healthy living conditions for them. Previously used techniques for the production of foodstuffs, although adequate in terms of yield, can hardly adapt to environmental criteria. Instead, green techniques are being used that provide savings both in time and energy and that nutrients in foods can be obtained without loss as much as in traditional techniques. Green technology is most obviously applied to extraction. Microwave-assisted extraction (MAE), which is known as a kind of green extraction technology, can be easily and innovatively compared with other extraction techniques. Within the scope of this study, the concept of sustainability in food production has been explained, and the traditional and new extraction techniques have been explained. As a new extraction technique, information about the types of green extraction method has been given, and explanations have been made to explain the definition, mechanism, application fields, advantages, and disadvantages of MAE technique.

Keywords: extraction, food process, green technology, microwave-assisted techniques, sustainability

1. Introduction

Food has a vital role in human's life. Increasing demand on food because of growing population of the world necessitates to change food production and consumption ways [1]. The idea of "sustainable development" or "sustainability" has become increasingly prominent across the globe, applied and discussed at the international and national level [2]. In this context, resources need to be used effectively for both food production and food consumption. For that reason, food industry officials have to become conscious on sustainable green food production and are researching alternative food processing techniques. There is an increasing public awareness of health, environment, and safety hazards associated with the use of organic solvents in food processing. High cost of organic solvents and increasingly stringent environmental regulations have pointed out the need for development of new and clean technologies for food product processing [3]. At this point, the importance of new and environmentally friendly techniques and their multidisciplinary combinations becomes noticeable. Those alternative techniques have been focused to acquire energy from various sources while controlling the emission rate as well as applying the limits on food safety and control. Among them, being a green technology, microwave-assisted extraction (as a side branch of extraction) has been proposed in a new promising way to produce inevitable variety of food production [4].

Microwave-assisted green extraction technology is a new promising warranty of alternative investment channels for innovative applications and scale-up processes. The possibility of using microwave-assisted technologies has received an increasing attention to develop new technologies for the production of materials or to substitute traditional technologies based on the use of organic solvents. This multidisciplinary synergy will allow scientists to develop products of standardized concentration of active ingredients and will simultaneously produce nutraceutical and pharmaceutical products of much higher concentration and quality than possible by conventional chemical engineering unit operations, such as liquid/liquid extraction, distillation, mechanical micronization, liquid- and/or gas-phase reactions, etc.

In the context of this chapter, the importance of microwave-assisted green extraction technology focusing on food examples will be introduced. Besides, while practicing production techniques about food, some technical expressions such as raw material selection, energy efficiency, resource and waste management, product valorization, fractionation, and analysis methods will also be explained in the framework of emerging microwave technologies' concept. To conclude, within the scope of this chapter, how to produce different foodstuffs or raw materials not only by classical methods but also by cooperation with different innovative techniques of microwave technology will be explained with examples of various food samples while providing theoretical background on food processes.

2. Sustainable food systems

It is an inevitable reality that food materials are necessary for the survival of life. In today's world, everybody is producing as much food as they can, but still 800 million people are starving. It is estimated that about 2 billion of the number are included with malnourished people. There can be many reasons for hunger. As well as environmental reasons such as soil and water deficiency and climate change, control of markets and food systems by companies, unfair income distribution, and prices can also create hunger [5]. The last half-century has been endeavoring to end the hunger and malnutrition of the world, to enable people to access healthy food and to produce food using sustainable technologies. It is obvious that the concepts of food,

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health, safety, and environment and the demographic and ethnic structure of the societies, as well as the lifestyle and social development levels of the societies, are mutually connotations. However, taking environmental considerations into consideration, it is essential to take important steps in order to apply green production principles, go beyond awareness in the awareness of the situation, and make food production based on sustainable bases.

According to the definition of the United Nations, sustainability is stated as "the ability of future generations to meet today's needs without jeopardizing their ability to meet their own needs" [6]. So, it can be defined and practiced in a way that today's social order will enable the living standards and business models to be used without damaging the possibilities of meeting the needs of future generations of resources that exist in nature. It is possible to classify the concept of sustainability as three-dimensional when going out from the definitions made. The factors that make up these dimensions can be grouped into three classes: social, economic, and ecological. The common goal for all factors is to solve current global problems.

Sustainability in food, which is the starting point of the food industry, is possible with adequate systems and applications to produce adequate and high-quality agricultural products at reasonable costs and to continuously improve the protection of agricultural land, farmers, and the environment and natural farming resources. Good sustainable food production practices are systems developed for this purpose. The concept of "sustainability" has gained importance because of the ever-increasing world population and increasing new resource requirements, rising energy prices, and climate changes caused by greenhouse gases. Environmental, social, and economic indicators can be taken into account as indicators of sustainability in food production.

It is generally known that sustainability has economic, social, and environmental dimensions. Sustainability in food is the system in which the social, economic, and environmental dimensions are taken into account in the process from the production to consumption of food. Processes such as the cooperation and cooperation of the civilian people or a group about food, forming their own structures, are defined as sustainable food systems [7]. These structures and processes include production, processing, distribution, wholesale and retail sales, consumption, and waste disposal. Sustainable food systems consist of producers' markets, producer-consumer cooperatives, community-supported agricultural systems, ecological markets, urban gardening, slow food systems, and food banks. The aims of sustainable food systems that have been developed in recent years in our country are defined as:

a. To promote adequate, nutritious, and healthy food access for all community members.

b. To support small family farming and ensure sustainable agricultural practices.

c. To provide direct connection between consumers and producers in processing and marketing processes.

d. To ensure the recycling of financial capital and to create business opportunities in food and agriculture-related enterprises.

e. To improve the working and living conditions of the workforce in the farm and food system.

f. To support local production, processing, and consumption.

The research shows that local products are sold in sustainable food systems and that products are produced by sustainable agricultural systems; thus, natural resources, especially local seeds, are protected. It is stated that the producers are actively involved, developing the producer and consumer interaction and increasing the solidarity. Provision of food safety and security in sustainable food systems, conservation and improvement of health, prevention of diseases, protection of nature, protection of agricultural biodiversity, strengthening of local and rural areas, and ensuring socioeconomic development are taken into consideration.

3. Extraction for food production

Among the methods used to obtain fast, accurate, and reliable results in food analyses, the first step is extraction process [8]. Extraction refers to the removal of another liquid phase by taking advantage of the different solubility characteristics of one or more compounds present in the solid or liquid phase [9]. The use of classical extraction methods such as Soxhlet, percolation, and steam distillation is very common in extraction stage [8]. Soxhlet extraction is the method that is frequently used in food extraction and analysis. However, the low efficiency in this method limits the use of the technique, which is low in the analysis and high in solvent consumption [10]. Taking all these conditions into account, the development of new extraction methods has been accelerated.

3.1. Traditional extraction techniques

Separation of a substance from two or multicomponent mixtures or the removal of undesirable impurities by solvent aid is called extraction. “Liquid-liquid extraction” is that if the mixture to be separated consists of liquid components. If a substance or group is to be separated from a solid material, this process is called “solid-liquid extraction.”

3.1.1. Liquid-liquid extraction

Liquid-liquid extraction is called separation by contacting a substance dissolved in the liquid solution with another liquid, which does not mix with the solution. The first application of this process is the extraction of gold and silver from the liquid copper by the Romans using lead as solvent.

A simple extraction process consists of three basic components: solute, carrier, and solvent. The part rich in the feed liquid separated from the extractant is called raffinate (aqueous phase), and the part rich in solvent is called the extract (organic phase).

Extraction is generally preferred over distillation in the following cases. These are:

a. The presence of dissolved or complexed inorganic substances in the solution

b. The desire to separate a very low concentration component

c. Separation of components which are very close to boiling or melting points

d. Separation of azeotrope-forming mixtures

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For example, water can be removed from acetic acid by distillation or liquid-liquid extraction using an organic solvent. Liquid-liquid extraction is used in the industrial separation of many mixtures. In the inorganic chemical industry, extraction is carried out at the removal of water from materials with high boiling points such as phosphoric acid, boric acid, and sodium hydroxide and organics containing hydrogen bonds such as formaldehyde.

3.1.2. Solid-liquid extraction

Solid-liquid extraction is called separation of one or more components contained in the solid with the aid of a bit solvent. The process can be considered in four stages:

a. The phase change of the solute phase and the solvent-phase flow.

b. Mechanical separation of the extract phase.

c. The separation of the solute from the extract phase.

d. The refined solvent is to be sent to the process.

Solid-liquid extraction is the process of separating sugar from sugar beet by means of hot water in a food industry; extracting oils from plants such as peanut, soybean, flaxseed, bean, and cottonseed through organic solvents such as hexane, acetone, and ether; and extracting oils of tea and fish from tea leaves to be used in different processes.

3.1.3. Solvent selection in extraction process

The most important key parameter in an effective extraction process is the choice of an appropriate solvent. "Similar solver" principle is used. In general, the following considerations are applied when choosing solvents:

a. Dispersion coefficient

b. Density and viscosity

c. Resolution

d. Selectivity

e. Surface tension between phases

f. Reusability

3.2. New green techniques for sustainable food production and processing

The efficient use of resources in different branches of the food industry and the maintenance of sustainability is a matter that has been on the move in recent times. At the same time as the use of renewable energy resources, the sector may be economically more advantageous in terms of product cost. Green technology can be applied in many important areas such as logistics, packaging, and waste disposal in food sector. The application of the green extraction technology, which has been particularly popular in recent years, to the food sector has been one of the important outputs of these researches. Extraction processes have also become commercially available in the fields of polymer technology, pharmaceutical industry, certain chemicals, and specialty oils. Products which cannot be obtained by conventional methods or which are difficult to obtain can be produced with high performance by this application. Such applications for environmentally friendly fluids offer significant potential for both technical and economic success. At present, there are many factors that are not paying attention to nutrition inevitably, and it is necessary to present an alternative by increasing the frequency of sharing meetings and by using new technological opportunities for consumers and using new technologies for healthy nutrition. Just as it is in green technology, it is a common view of the food industry that it is an important opportunity to emphasize that these studies have been successfully applied to agricultural products as a healthy alternative to food and that it is an opportunity to share new application fields as research models.

3.2.1. Supercritical extraction

Many food items are produced using different methods and are used after a number of separations [11]. It is also possible to use alterative techniques in conditions more suitable to the particular techniques utilized in production. The primary goal of the production and decomposition processes is to have a process that contributes to the people in production, to the manufacturing enterprises, to the sector, and even to the environment. For this reason, supercritical fluids (SCFs), which have become increasingly popular in the last 40 years, have become the focus of many different food production processes [12–14]. As a result, legal regulations on solvent residue limits in food products and environmental regulations on sector wastes have become widespread, increasing the use of SCFs.

SCFs have several advantages over the conditions provided in conventional methods. The most important advantage is that it allows for less solvent consumption and shorter processing times, as well as achieving dimensions that will not harm the environment in waste regimes. Another important feature of SCFs is that the dissolution power can be controlled by changing the density because the physicochemical properties are located between the gas and liquid phases. A small change in the pressure and/or temperature parameters can make a significant difference in the fluid density used and can increase the solving power by about 80–100 times. Materials with different polarities on this count can be processed by using only one type of SCF. This is due to the fact that the molecular diffusion rate of SCFs is as high as that of gases and the solubility density is as effective as liquids [15]. In parallel with the technological developments used in recent years, new materials and methods have been started to be used in the food processes that are progressing to start with raw material supply [16]. Supercritical extraction (SFE), microwave extraction (MWE), and ultrasonic extraction applications are the most well-known examples.

3.2.1.1. Definition and basic properties of supercritical fluids (SCFs)

SCF is defined as the fluid whose temperature and pressure values are above the critical temperature (Tc) and critical pressure (Pc) values. In other words, an element or a component can be defined as a mixture of Tc and Pc. Like a gas, it is a compressible flow that can take the

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form of a container and fill it. It is not a liquid, but has near-liquid density and solubility values (**Figure 1**). Tc and Pc values are different for each supercritical fluid. Tc and Pc values for carbon dioxide, one of the most common supercritical fluids, are 31.1°C and 7.38 MPa and 646.8°C and 22.06 MPa for water, another fluid. Controlled increase in temperature and pressure values brings these two parameters together at a common point called the "critical point." The said Tc and Pc values are the temperature and pressure values possessed at the critical point. When this point is reached, the solvent is described as SCF. The properties in the SCF region are a combination of the good solvency of the fluids and the good diffusivity of the gases (**Table 1**).

Different thermodynamic properties that SCFs exhibit at the critical point and near these points can be predicted with the aid of phase diagrams. From these approaches, different modeling and system optimization studies can be done on the way of engineering.

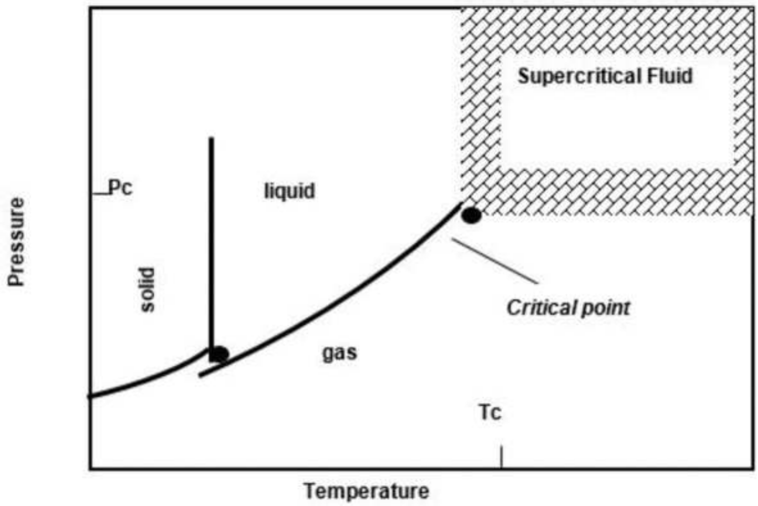

Figure 1. SCF temperature-pressure diagram.

Property	Gas	SCF	Liquid
Density (g/mL)	$(0.6–2) \times 10^{-3}$	0.2–1.0	0.6–1.6
Viscosity (g cm^{-1} s^{-1})	$(1–3) \times 10^{-3}$	$(1–9) \times 10^{-3}$	$(0.2–3) \times 10^{-2}$
Diffusivity (cm^2 s^{-1})	0.1–0.4	$(2–7) \times 10^{-4}$	$(0.2–2) \times 10^{-5}$
Surface tension (dynes cm^{-1})	0	0	30–60

Table 1. Properties of some fluids at critical conditions.

3.2.1.2. Application areas of supercritical fluid extraction (SFE) in food industry

SFE is an important alternative to traditional extraction methods. The SFE process can be carried out as a continuous and continuous process depending on the production capacity. In the extraction process, the food substance to be extracted is placed in the extraction cell located in the heating chamber. SCF fed to the system with the aid of a pump is brought to the desired pressure value according to the polarity and solubility characteristics of the target food material and reaches the appropriate temperature level corresponding to the pressure value with the help of the heating reservoir. At this time, the solvent is transported to subcritical or supercritical conditions, and the sample migrates to the extracellular medium contained in the food. Throughout the extraction period, the pressure value of the solvent leaving the extraction cell begins to decrease by interfering with the food and extracting the target material with the polarity appropriate to it. This liquid which is loaded with the target substance and which is in the properties of SCF passes through the liquid fascia by lowering the pressure and, preferably, depending on the desired temperature value. It is separated from the target substance extracted from the difference of boiling point and density due to the physicochemical property. It is then fed back to the system for reuse with the pump again (**Figure 2**).

The viscosity of the SCF is lower than the liquids, and the flow properties are good. Due to its low surface tension, it penetrates into food raw materials and increases extraction yield. The resolution values can be changed by adjusting the temperature-pressure values. Costs are low, solvents are used, and extraction does not leave waste as a result. Due to all these positive features, SFE operated using SCF has a wide use as a good example of green technology.

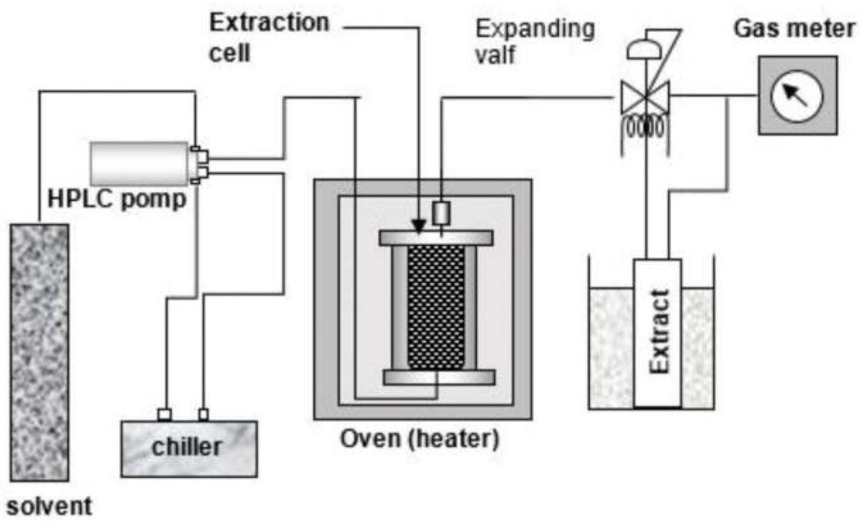

Figure 2. SFE system.

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SFE has been used commercially in the food industry for the first time to remove caffeine from coffee. In addition, spices are used to obtain important components from many foodstuffs such as aromatics, essential oils, medicinal plants, fruits and vegetables, and animal oils.

3.2.2. Ultrasound-assisted extraction

Ultrasonic sound waves are the sound waves on the level that the human ear can handle. Ultrasonic wave application is divided into two groups as low-energy and high-energy application in food industry. The amount of energy produced in this classification is the most important criterion and is defined by sound power (W), sound density (W/m^2), or sound energy density (W/m^3). Low-energy ultrasonic application is most commonly used to determine the physicochemical properties (rigidity, maturity, composition, particle size, acidity, etc.) of foods. High-energy ultrasonic application is used for microbial and enzymatic inactivation in food. High-energy ultrasonic application affects food physically, chemically, and mechanically, while low-energy ultrasonic application does not.

Ultrasound technique has been successfully used in food industry to determine chocolate content and eggshell thickness; to determine fat content; to determine lean tissue in meat; to determine contaminants such as metal, glass, or wood in food; and to determine food composition and particle size. In addition to these, it has been reported that it can be used as an alternative to traditional extraction methods in many studies such as extraction of phenolic compounds from the consortia, extraction of red and yellow pigments, extraction of fat and proteins from soybean, and oil extraction from oil seeds. Ultrasonic application increases the surface area between solid and liquid parts by decreasing particle diameter. The mechanical activity of the ultrasound accelerates the distribution of solvent toward the tissues. Because mechanically the cell wall is destroyed, the passage of the component to solvent, which is the solvent, will be facilitated. Ultrasonication also increases the extraction kinetics and the quality of the extract.

In recent years it has been reported that the combination of ultrasound and supercritical carbon dioxide application significantly increases the extraction efficiency. There are many more studies in which ultrasound techniques are used for extraction purposes.

3.2.3. Ohmic heating-assisted extraction

Ohmic heating is a process applied by the passage of electric current through the food. It is also known as joule heating, electric-heating and electrical resistance heating. Ohmic heating is achieved by the conversion of electrical energy into heat energy, depending on the electrical resistance of the glass. In other words, when food shows resistance against flow, heat formation is seen. The higher the electrical resistance of a food, the more homogeneous heating is achieved. Therefore, since the conductivity of solid materials is higher, if the process conditions are applied correctly, it will heat up faster than liquid materials. One of the advantages of ohmic heating is that it homogenizes food very quickly. It is very suitable for materials sensitive to heat since the hot zone does not occur on the surface during heating. Other important advantages of the system are its high product quality, silent operation, and its ability to be used in particulate matter. The success of ohmic heating depends primarily on the rate of heat production, the electrical conductivity of the food, the composition of the food, the intensity of the electric field, and the duration of the waiting period.

Preliminary treatment of rice brass raw materials and extraction of oils by solvent extraction are examples of studies in which ohmic heating systems are used as pretreatment in extraction processes. For food samples pretreated using ohmic heating method, the yield varied between 49 and 92%, while for non-pretreated samples, the yield was 53%.

3.2.4. Pulsed electric field extraction

Pulsed electric field (PEF) technology is a food preservation process that is based on the use of the electric field to eliminate food-borne pathogenic microorganisms and to control microorganisms that destroy food, is nonthermal, and does not adversely affect food quality. A typical PEF unit consists of a high-voltage boost generator, application chamber, flow control system, control, and monitor device. The most important one of these is the application chamber, and it must be treated with care during design.

The successful results of PEF technology in liquid foods (especially fruit juice, milk, etc.) are noteworthy and lead to the production of high-capacity systems. In the near future, it is known that in developed countries, high-quality products will be obtained by processing liquid and semiliquid foods with PEF technology. In this context, it will be inevitable that many countries will follow these developments as the result of the conjunctural changes that will take place in the competition of international food trade. For this purpose, attention should be paid to other disciplines (such as machinery, industry, electrical-electronics, materials, and food engineering) to produce PEF technology in our country. Initiation of studies on PEF technology, transmission, and dissemination of this technology in the industry will enable the technology to be produced by the domestic industry.

3.2.5. Microwave-assisted extraction

The use of microwave technology, which has been in use since the Second World War, in the analytical laboratory was at the end of the 1970s. Microwaves are electromagnetic radiation that varies in the range of 0.3–300 GHz and are usually extracted at 2.5–75 GHz in natural products. The efficiency of microwave energy depends largely on the content of the solvent, the plant material, and the applied microwave power. The advantage of microwave heating is the decomposition of oxidized weak hydrogen bonds at the poles of the molecules. Extraction with microwave is realized with two different systems. The most common system is the closed system extrusion made in a closed container that can control temperature and pressure. The other method is carried out in an open container under atmospheric pressure. The advantage of this method is that the amount of extraction and the amount of solvent used are largely small.

4. Process and procedure of microwave-assisted extraction

There are two mechanisms in microwave heating: dielectric conduction and ionic conduction. The principle in dielectric heating is to rearrange the molecules in the dipolar structure by rotation in the presence of electrical changes. The dipoles are arranged at 2450 MHz and distributed randomly at 4.9×10^9 times in the second. As a result of this motion, heat is generated by the vibration. In the ionic conduction mechanism, the magnetic field is generated by the movement of ions at the end of the application. The solvent heats up by friction resulting from the resistance of the solvent to the ion flux. In most applications, two mechanisms occur simultaneously.

The frequency, microwave power and heating speed, temperature, mass of food, water content, density, physical geometry, thermal properties, electrical conductivity, and dielectric properties of food are affected by microwave heating. Microwave, which has been used for various applications in food for many years, is also a preferred method for increasing extraction efficiency (**Table 2**). Contrary to classical heating, in the case of microwave heating, for example, all are heated uniformly and quickly at the same time. The cells are heated by microwave radiation by the moisture in them and apply pressure to the cell wall as a result of evaporation. The cell wall is disrupted by this high pressure, and the passage of the components to the solvent is ensured. One of the most important parameters in extraction process is solvent choice. Solvents with a larger dipole moment will heat up faster. According to the solvent dipole moments, acetonitrile, methanol, acetone, ethyl acetate, water, ethyl alcohol and hexane are the most commonly used solvents for phenolic substance extraction from plant source. The nonpolar solvent hexane (dipole moment <0.1) will not heat up in the microwave.

Microwave extraction is performed with two different systems (**Figure 3**). The most common system is the closed system extrusion made in a closed container that can control temperature and pressure. The other method is carried out in an open container under atmospheric pressure. The advantage of this method is that the amount of extraction and the amount of solvent used are small at large. The principle of heating using microwave energy is based on the direct effect of the microwave on the molecule through ion conduction and dipole rotation (rotation). In most applications, these two mechanisms come into play simultaneously. Ionic conduction is the electrophoretic migration of ions when a magnetic field is applied. The solution results in

Application	Purpose	Product
Tempering	Temperature rise below freezing point	Meat, fish, butter
Vacuum drying	Moisture content reduction	Seeds, cereals, citrus juices
Freeze drying	Moisture content reduction	Meat, vegetables, fruits
Drying	Moisture content reduction	Pasta, rice, snacks
Cooking	Aroma and texturing	Ham, meatballs, potatoes
Bleaching	Inactivation of impaired enzymes	Fruit, corn, potato
Baking	Heating and activation of bleaching agents	Bread, pasta, donut
Roasting	To develop heating and heating reactions	Coffee, cocoa, berries
Pasteurization	Inactivation of vegetative microorganism	Dairy products, ready-to-eat foods
Sterilization	Inactivation of microbial spores	Pastries, cheeses, milk, fruit juices

Table 2. Microwave applications in the food industry.

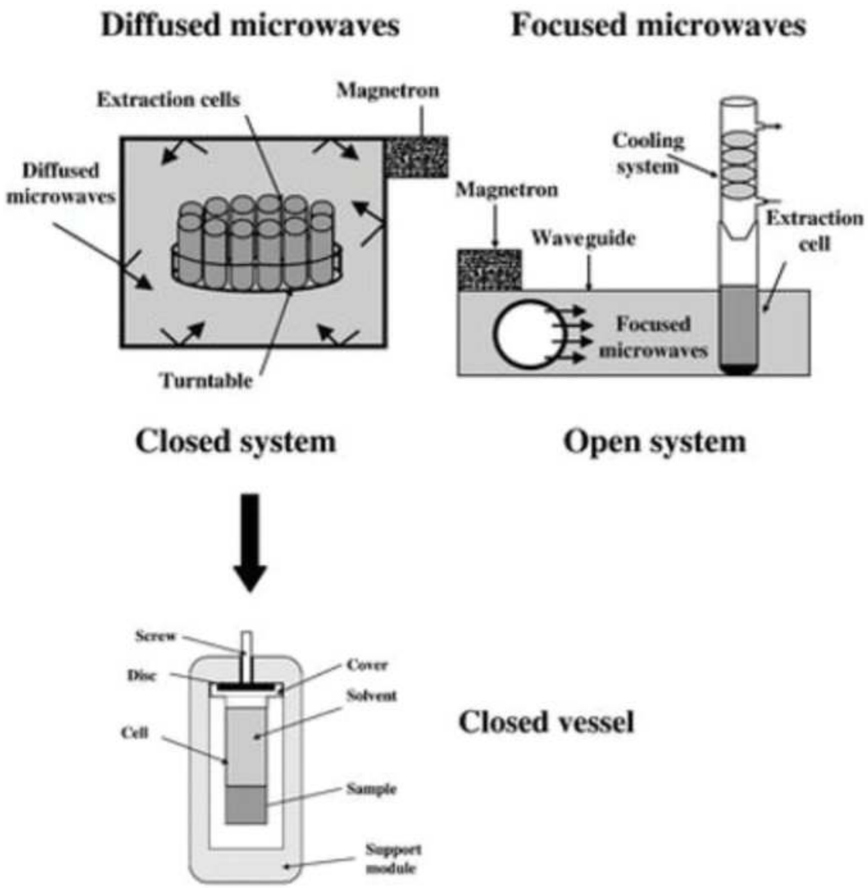

Figure 3. Schematic view of the microwave-assisted extraction system (closed system and open system).

a resistive friction (friction) to this ion flow, and thus the solution heats up. Extraction is usually carried out in a closed container. In this case the pressure increases, and the solvent can be heated to higher temperatures than the boiling point. For most solvents (such as acetone, acetone hexane, acetone), the temperature in the container is two to three times the boiling point of the solvent. Two main types of MAE systems can be used: closed-vessel system (under controlled temperature and pressure) and open-vessel system (atmospheric temperature). Both systems and MAE apparatus (DKSH Australia Pty. Ltd.) are shown in **Figures 3** and **4**, respectively.

While the cells are being irradiated simultaneously in the closed-vessel system, the vessels are successively irradiated in the open system. In open vessels the temperature is limited by the atmospheric pressure boiling point of the solvent, while in closed vessels, the temperature can be increased by the applied pressure. The closed container system seems to be most

Figure 4. MAE apparatus.

appropriate if it is a fugitive compound. However, in closed containers it is necessary to wait for the temperature to fall before opening the container after extraction. The main difference is the heat. The extraction process begins with the extraction cell being loaded, for example. Microwave radiation is applied, and the pre-extraction step is started to heat the solvent to the set values. Normally, heating takes less than 2 min. The specimen is then irradiated and generally extracted at intervals of 10–30 min [17–19].

The advantages of microwave-assisted extraction are reduction in solvent consumption, increase in extraction efficiency, high recovery, ease of use and low cost, wide solvent, and solvent blends. The disadvantages are that if the target component or solvent is polar or volatile, the efficiency of the microwave is too weak, and it is applied at high temperatures such as 110–150°C, which requires additional filtration or centrifugation to separate the solids as compared to supercritical fluid extraction.

5. Applications of MAE as a green extraction technique in food industry

MAE is usually used in environmental analyses. Extraction of polyaromatic hydrocarbons, polychlorobiphenyls, and organochlorine pesticides from matrices such as sediment and soil has been studied. MAE has also been applied to food analyses. Extraction of 16 organochlorine insecticides in sesame seeds, use of microwave confinement in drug extraction from seed, and extraction and testing of lidocaine, methadone, diazepam, nordiazepam, proxifene, and norproxifen materials as model medicines are the main applications in which the MAE technique is used. At the same time, extraction of natural products such as drugs (pentobarbital, ketamine, diazepam); extraction from skeletal tissues; extraction of natural products such as terpenes, alkaloids, volatile oils, and carotenoids; extraction of color pigments in the paprika; identification of pesticide residues in sunflower seeds; discovery of a rapid method using dichloromethane solvent; and applications such as rapid extraction of aromatic hydrocarbons are examples of other applications that can be given for MAE technique. The irradiation power, time, number of revolutions, and solvent volume among the MAE method parameters can be optimized using experimental design methodology [20]. Examples of food industry that can be given to microwave-assisted extractions are very diverse and are summarized in general as the following, diversified by explaining the study title and scope:

a. Supercritical carbon dioxide and microwave-assisted extraction of functional lipophilic compounds from *Arthrospira platensis*: The study investigated the effect of extraction parameters on lipophilic material content in the extracts obtained by using SFE and MAE methods. Pressure and temperature in the study were 45 MPa and 60°C, respectively. When the cosolvent is used at 53.33% of CO_2 ratio, the highest amount of extracts was obtained. In case of MAE extraction, the most efficient experimental condition was obtained at 400 W and 50°C [21].

b. Green extraction from pomegranate marcs for the production of functional foods and cosmetics: The aim of the study was to investigate the potential of retrieving polyphenolic antioxidants by green extractions directly from wet pomegranate juice marcs, the fresh edible by-products obtained after pomegranate juice processing. Green extraction was performed below 50°C, microwave-assisted extraction (MAE) was done below 300 W, and ultrasound-assisted extraction (UAE) was operated with the output of 200 W. Each technique has been efficient in obtaining different foodstuffs [22].

c. Applications of green extraction of phytochemicals from fruit and vegetables: This study compared the conventional methods for extraction with the new methods that are called green extraction techniques and for recovery of phytochemicals and natural compounds (phenolic compounds, ascorbic acid, carotenoids, aroma compounds, etc.) obtained from plant materials [23].

d. Novel eco-friendly techniques for extraction of food-based lipophilic compounds from biological materials: This study investigated the various possible novel eco-friendly extraction methods, their scientific concepts, principles, challenges, limitations, and technological effort needed for successful implementation at the production scale [24].

e. Phenolic compound recovery from grape fruit and by-products: Several convectional and emerging technologies (including MAE) have been evaluated in order to recover phenolic compounds from grape fruits and wastes such as chemical, physical, and biotechnological techniques, which offer different advantages related to economic, environmental, time-saving, and yield aspects [25].

f. Microwave-assisted extraction of free amino acids from foods: In this study the use of microwave energy to assist extraction of amino acids from foods is presented. This method is compared with shaking extraction, and the effects of various experimental conditions on the extraction yield are tested (irradiation time, temperature, extractant volume, mixing, etc.) in order to determine the optimum extraction conditions. The efficiency of extraction gave better results for MAE by 10%, and the extraction time was reduced by 66% [26].

g. Microwave-assisted extraction of flavonoids: This study investigated the MAE mechanism and exerts the key points that bring advantage in extraction [27].

h. Microwave-assisted extraction of anthocyanin from Chinese bayberry and its effects on anthocyanin stability: The study used MAE to extract antioxidant compounds from Chinese bayberry at 80°C for 15 min. The results for anthocyanin content and antioxidant activity were obtained as 2.95 ± 0.08 $mg \cdot g^{-1}$ and as 279.96 ± 0.1 μmol g^{-1}, respectively. So, MAE showed an important potential to recover bioactive compounds [28].

i. Microwave-assisted extraction of pectin from jackfruit rinds using different power levels: Since conventional extraction of pectin is time-consuming (1 h), this study focused on the use of MAE to recover pectin from fruit material (10 min). The experiments were done at 90°C for conventional method, and three different power levels of 450, 600, and 800 W were used for MAE. The highest efficiency was obtained at 450 W power [29].

j. Optimization of microwave-assisted extraction of ergosterol from *Agaricus bisporus* L. by-products using response surface methodology: The study compared MAE with conventional methods for time and solvent consumption. MAE was efficient where conventional methods were inappropriate. Ergosterol component was best extracted at around 19.4±2.9 min and at around 132.8±12.4 C yielding 556.1±26.2 mg of extract [30].

k. Microwave-assisted extraction of phenolic compounds from olive leaves—a comparison wıth maceration: The purpose of the study was to extract phenolic compounds from olive leaves of with MAE methods using different solvents. Among the solvents used, ethanol was the most efficient where acetone was the least. The highest extraction yield was obtained at 24 h with conventional method, while it was obtained at 15 min with MAE method [31].

l. Extraction of phenolic compounds from melissa using microwave and ultrasound: The comparison of microwave and ultrasound has been studied for the extraction of essential oils from melissa. Extraction time and solid-to-solvent ratio were investigated for recovery of total phenolic compounds (TPC). Recovery rate for TPC was 145.8 mg extract/dry matter using MAE in 80% power rate where the yield was 105.5 mg extract/dry matter in 50% power rate [32].

6. Advantages and disadvantages of MAE

MAE process efficiency is dependent on various extraction parameters. These parameters can be counted as the nature of raw material, strength and level of microwave irradiation, extraction time, extraction pressure, and solvent flow rate. In the extraction process where the heat-labile compounds have to be recovered, lower levels of irradiation may bring lower efficiency because sensitive component recovery effectiveness may be decreased due to high microwave power levels. Extraction time is also important that is acts together with the microwave power. Even if the same amount of microwave power is used, if a raw material is extruded for a longer period, the yield will definitely be lower. Because the liminal structure of the material will

Open-vessel system		Closed-vessel system	
Advantages	**Disadvantages**	**Advantages**	**Disadvantages**
Enhanced and safer possibility of reagent addition	Comparatively exhibit less precision than in close-vessel system	Higher temperature and constraints of closed vessel system render reduced extraction time	Application of high pressure poses safety risks
Utilization of vessel manufactured from various materials, that is, quartz or glass	Inability to process multiple samples simultaneously due to low throughput of equipment	Avoidance of loss of volatile substances	High-solution temperature is not permissible by constituent material of vessel
Easy removal of excessive quantities of employed solvents	Longer time spans are required than closed-vessel system	Less solvent requirement due to the absence of evaporation phenomenon	Impossibility of regent addition since it is single-step process
Easy processing of larger samples volumes	—	No production of hazardous fumes during pressurized extraction under closed-vessel system	Constraint of cooling down vessel before opening rendering prevention of volatile constituents
No need of operational cooling down or depressurization	—	High yield by using ionic liquids at ambient temperature	Handling and processing of limited sample volumes
Cost-effective availability of sophisticated equipment for polyphenol extraction	—	Simple procedural setup without any inherent complexity as compared to SFE and other techniques	Requirement of cooling step after each treatment for further processing

Table 3. Advantages and disadvantages of MAE depending on the operating systems.

deteriorate over time and gradually lose its originality. In this case, especially the structure of the food material or the preparation before extraction will enter the circuit. Of course, the preparation of the foodstuff or the preparation before extraction is particularly important here. Because the structure of a solid material is tighter, the solvent that extracts may not penetrate into every cell. Rather, it is possible to obtain a higher extraction yield than the granular or powdery sample forms in order to increase the food-solvent interaction. All this facts are considered together with the correct solvent selection and effect of external forces.

Although the process parameters are well combined, even if the sample material is carefully chosen, it will have disadvantages as well as the advantages provided by the MAE technique. **Table 3** summarizes the advantages and disadvantages of the MAE technique for using open-vessel and closed-vessel systems [33].

7. Conclusion

For many years, various extraction techniques have been used to recover organic and/or inorganic compounds from food materials. But referring to their positive and negative effects and when they are compared to modern techniques, traditional extraction methods have been assigned to be inadequate in terms of green technology applications and waste of time/money, etc. However, there may be strict regulations about the use and recycling of solvents that are used in conventional techniques. In addition, thermal degradation of organic materials may occur due to the long extractions at elevated temperature. Many extraction studies could not be carried to further innovative applications because of using the area of expertise to only extract and to only characterize the extracted compounds from food materials. In later periods, researchers have started to investigate the possible ways to make optimization studies being related to extraction and to collaborate by exerting multidisciplinary studies to test the synergy between the extraction modules. So, being one of the green extraction methods, microwave-assisted extraction has many advantages of being cheap and safe and is applicable to a wide range of food materials [2, 3, 11]. This emerging technique uses the advantages of diffusivity of solvents being close to gases and being at least two orders of magnitude larger than liquids. By exploiting the advantage of the microwave-assisted extraction system and observing the basic principles of the extraction system, the current study has conveyed the information on the operation and industrial usage of extraction. The current status of the method gives a promising sign for the use of green extraction in the food industry, and it can be evaluated as convenient to be scaled up and to be transferred to other disciplines such as pharmacy, chemistry, medicine, materials science, etc.

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