A Comprehensive Review on Valuable Components in Food Processing Waste and Their Recovery by Microwave Assisted Extraction

Gıda İşleme Atıklarındaki Değerli Bileşenler ve Mikrodalga Destekli Ekstraksiyon ile Bunların Geri Kazanımları Üzerine Kapsamlı Bir Derleme

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ABSTRACT

In the food industry, huge amounts of waste or by-products are generated during the processing of them. Reutilizing and reducing food waste is essential for both environmental concerns and food security. Food wastes are generally rich in components that can be converted into valuable bioproducts such as bioactive compounds, natural pigments, biochemicals, enzymes, and biofuels. Extraction of these compounds from the waste is a common practice to gain them. In this respect, microwave-assisted extraction (MASE) has been addressed as an efficient and environmentally friendly method compared to traditional ones due to its rapid volumetric heating ability. When MASE is operated in a closed vessel it helps to reach a higher temperature than the boiling point of the solvent and accelerates the mass transfer. Therefore, even components that are difficult to extract can be easily extracted in a few minutes. The present review compiles the potential valuable components present in food waste and gives a brief theoretical background on the fundamentals of microwave heating. It also summarizes recent studies on microwave-assisted extraction of valuable components from food waste. The impact of MASE on the quality attributes of extract, as well as the benefits in terms of processing parameters are discussed. The information presented in the review will assist food processors in choosing the appropriate extraction methods during the food waste valorization.

Keywords: Food waste, microwave assisted extraction, by-products, value-added components

ÖZET

Gıda endüstrisinde, gıda işleme sırasında büyük miktarda atık ya da yan ürünler ortaya çıkmaktadır. Gıda atıklarının yeniden kullanılması ve azaltılması hem çevre hem de gıda güvenliği için oldukça önemlidir. Gıda atıkları genellikle biyoaktif bileşikler, doğal pigmentler, biyokimyasallar, enzimler ve biyoyakıtlar gibi değerli ürünlere dönüştürülebilen bileşenler bakımından zengindir. Bu bileşiklerin atıklardan ekstraksiyonu, bu değerli bileşenleri elde etmek için yaygın bir uygulamadır. Bu bağlamda mikrodalga destekli ekstraksiyon (MASE), hızlı hacimsel ısıtma özelliğinden dolayı geleneksel yöntemlere göre verimli ve çevre dostu bir ektraksiyon yöntemi olarak ele alınmaktadır. MASE kapalı bir kapta çalıştırıldığında, çözücünün kaynama noktasından daha yüksek bir sıcaklığa ulaşmasını sağlayarak kütle transferini hızlandırmaktadır. Bu nedenle, elde edilmesi zor bileşenler bile birkaç dakika içinde kolayca ekstrakte edilebilmektedir. Bu derleme, gıda atıklarında bulunan katma değerli bileşenler ve mikrodalga ısıtmanın temelleri hakkında kısa bir teorik bilgi sunmaktadır. Ayrıca, mikrodalga destekli ekstraksiyonu ile gıda atıklarından elde edilen değerli bileşenler üzerine yapılan son çalışmaları da özetlemektedir. MASE'nin ekstraktın kalite özellikleri üzerindeki etkisinin yanı sıra işlem parametreleri açısından faydaları tartışılmaktadır. Derlemede sunulan bilgiler, gıda atıklarının değerlendirilmesi sırasında uygun ekstraksiyon yöntemlerini seçmede gıda işleyicilerine yardımcı olacaktır.

Anahtar Kelimeler: Gıda atığı, mikrodalga destekli ekstraksiyon, yan ürünler, katma değerli bileşenler

1. INTRODUCTION

Food waste and losses occur during harvesting, production, transportation and consumption stage of food chain. Huge amount of lquid, solid or semi solid waste consisting mainly pomace, peel, cut pieces, seed etc are generated in food processing line due to FAO in 2011 reported that about 1.3 million of the world's food was lost before even reaching the market (FAO (2011)). Valorization of food waste in necessity not only to ensure food security but also for environmental and economical concerns.

Food waste coming from different food sectors is in different constituents and forms. For instance, fruits and vegetable waste are rich in bioactive compounds such as antioxidants, phenolic acids, flavonoids, carotenoids, pectin, etc. On the other hand, animal-origin by-products are rich in collagen, natural pigments, omega fatty acids, chitin, chitosan, proteins, peptides, and calcium. Grain processing wastes are rich in pectin, proteins, citric acid, fibers, cellulose, hemicellulose and lignin. These valuable components can be recovered to be used in the food, pharmaceutical, and cosmetic industry.

Therefore, green and effective methods should be developed to recover bioactive components from food wastes. Among the various extraction technologies, microwave assisted solvent extraction (MASE) stands out with its superior features, especially with its short processing time. MASE provides an effective extraction by rapid heating the extraction solvent and/or sample to high temperatures. Therefore, MASE provides energy savings, low solvent requirements and high productivity compared to traditional heating methods.

The performance of MASE depends on several parameters like sample matrix, its chemical structure and process parameters including solvent, pressure, time and temperature (Azmir, et al. 2013). MASE has recently been succesfully used for extraction of phenolic compounds from tea residues (Tsubaki, et al. 2010), pectin from orange peel (Maran, et al. 2013), carotenoid from carrot processing waste (Elik, et al. 2020), gelatin from duck skin (Kim, et al. 2020), fermentable sugar from canola straw (Agu, et al. 2017), and oligosaccharides from lotus seed (Lu, et al. 2017).

The present study aimed to provide a review on valuable components present in food waste, give a brief theoritical knowledge on MASE and to summarize recent developments on extraction of valuable compounds from food industry waste.

2. VALUABLE COMPONENTS in FOOD WASTE

Food waste consists of valuable components resulting along production and supply chains, including post-harvest losses. Food waste or by-products from different food sectors can be categorized into two groups of plant and animal origin. The plant originated wastes are generally rich in carbohydrates, protein, fat, vitamin and bioactive components whereas proteins, minerals, natural pigments, fatty acids, gelatin and etc. are important components originated from animal wastes.

2.1 Plant-Based Wastes

Cereals

Cereal grains have the largest share in food industry among other sectors. Straw (wheat, barley, oat, rice, rye, sorghum etc.) and stalk (corn, cotton, sunflower, tobacco etc.) are by-products formed from grains and are generally used for animal feed. However they can be converted into value-added products because of their richness in cellulose, hemicellulose and lignin. Bran and germ are wastes that are known with high protein, mineral, and vitamin, released during grain processes and the amount and content of these wastes vary according to the process applied. Bran has high dietary fibers, lipids, minerals, B and E vitamins. Among cereal-derived waste, rice bran, one of the by-products emerged during rice production, is known as high in dieatery fibers and antioxidant characteristics. This by-product affects the functional and textural properties of the foods (bread, cake, noodle, ice-cream etc.) added (Helkar, et al. 2016). Likewise, rice husk is the major by-product generated from rice milling and has been reported that it has higher antioxidant capacity compared to fruits and grains (Gao, et al. 2018). In addition, semolina flour is a by-product coming out during semolina production and also very rich in protein (14-16%) and starch (65%) (Kılıç, 1999). The brewing industries produce million tones of spent grain which is the main waste from brewery industry, has a lignocellulosic form and contains high polysaccarids and polyphenols especially phenolic acids (Moreira, et al. 2012).

Legumes

Legumes are the most consumed food product after grains. The production steps of the legumes consist of peeling, puffing, grinding and slicing and several by-products coming out during production are broken grains, powder products, husk and other residues that contain high carbohydrates, dietary fibers, vitamins, minerals and phytochemicals (polyphenols, flavonoids and phytosterols). There are several researches associated with the extraction of bioactive components, the production of the dietary fibers, the production of the legume flour and the production of protein concentration by purification of proteins in legumes (Mullen, et al. 2015). Because of their richness in proteins, demand in food industry for implementing the by-products of the legumes as a meat alternative source has increased significantly not only targeting vegetarians or vegans but also addressing non-vegetarians. Therefore, other types of wastes from legumes such as pea and bean flours has been used in gluten-free snacks and breakfast cereals due to their health benefits, low cost, availability and nutritional value (Boukid, 2021). Niño-Medina, et al. (2017) reported that soybean and chickpea hulls can be used as dietary fibers and phenolic compounds sources.

Root and tubers

When processing roots and tubers, a large amount of waste rich in valuable components is produced. The production of the potato is estimated around 2 million tones globally thus accumulating considerable amounts of the wastes during processing every year. Potato peel, potato slicing waste, potato wastewater and broken chips particles are some of the waste resulting from the potato processing industry. Among these wastes, potato peel is particularly rich in phenolic components. The phenolic acids (clorogenic acid, cafeic acid, pherulic acid, p-cumaric acid, siringic acid, vailic acid, sinapic acid and salicilic acid) and flavonoids (flavanols, flavonols, and anthocyanins) present in peel can be extracted to be used as an natural alternatives in food industry (Akyol, et al. 2016). Besides its phenolic compounds, potato is very rich in dietary fibres (50%) which are very beneficial for human health, and also contains amino acids, minerals, and vitamins (Sharma, et al. 2016; Venturi, et al. 2019). Additionally, the potato peel was used for several applications such as a substrate for some enzymes, mannanase (Mona and Amani 2008), α-amylase

(Ikram-Ul-Haq, et al. 2012), and polyphenol oxidase (Niphadkar and Rathod 2015). Sweet potato residues from starch production can be used to extract the pectin (Zhang, et al. 2013). From the cassava flour production processes, peel and husk are formed as cassava residues. Cassava bagasse revealed during the sieving or straining stage, has been utilized as a sole carbon source to produce fumaric acid by *Rhizopus* strains (Osorio, et al. 2021).

Vegetables and fruits

According to FAO (FAO 2021), vegetable production was 1 billion 89 million tons in 2018 whereas fruits production reached 868 million in the world, inevitably leds to large amounts of wastes and by-products from agriculture and agri-food processing industry.

Drying, juice production, jam production, frozen fruit and vegetables processing, pickles, cans, marmelade processings and spreads productions are common applications for fruit and vegetable industry. Solid and liquid residues containing a rich composition of dietary fibres, antioxidants, carbohydrates (fructose, glucose and saccarose), pectin, fatty acids and vitamins are generated during fruits and vegetables processings. For example, peels and seeds from the wastage are rich in phytochemicals allowing them to be used as flavoring agents and preservation compounds. Likewise, the vegetal tissues containing high amount of carotenoids, vitamins, and fibres are great sources to avoid human disease and disorders thanks to their capacity of antioxidants and antidiabetics (Ganesh, et al. 2022).

In citrus juice production, a half of the citrus is disposed as by-products. The production of pectin, limonen, flavour components, monosaccharids, and cellulose from the citrus wastes have been patented by Clark (2016). Besides these compounds, essential oils are also valuable components in citrus by-products used as flavoring ingredients for beverages, ice cream and other food products as well as being utilized in pharmaceuticals due to their effect of antiflamatuary and antibacterial properties (Boukroufa, et al. 2015). There are several studies about pectin production from citrut peel, banana peel, mango peel, apple pomace, sugar beet, passion fruit peel, watermelon waste, and pomegranate rind (Wang, et al. 2007, Masmoudi, et al. 2008, Cho, et al. 2019). Grape pomace produced in wine industry is another source of polyphenols (phenolic acids, anthocyanins, and flavanols) and having potential to be utilised in fruit juice as a colourant (Allison and Simmons 2018). Grape seed consists of high antioxidant and vitamin E (tocopherols and tocotrienols) which have benefical effects for human health (Barba, et al. 2016). Tomato by-products particularly tomato peels known with its high lycopene content (Choudhari and Ananthanarayan 2007).

Olive pomace is a by-product of olive oil industry. It consists of wastewater, seed and shell and contains up to 8% oil depending on the extraction methods. Olive pomace is rich in polyphenols, fatty acids, pigments, tocopherols, and phytosterols. Milutinović, et al. (2015) studied the phenolic composition of the olive pomace due to its antioxidant, neurosedative, anti-flammatory, antiviral, and anticancer properties. Additionally, there are plenty of studies in the extraction of the phenolics from olive pomace using different methods. For instance, Cea Pavez, et al. (2019) were reported high phenolic components in the extract obtained using pressured water. Goldsmith, et al. (2018) on the other hand, were used ultrasond to extract phenolics from olive pomace.

By-products from other plant-based waste

There has been large quantities of waste from other plant-based products discarded at every point along the food chain and households. Coffee processing systems can accumulate valuable residues such as cofffe cut-steams, coffee silverskin, spent coffee grounds, coffee pulp, and coffee husk which are higher with carbohydrates, proteins, pectins and bioactive compounds (Aristizábal-Marulanda, et al. 2017, Dadi, et al. 2018). Spent coffee ground is generated after brewing from coffee machines by homemade or manufactures. This by-product is rich in lipids (palmitic and linoleic acids) and vitamin E, thus can be used as liposoluble antioxidant vitamins. Immature and defective beans are sorted out during coffee harvesting and roasting processing to keep the quality of the coffee. These waste is rich in free amino acids and phenols. Therefore, they might be considered as a potential for the extraction of chlorogenic acid and caffeine in food and pharmaceutical industry. Coffee silverskin is also a possibility of the use as an antioxidant with content of melanoidins. In addition, coffee husk forms the outmost part which covers coffee bean, mucilage and silverskin, consisting of lignocellulosic polymers (cellulose, hemicellulose and lignin) thereby it has high potentiol to be used in food industry such as diet beverages, diet bread and biscuits (Hoseini, et al. 2021). Martinez-Saez, et al. (2014) studied coffee silverskin as an alternative body weight control beverage. They produced a beverage containing caffeine and chlorogenic acid using coffee silverskin, and it showed a significant impact on antioxidant activity. On the other hand, coffee silverskin was used for biofuels production such as biobutanol (Niglio, et al. 2019) and ethanol (Mussatto, et al. 2012) since it contains considerable amounts of carbohydrates and lignin. Coffee pulp contains phenolic acids, flavan-3-ols, hydroxycinnamic acids, flavonols, and anthocyanidins. Likewise, there has been wide researches on the phenolic compounds of coffee pulp (Ramirez-Coronel, et al. 2004; Farah and Donangelo 2006). In another study the antioxidant activity of spent coffee grounds and coffee husks has been evaluated. Coffee husks showed greater activity compared to spent coffee grounds. In addition, in this study, caffeine and chlorogenic acid were obtained from coffee husk using supercritical extraction (Andrade, et al. 2012).

During cocoa production, cocoa pod husk, cocoa bean shells and cocoa mucilage are produced as by-products. There are different applications of cocoa pod husk for various purposes. Martínez, et al. (2012) studied cocoa co-products (cocoa pod husk, cocoa bean shell and cocoa mucilage) as a natural compound and found that these by-products were superior in antioxidant activity. Cocoa pod husk is also a great source of pectin, lignocellusic biomass, antioxidant capacity, energy production, and activated carbon. Sarmiento-Vásquez, et al. (2021) extracted fermentable sugars from cocoa pod husk to produce propionic acid. In other study, cocoa pod husk was used to investigate its possibility as a pectin source and findings showed that it was as productive as sugar-beet pulp pectin (Yapo and Koffi 2013). Cocoa bean shells, another by-product from cocoa or chocolate processing, are composed of 10%-17% of the total cocoa bean. Cocoa bean shells are rich in dietary fibers together with higher content of bioactive compounds such as polyphenols (Rojo-Poveda, et al. 2020). Barbosa-Pereira, et al. (2018) used pulsed electric field to extract polyphenols and methlyxanthines from cocoa bean shells and coffee silverskin and concluded that bioactive compounds were 20% more than those used by conventional extraction method. Cocoa mucilage is the whitish part which covers the cocoa bean, is used for alcohol production, vinegar, juice, citric acid, and cocoa jelly production. It consists of 10–14% fermentable sugars such as sucrose, glucose, and fructose, nutrients, pectin, proteins, citric acid, fibers, cellulose, hemicellulose, and lignin (Rojasa, et al. 2020, Mendoza-Meneses, et al. 2021). Delgado-Noboa, et al. (2021) reported that cocoa mucilage had a great potential for production of bioethanol using *Saccharomyces cerevisiae* yeast.

Tea is the one of the most consumed and popular beverages around the World. Tea waste is a lignocellulosic biomass composed of cellulose, hemicellulose, lignin, polyphenols, proteins and tannins. This waste consists of as same amounts of bioactive compounds as regular tea. Pruned leaves and branches of tea are wastes produced by tea processing and can be used because of its high content of cellulose, holocellulose, lignin and bioactive compounds. Likewise, tea leftover after infusion are also great source of bioactive compounds (Debnath, et al. 2021) In a study, tea waste was used for bio-fuel production (Uzun, et al. 2010) and for biogas production (Yadav, et al. 2016) due to higher lignin content.

2.2 Animal-Based Wastes

Meat products

Meat and meat-products cover an important part within the food industry. Different by-products of meat processing such as blood, fatty tissues, protein, bones, skin, etc. arise mainly during the slaughter of animals. Among several animal originated waste, blood is the major by-product in slaughterhouses and also rich in proteins such as albumin and fibrinojen. The application of the blood proteins have been widely studied for their nutritional value and functional properties, but today the use of the blood from meat is still a challenge with their limitations when implementing as a protein source in the food products. Out of the protein characteristics, the meat by-products are also high in lipids, fibres, and carbohydrates which have the possibility of using for biogas production along with reducing greenhouse emissions (Mofijur, et al. 2021). Collagen is another important content in the blood. Vidal, et al. (2020) investigated that 18% of collagen recovered from small cattle slaughtered residues. The collagen obtained from lamb showed higher foaming property compared to the collagen in sheep blood whereas viscosity was higher in the sheep blood. Chicken by-products can also be a source of gelatin, functional proteins, etc. Santana, et al. (2020) used the feet of chickens to gain gelatin and contrast to commerical gelatin, found that the gelatin produced from the chicken waste was selected in terms of sensory aspects. They also revealed that films prepared using the gelatin from chicken residues were similar to those commerical ingredients such as cellophane and latex.

Seafood products

Fish, marine animals and mollusks result in considerable amounts of waste or by-products (around 25-30% of total weight) during processing, production and storage. These by-products contains high amounts of collagen, natural pigments, fatty acids, chitin, chitosan, proteins, peptids, and calcium, are mainly used for animal feed, collagen and oil production. Therefore, these high value-added compounds are recovered by different methods to be utilised in various sectors such as pharmaceutical industries, cosmetic industries, and food industries. Due to their richness in polyunsaturated fatty acids, their applications are immense. Some fish and shellfish by-products are rich in carotenoids. Marine by-products (bones and shells) are also great sources of calcium Additionally, the residues of the marine products are the source for the extraction of some enzymes. Shrimp shell can be used as a natural colorant and is also rich in vitamin E (Helkar, et al. 2016). Shrimp shell contains chitin and protein as well. Chitin and chitosan derived from chitin or its derivatives have antimicrobial, antitumor, antioxidant, antimutagenic, and cholestrol-lowering properties due to their biodegradability, thus can be used in various applications such as food industry, pharmaceutical, and cosmetic industries (Racioppo, et al. 2021). On the other hand, shrimp residues rich in biactive compounds such as astaxanthin, are basically used to feed animal in the aquaculture farms (El-Bialy and Abd El-Khalek 2020). High amounts of proteins in the seafood being extracted from bones, viscera, liver, kidney, eggs, and skin by enzymatic or biological hydrolysis are more valuable than plant-based proteins and are great source for food supplements (Racioppo, et al. 2021).

Dairy products

Dairy production system is the largest part of the food industy among others. Large amounts of by-products are created during milk, cheese, yoghurt, butter and other dairy productions. Basically, casein and whey proteins form milk proteins. Whey, known as the most popular substrate, generated by cheese production is rich in both proteins and lactose and is used directly or indirectly in various food operations. Thanks to antimicrobial properties of lactoferrin against gram-positive or gram-negative bacteria, yeasts, viruses, etc., is one of the whey proteins obtained from cheese residues considered as a valuable biactive compound (Dinika, et al. 2020). Lactose is the main carbohydrate in the milk, for example, utilised in the food applications and is also transformed chemically, enzymatically, or microbiologically into galacto-oligosaccharides, lactulose, lactitol, lactobionic acid, hydrolyzed lactose, and tagatose. Fresh milk is centrifuged to remove impurities before processing, after the process remarkably high nutritional value of lees emerges that can be used for different purposes. Skimmilk, buttermilk and ghee are also produced during the manufacture of dairy products. Skim milk, a by-product of whipped cream production, functions as a moisture retainer in the standardization process in milk production or in spray drying. It consists of high non-fat solids (lactose and protein) and nutritional components used in the formulation of food products, fat-filled production, the content of protein standardization (Oliveira, et al. 2019). Among others, casein is the major protein in milk and total 80% of casein present in bovine, buffalo, caprine, or ovine milk particularly used in food and beverages applications. There is a wide range of study for the extraction of bioactive compounds from dairy industry side-streams. For instance, Silva and Hiibel (2021) studied dairy by-products to exract phosphorus and nitrogen by hydrothermal carbonization and membrane distillation. A possibility of obtaining nutritional components from whey occured during dairy production has been performed by ultrafiltration in several research studies (Atra, et al. 2005, Baldasso, et al. 2011, Iltchenco, et al. 2018).

3. BASIC PRINCIPLES OF MICROWAVE-ASSISTED SOLVENT EXTRACTION

The effect of microwave energy in microwave-assisted solvent extraction systems depends on the dielectric properties of solvent and matrix (absorption, dielectric constant and loss factor). Dielectric constant (έ), also known as relative permeability, indicates a measure of the ability of a material to be polarized by an external electric field (as that of microwaves) storing energy within it. Dielectric loss factor (ε") represents the ability of the material to dissipate the absorbed electromagnetic energy, converting it into heat. The efficiency of the material subjected to microwave to transform electromagnetic energy into heat energy at a fixed frequency and temperature is measured by the loss tangent (tan δ) and this value is the ratio of the dielectric loss (ε") to the dielectric constant (έ) of the material (Samanlı, et al. 2017). Thus, the materials low in the dielectric factor do not heat due to their transparent form for microwave while the materials with high dielectric loss factor is easily heated by microwave energy. On the other hand, in electrically conductive materials (as that of metals), microwaves reflect back from the surface and thus do not heat. Briefly, the materials absorbing microwaves such as water, sugar and oil can be heated by microwave. Solvents with low dipole moment (non-polar hexane and tetrahydrofuran) do not heat under microwave radiation, while solvents with high dipole moment (acetone and water) will heat within seconds. Therefore, the use of combination of different solvents in microwave-assisted solvent extractions are very common in order to provide the selectivity in extraction and/or to change the microwave behaviour of the medium in the desired direction. For instance, ionic liquids to increase microwave absorption capacity of the medium or polar materials such as alcohols or SiC which is ineffective as chemical, and high with microwave absorption ability can be supplemented to the medium. Another important issue is the water content of the matrix, which has high dielectric constant and dipole moment, provides localized superheating, allowing the component to be extracted to pass into the solvent easily. The water content of the matrix in MASE has thus to be controlled to obtain accurate and repetable results.

As a result of the absorption of microwaves in materials exposed to microwaves, the basis of heating is based on the conduction of ions and dipole rotation (rotation) mechanisms caused by this electric field (Kaufmann and Christen 2002). These two mechanisms occur simultaneously in most applications. Ionic conduction is the electrophoretic migration of ions when a magnetic field is applied. Dissolved charged particles participating in the oscillatory motion under the influence of a variable electric field collide with adjacent molecules, thereby heat the solution (Gjuraj, et al. 2012).

Dipole rotation means reconstructing of dipoles with microwave radiation occuring mostly in a frequency of 2.45 GHz. As a result of friction force generated by molecular rotation, a quick heating develops (Kaufmann and Christen 2002). Thus, the whole system in MASE including solvent and sample heat simultaneously compared with traditional heating concepts. Hence

Finally MASE can be described as a technique in which microwave radiation is used to heat the medium to help the transfer of the solutes from the matrix into the solvent. In some cases, microwave energy applications provide non-thermal effect to the extraction. Localized heating causes the cell walls to widen and rupture in the samples, thus allowing extractable components to pass easily into the solvent (Haswell and Kingston 1997).

3.1. Microwave Extraction Systems

Closed (under pressure) vessel and open (under atmospheric pressure) vessel operations can be

applied in microwave systems. Closed-vessel in MASE which can be controlled under pressure and temperature is the most favored system. As the pressure increases in the closed-vessel systems, the solvents used can be heated to higher temperatures than the boiling point at atmospheric pressure. The pressure of the vessel in the closed-vessel design changes depending on the boiling point and of volume of the solvent applied. Another disadvantage of the closed-vessel designs is to cool down the system until room temperature before opening the vessel. The maximum power in the closed-vessel systems is between 600 and 1000 W (Destandau, 2013).

The process is conducted under atmospheric pressure in the open vessel system, so temperature of the solvent is limited by its boiling point at atmospheric pressure. The solvent heated and evaporated is condensed through the reflux and again sent back to the vessel. Meanwhile, MW placed on the vessel generate fast and homogeneous heating. Despite the safety of the open vessel system, the extraction of large quantities of samples at once can be processed in the open vessel design compared with the closed-vessel designs.

There are also various modified microwave extraction systems used in scientific researches. For example, vacuum microwave-assisted extraction systems which moderate working conditions are provided, has been developed for the extraction of sensitive components. The mass transfer mechanism of active compounds from substance to solvent is resulted by suction pressure in these systems. Nitrogen-protected microwave-assisted extraction is another type of modified microwave extraction system where nitrogen is used to keep the exraction vessel under pressure and to prevent oxidation of oxygen sensitive molecules during extraction. The combined systems in which microwave and ultrasonic waves are used to intensify mass transfer mechanism, has been also developed. Dynamic microwave-assisted extraction systems where the extraction process is applied continuously and automatically as well as combined with a non-linear analytical step is another example (Llompart, 2019).

Microwave designs have been developed as lab-scaled therefore only miligrams of product could be obtained over the years. However, today, versatile microwave-powered continuous flow reactors that can easily be integrated into a wide variety of processes and capacities up to tens of thousands of liters per hour have been designed and manufactured commercially to eliminate this advantage.

Microwave heating is faster, more efficient, cleaner, greener and safer than traditional heating methods. Particularly the systems designed for extraction have advantages such as increasing the concentration of the components, decreasing the solvent requirement and short time, yet it has also disadvantages such as high investment cost and the necessity of a filtration process to separate the solid phase after extraction.

3.2 The Effect of Microwave Parameters on Extraction Efficiency

Solvent`s nature and volume, extraction temperature, extraction time and microwave power are such important parameters for enhancing extraction productivity in MASE technique. In many studies, MASE parameters have been optimized using different factors to have the highest efficiency in MASE. The effects and interaction between these parameters are important to understand the MASE process. Therefore, this part will highlight the importance of accurate selection for the operation parameters with an optimum productivity.

Solvent and solvent volume

An adequate choice of solvent is a critical factor for obtaining optimal extraction yield in MASE and can influence the efficiency of the extraction process. If the solvent with high values of dielectric constant is used in the process, the solvent capacity will be higher for absorption of microwave energy. The dielectric constant shows the capability of the solvent to be polarized by an external electric field storing energy within it (Gala, et al. 2018). The solvent interaction with the matrix, solvent properties, and the analyte solubility in the solvent should be taken into account when implementing the process. In order to remove undesirable components, for example in the extraction of pesticides and organic pollutants from soil, high selectivity towards analyte is very important for the solvent`s choice.

Although MASE requires less solvent, less extraction time, high productivity etc. than conventional systems, the optimum extraction is not always favor of those used in MASE. For instance, the yield extracted using MASE with hexane as a solvent was lower than used with soxhlet extraction because its transparency function prevents to be heated by microwave. However, the extraction yield was higher when ethanol used in MASE than soxhlet method due to better ability of absorption capacity of microwave. Therefore, dielectric properties of the solvent play an important role for an optimal production (Mandal, et al. 2007). In this case, due to lower dielectric constant and dissipation factor of non-polar solvents, microwave does not heat the non-polar solvents. Among polar solvents water with its high dielectric constant has an excellent efficiency in microwave absorption. Despite ethanol and methanol are both polar but lower than water again associated with dielectric constant, they perform higher efficiency when mixed with water (Rafiee, et al. 2011). Further, Rodriguez-Padron, et al. (2020) investigated the extraction of phenolic compounds from green walnut shell residues by MASE with different solvents (water, water:ethanol, water:acetonitrile, dichloromethane, ethyl acetate, and acetonitrile) and the combination of water:acetonitrile was superior for this extraction method. Therefore, different solvents can be integrated for microwave process and this in turn can improve the productivity of the extraction. The extraction productivity relies on the analytes` solubility in the extraction solvent that can be either polar or non-polar in MASE. Particularly flavonoids can act differently in polarity, thus can be polar or less polar. Less polar solvents (benzene, chloroform, ether, and ethyl acetate) generally are used to extract flavonoid aglycones (isoflavones, flavanones, flavones, etc.) whereas more polar solvents (water, ethanol, methanol, and acetone) are implied for extracting of flavonoid glycosides (flavonols, hydroxylated flavones, aurones, etc.) and anthocyanin (Routray and Orsat 2012).

Solvent volume is another parameter affecting extraction productivity in MASE. During irradiation time, plant components used in MASE must be entirely immersed in the solvent, the volume of the solvent is therefore crucial with respect to the amount of sample (Mandal, et al. 2007). According to research by Maran, Sivakumar et al. (2013) after microwave extraction of pectin from orange peel, pectin yield increased when increasing the solid:liqud ratio up to 1:16 g/mL due to swelling of the materials with higher volume of liquids and absorbing microwave irradiation by the material, thus resulting in the cleavage of the cell walls. However, increasing the extraction solvent does not always provide high extraction efficiency. If the solvent volume is too high, it will not be able to provide enough energy to heat the solvent, resulting in reduced extraction efficiency (Nguyen, et al. 2020).

Microwave power and temperature

In MASE, the extraction temperature is proportional to the applied microwave power, increasing power leads to rapid internal heat generation (Pereira, et al. 2007). In general, high temperature lowers the surface tension and viscosity of the solvent, thereby increasing the wetting and penetration effect of solvent, and ultimately facilitating the transfer of the analyte from matrix to the solvent in extraction process (Eskilsson and Björklund 2000). On the other hand, low microwave power slows down the molecular movement and prolongs the extraction time (Mwaurah, et al. 2020). Hence it is important to determine the optimum power requirement in the microwave assisted extraction process. Some studies reported that the extraction yield enhanced with increasing temperature but a decrease revealed after an optimum temperature. Some publications have shown that prolonged processing at elevated temperature or elevated temperature causes degradation of heat sensitive compounds, reducing the yield and/or purity of target compounds. For instance, Alara and Abdurahman (2019) reported that the extraction efficiency increased when the microwave power was increased up to a certain power, and the efficiency began to decrease with further power application, in the study where phenolic compounds was extracted from Hibiscus with MASE. Likewise, Kurtulbaş Şahin, et al. (2021) was reported that phenolic recovery reduced after an optimum microwave power in the study where phenolic compounds and anthocyanins extracted from sour cherry peels by MASE. Zhang, et al. (2022) reported that high microwave power cause destruction of cell and accelerates the oil extraction yield from C. oleifera seed. However it was also reported that the structure of C. oleifera oil was damaged by too high microwave energy application.

Extraction time

Extraction time is a key variable that influence the efficiency of the extraction. Generally, increasing the extraction time causes to increase in yield. On the other hand extending the time excessively can reduce the yield due to some undesirable reactions, such as enzymatic degradation, oxidation, etc. Therefore extraction time is another critical parameter should be optimized for a MASE process. Dhobi, Mandal et al. (2009) examined the extraction of silybinin by microwave assisted extraction and reported that the yield of silybinin increased over time, but there was no change in yield after 6 minutes. Xiaokang, et al. (2020) reported that total phenolic content and antioxidant activity decreased with an over extension of extraction time in MASE of polyphenols from shiitake mushrooms. Similarly, Kaderides, et al. (2019) reported that longer extraction times after 4 minutes reduced the extraction yield of phenolics from pomegranate peel.

3.3 Applications of Microwave-Assisted Solvent Extraction From Food Waste

Microwave heating is an alternative and advantageous heating method compared to conventional heating. Many processes that require heating, such as drying, extraction, and synthesis, can be performed efficiently using microwave heating. The systems used microwave energy provide short reaction time and higher reaction yield than traditional heating systems. Therefore, microwave heating has been considered as an alternative method to recover valuable components from food waste. There has been an increase in studies on this subject in recent years. The microwave-assisted extraction system, the recovered components, extraction conditions and the solvents used in extarction in the literature are summarized in Table 1.

Table 1. Literature summary for the application of microwave assisted extraction

Target component	By-product	Microwave system	Extraction conditions (Solvent, sample quantity, power, temperature, time)	References
Pectin	Apple pomace	Open vessel	HCl solution; 2 g; 499,4 W; 20.8 min	(Wang, et al. 2007)
Pectin	Grapefruit peel	Open vessel	Water (pH 1.5); 6 g; 900 W; 6 min	(Bagherian, et al. 2011)
Pectin	Mango peel	Open vessel	Water; 413 W; 134 s	(Maran, et al. 2015)
Pectin	Papaya peel	Household microwave oven	Water; 512 W; 140 s	(Maran and Prakash 2015)
Pectin	Sour orange peel	Microwave oven	Citric acid solution; 700 W; 3 min	(Hosseini, et al. 2016)
Pectin	Sugar beet pulp	Microwave oven	Sulfuric acid solution; ~152 W; 3.53 min	(Li, et al. 2012)
Phenolic acids	Mandarin peels	Open vessel	Methanol (66%); 5 g; 152 W; 49 s	(Hayat, et al. 2009)
Phenolic compounds	Peanut skin	Closed vessel	Ethanol (30%); 1.5 g; 855 W; 150 s	(Ballard, et al. 2010)
Phenolic acid	Mandarin peel	Closed vessel	Water; 1 g; 400 W; 135 °C; 3 min	(Ahmad and Langrish 2012)
Phenolic compounds	Potato processing wastes	Closed vessel	Ethanol (60%); 0.5 g; 300 W; 80 ºC; 2 min	(Wu, et al. 2012)
Phenolic compounds	Olive pomace	Closed vessel	Choline chlorite: citric acid (1:2); 2 g; 200 W; 30 min	(Chanioti and Tzia 2018)
Phenolic compounds	Olive pomace	Closed vessel	Ethanol (20%); 700 W; 10 min	(Jurmanović, et al. 2019)
Phenolic compounds	Pistachio hull	Closed vessel	Ethanol (56%); 1 g; 140 W, 4.5 min	(Özbek, et al. 2020)
Phenolic compounds	Wine lees	Closed vessel	Ethanol (75%); HCl (1%); 2 g; 200 W; 17 min	(Pérez-Serradilla and De Castro 2011)
Phenolic compounds	Red grape pomace	Closed vessel	Water or water:ethanol (1:1); 2 g; 200 W; 50 °C; 60 min	(Drosou, et al. 2015)
Polyphenols and flavanoids	*Achillea millefolium* (yarrow) dust	Household microwave oven	Ethanol–water; 3 g; 170 W; 33 s	(Milutinović, et al. 2015)

Target component	By-product	Microwave system	Extraction conditions (Solvent, sample quantity, power, temperature, time)	References
Essential oil	Grapefruit peel	Open vessel	Solvent-free; 250 g; 85 W; 20 min	(Uysal, et al. 2011)
Oil	Olive pomace	Closed vessel	Hexane; 2.5 g; 287 W;16 min	(Yanık 2017)
Maslinic and oleanolic acids	Olive pomace	Closed vessel	Hexane; 2 g; 150-300 W; 4-20 min	(Biltekin, et al. 2022)
Maslinic and oleanolic acids	Olive pomace	Open vessel	Ethanol: water (9:1 v/v); 40 °C (10 min for MA, 2.93 min for OA)	(Ozkan, et al. 2017)
2-furfural and 5-HMF	Wheat straw	Closed vessel	H_2O/HCl; 140-190 °C; 1-30 min	(Yemiş and Mazza 2012)
Bioactive carbohydrates (inositol and inulin)	Artichoke external bracts	Closed vessel	Water; 0.1 g; 900 W; 50 ºC; 3 min	(Ruiz-Aceituno, et al. 2016)
Fermentable sugars	Cotton plant residue	Household microwave oven	Alkaline water; 300 W, 6 min	(Vani, et al. 2012)
Ferulic acid	Brewery by-product	Closed vessel	H_2O/ NaOH (0.5%); 1 g; 100 ºC; 15 min	(Moreira, et al. 2012)
Gelatine	Duck feet	Household microwave oven	350 W, 5 min	(Chanioti and Tzia 2018)
D-limonene	Orange peel	Closed vessel	Hexane; 1 g; 200 W; 110 ºC; 30 min	(Attard, et al. 2014)
Carotenoids	Carrot juice processing waste	Clossed vessel	Flaxseed oil; 8.06 g; 165 W; 9.39 min	(Elik, et al. 2020)
Lycopene	Tomato peel	Closed vessel	Ethyl acetate; 1-2-4 g; 400 W; 1 min	(Ho, et al. 2015)
Non-polar compounds	Pistachio hull	Closed vessel	Hexane; 1.5 g; 250 W; 12.5 min	(Özbek, et al. 2018)

Microwave assisted extraction has been frequently used in the extraction of phenolic compounds from various food wastes. It has been reported that the components are obtained in a very short time and/or with higher extraction efficiency compared to conventional methods with microwave assisted extraction. In conventional extraction systems (eg soxhlet extraction), process is completed between 3-6 hours, while this time is limited to minutes in microwave heating. Li, et al. (2011) emphasized that more than 90% of the polyphenols of grape seed are extracted with the microwave system in just a few minutes. Liazid, et al. (2011) extracted anthocyanins with a notable short extraction time (5 min) from grape skins by microwave assisted extraction. Mirzapour-Kouhdasht, et al. (2019) and Binsi, et al. (2017) successfully extracted the colloidal gelatin from by-products of fish using microwave assisted extraction. Also, Park, et al. (2013) reported that gelatin obtained by MASE from duck feet had better quality properties than those obtained by other methods. Yanık

(2017) obtained higher quality oil in a very short time (16 min) from olive pomace using MASE compared to soxhlet extraction. Keskin Çavdar, et al. (2017) reported that pomegranate seed oil extracted by MASE had significantly lower peroxide value, free fatty acidity and higher total phenolic content and antioxidant activity than those of the oil obtained by cold extraction. Traditionally, pectin was extracted in acidic solution at about 90°C for at least 1 hour, while Hosseini, et al. (2016) successfully extracted pectin with an appropriate purity from sour orange peel within 3 minutes by MASE. Wang, et al. (2007) extracted pectin from apple pulp within 20 minutes. Ho, et al. (2015) conducted studies on obtaining lycopene from tomato peel by microwave heating and showed that while conventional extraction showed a high yield of cis-lycopene, MASE significantly improved trans and total lycopene yield. Binod, et al. (2012) demonstrated that short-term microwave pretreatment significantly improves yield in obtaining fermentable sugar from sugar cane pulp. Vani, et al. (2012) compared the hydrolysis performance of microwave-assisted alkaline pretreatment and high pressure pretreatment to obtaine fermentable sugars from cotton plant wastes. They reported that bioethanol can be produced with 5 times lower energy requirement in microwave application compared to high pressure application. Some studies have been carried out on the separation of lignocellulosic components by using different sources with microwave application, and the production of sugars that can be used for different. In these studies, while an increase in yield was obtained, it was observed that toxic by-products were also reduced (Zhu, et al. 2015; Singh, et al. 2017). Jurmanović, et al. (2019) succesfully extract the phenolic compounds from olive pomace using ethanol by MASE in a few minutes. Similarly, Chanioti and Tzia (2018) emphasized that the MASE was an effective technique for the extraction of phenolic compounds from olive pomace.

4. CONCLUSION AND RECOMMENDATIONS

Valorization of food industry by-products is essential to reduce its threatens effects on environment, economy and food insecurity. The studies on the utilization of the food by products are increasing gradually and valorization of food waste and losses will continue to be a hot topic in the coming years. Microwave-assisted extraction can replace conventional methods for the recovery of target components such as polyphenols, oil, essential oil, pectin, fermentable sugars, etc. from food waste. Studies cited in this review figure out that microwave-assisted extraction method shortens the processing time, reduces the solvent consumption, increases the extraction yield and minimizes the deterioration of these target components. Most of the work in the literature on microwave extraction is lab-scale and batch operation, there are limited number of studies on pilot scale and/or continuous microwave extraction sytems. Future studies should concentrated on pilot scale studies on the extraction of valuable components with MASE and should reveal also the efficiency and quality impact of this technique as well as its energy consumption and economic advantages.

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