Malaysian Journal of Chemical Engineering & Technology 4 (2) (2021) 73–89

Malaysian Journal of Chemical Engineering & Technology

e-ISSN: 2682-8588

Journal Homepage: http://myjms.mohe.gov.my/index.php/mjcet

An overview of the extraction methods of plant-based natural antioxidant compounds

Nur Fadilah Harun, Farah Hanim Ab Hamid*

School of Chemical Engineering, College of Engineering, Universiti Teknologi MARA, Selangor, Malaysia

*Corresponding email: farah88@uitm.edu.my

Abstract

Natural antioxidants are widely used in food additives, application in functional foods or also known as ingredients that offer health benefits that extend beyond their nutritional value, and pharmaceutical. These natural antioxidants such as carotenoids, vitamins, and polyphenol can be obtained from fruit, vegetables, and traditional herbal medicines. However, there have several issues regarding the conventional extraction method to extract natural antioxidants compounds from food and medicinal plants such as require a large volume of solvent and long extraction time. Therefore, new green extraction methods such as microwave-assisted, ultrasound-assisted, pulsed electric field, enzyme-assisted, supercritical fluid, and pressurised liquid, technologies were studied to overcome these constraints. Thus, different types of extraction and their mechanism in natural antioxidant compounds extraction was further discussed in this study. Besides, the main classes, source of natural antioxidants and their health benefits also were presented in this paper.

Article Info

https://doi.org/10.24191/mjcet.v4i2.13055

Article history:

Received date: 6 April 2021
Accepted date: 30 July 2021
Published date: 31 October 2021

Keywords:

Natural antioxidant
Extraction
Conventional extraction
Natural resources
Health benefits

1.0 Introduction

Antioxidants are considered as essential bioactive compounds due to multiple health benefits and their vital role in reducing the oxidation process. The reactive nitrogen species (RNS) and the reactive oxygen species (ROS) in the biological system, such as nitric oxide radicals, superoxide, and hydroxyl can cause DNA rupture and lead to lipid and protein oxidation in cells (Li et al., 2015). Typically, the antioxidant mechanism that exists in the human body would be scavenged these radical, which can maintain the equilibrium between oxidation and antioxidation. However, exposure to cigarette smoke, alcohol, radiation, or environmental contaminants causes excess formation of ROS and RNS, which interferes with the equilibrium between antioxidation and oxidation, leading to some chronic inflammatory diseases (Wang et al., 2016).

Aside from that, research confirmed that the advantages of consumption of natural antioxidants could reduce the harm caused by oxidative stress through blocking the formation oxidative chain reaction and it acts as free radical scavengers (Baiano & Del Nobile, 2016). Furthermore, antioxidants also have various biological properties such as anti-inflammatory, anti-carcinogenic and anti-atherosclerotic effects, minimise the incidence of coronary artery disease and by modulating the intestinal microbiota balance, contribute to the preservation of digestive health (Oroian et al., 2015).

The extraction of antioxidant compounds in food and plants can be done using conventional and non-conventional method. The results obtained from the conventional extraction method can be served as a guideline to compare with the new extraction method. Hence, the non-conventional method was introduced to improve the conventional method by reducing the operating time to obtain higher yield of extract at lower solvent consumption.

The aim of this study is to review the various extraction methods of natural antioxidant and to present the comparison between conventional and non-conventional extraction methods.

2.0 Natural sources of antioxidant

Natural antioxidants are produced by metabolic processes in the human body or supplemented by other natural sources, and their function depends on their mechanisms of action, physical, and chemical properties. Hence, antioxidants can be classified into two groups which are enzymatic antioxidants and non-enzymatic antioxidants.

Generally, enzymatic antioxidants are generated in the human body and categorised into primary and secondary antioxidants. The primary antioxidants consist of superoxide dismutase (SOD), glutathione peroxidase, and catalase. Meanwhile, for secondary, it includes glutathione reductase, and 6-phosphate dehydrogenase (Rasheed et al., 2019).

Vaisi-Raygani et al. (2007) stated that non-enzymatic antioxidants are not naturally present in the body but need to be supplemented for proper metabolism. Vitamins, mineral, polyphenols, carotenoid, and other antioxidants are known as non-enzymatic compounds. Copper, iron, zinc, and selenium are among of minerals which serves as cofactors for the antioxidants of the enzymes. On the other hand, vitamins are categorised as micronutrients consists of vitamin C, vitamin B, vitamin A, and vitamin E that are essential for effective utilisation of antioxidant enzyme in the body system (Rasheed et al.,2019). It needs to be added to the diet because it could not be synthesised in human body.

Furthermore, lycopene, zeaxanthin, β-carotene, and lutein are made of carotenoids. These compounds with fat-soluble colour found in fruits and vegetables. the benefits of Lutein in shielding the retina from harmful free radical activity and avoid atherosclerosis (Sikora et al., 2008). Lycopene has been shown to be a powerful and beneficial antioxidant compound found in strawberries, watermelon, guava, and other foods.

Aside from that, polyphenols are classified as phytochemicals, where the antioxidant activities focus on their physical and chemical properties, which influence the metabolism of their molecular structures (Ajila et al., 2011). These are composed of phenolic acids, curcumin, flavonoids, and gingerol (Amit et al., 2011). Flavonoid as one of the main groups of polyphenolic compounds are found in vegetables, fruits, grains, seeds, leaves, flowers, and bark. Other than that, curcumin is an effective ROS scavenger that induces oxidative stress, such as O radicals, lipid peroxyl radicals (LO_2), OH radicals, and nitrogen dioxide (NO_2) radicals. Curcumin has been used to inhibit lipid peroxidation and GSH levels have also been shown to increase in epithelial cells, leading to lower development of ROS (Biswas et al., 2005).

Natural antioxidants can be obtained from many sources such as fruits, vegetables, and from waste processing industry. In fact, most vegetables consumed in daily meals like basil, coriander, carrots, and many more contain high antioxidants. These natural sources not only safe to consume but also cheap and easy to get. Table 1 shows the main sources of antioxidants compound such as vitamin C, vitamin E, carotenoids, and polyphenols and its health benefits.

3.0 Extraction method of natural antioxidant compounds

Basically, the effective extraction process can be accomplished by undergoing detection, isolation, and characterisation of natural antioxidant compounds. Xu et al., (2017) stated that temperature, time, pH, solvent, and concentration of the sample are the factors that affects the efficiency of extraction method. Besides, the selectivity of the solvent is referred based on chemical structure and the polarity of extracted antioxidants compounds.

Meanwhile, several authors stated polar and medium polar solvent are used in extraction process such as water, methanol, propanol, acetone, and other aqueous mixture (Belwal et al., 2016; De Camargo et al., 2016; Sharmila et al.,2016; Nguyen et al., 2017. According to Nawaz et al. (2020), high polar solvents will lead to high extract yield, but low phenolic and flavonoid content as compared to non-polar.

4.0 Extraction method of natural antioxidant compounds

Effective extraction process can be accomplished by undergoing detection, isolation, and characterisation of natural antioxidant compounds. Xu et al., (2017) stated that temperature, time, pH, solvent, and concentration of the sample are the factors that affects the efficiency of extraction method. Besides, the selectivity of the solvent is referred based on chemical structure and the polarity of extracted antioxidants compounds. Meanwhile, several authors stated polar and medium polar solvent are used in extraction process such as water, methanol, propanol, acetone, and other aqueous mixture (Belwal et al., 2016; De Camargo et al., 2016; Sharmila et al.,2016; Van et al., 2016). According to Nawaz et al. (2020), the highly polar solvents will lead to high extract yield, but low phenolic and flavonoid content as compared to non-polar

In addition, natural antioxidants can be obtained from food and medical plant are carotenoids vitamins and polyphenols (Baiano & Del Nobile, 2016;

Table 1: Source and health benefits of natural

Antioxidants	Natural sources	Benefit for health	References
Vitamin C	Spearmint, peppermint, strawberry, broccoli, citrus peel, tangerine, apple banana, garlic, orange juice tangerine, strawberry, pear,	• Increase plasma resistance to lipid peroxidation when consume the supplement in short and long-term. • Vitamin C is high benefits reduce serum uric acid levels, and reduced risk of gout. • Substantially minimizing the risk of stroke. • Decreases chronic and degenerative disease occurrence.	• Shahkar et al., 2015 • Roddy et al. 2014 • Yamagata et al., 2015 • Roddy et al., 2014
Vitamin E	Grains, green tea, olives and olive oil, palm oil, Dabai, sunflower seeds and sunflower oil, and pumpkin seeds	• Vitamin E can protect membranes against reactive oxygen species and lipid peroxidation and is the primary component of the spermatozoa antioxidant mechanism.	• Yousef, 2010 • Anel-López et al., 2012
Carotenoids	basil, coriander, sunflower seeds and sunflower oil, orange juice, and grains	• Carotenoids have been seen to have a variety of roles in the prevention and treatment of various health disorders, including metabolic disease likely cardiovascular disease and cancer.	• Jomova et al., 2013
Carotenoids (lycopene)	Tomatoes, guava, papaya, watermelon, carrot, apricots, and grapefruit, vegetables	• Lycopene is inhibited a few of pathologies as obesity certain forms of cancer and cardiovascular disease.	• Kim et al., 2012 • De Groot et al., 2012 • Riccioni et al., 2012
Carotenoids (β-carotene)	Olive oil, red carrots, sweet potato, amaranth, dark green, and leafy	• β-carotene have a beneficial impact on cardiovascular diseases and form of cancer.	• Greenlee et al., 2012
Carotenoids (xanthophylls)	Kale, Zea mays, carrots, and spinach	• Visual wellbeing is closely related to lutein and zeaxanthin and can prevent or reduce cardiovascular diseases.	• Pasaporte et al., 2014
Polyphenols (Flavonoid)	Honey, orange juice, grains, Stevia Drumstick (Moringa oleifera	• Flavonoid consumption is inversely related to subsequent cancer. • It also shows anti-viral activity, anti- inflammatory, anti-cancer can also help prevent cardiovascular disease.	• Kurzawa et al., 2012 • Chen et al., 2013 • Sanros et al., 2014 • Caridi et al., 2007
Anthocyanins	Grapes, pomegranates, tomatoes, and purple carrot, berries, sweet potatoes, Drumstick (Moringa oleifera), green coffee beans, berries, and wine	• Anthocyanins have advantageous effects on the human body, they have anticarcinogen activity and antioxidant that can prevent cancer, diabetes neuronal and cardiovascular disorders. • Consume anthocyanins for 4 weeks has been shown to reduce symptoms of obesity, myopia, diabetes and apoptosis. • Besides, anthocyanins' antioxidant ability depends on the chemical structure of the molecule, providing antioxidant properties to the phenolic structure.	• Hui et al., 2010 • Tomas et al., 2012 • Santos et al., 2014 • Tsuda et al., 2012 • Pojer et al., 2013

Manach et al., 2004). Hence, there are various types of extraction method available to extract natural antioxidants from food and medicinal plants such conventional and non-conventional extraction method, and these methods are discussed in this paper.

5.0 Conventional extraction method

There are few methods to extract natural antioxidant from plants in conventional extraction method which are maceration, hydrodistillation, and Soxhlet extraction. The conventional extraction method is used at a small-scale level to extract bioactive materials from many plants and these methods are typically based on the extraction efficiency of various solvents have been used (Selvamuthukumaran et al., 2017).

In 1879, the Soxhlet extraction technique was first developed by German chemist Franz Ritter Von Soxhlet (Xu et al., 2017). According to Soxhlet extraction technique proposed by Sagar et al. (2018), the sample of dry plant material is preserved in the thimble. When the solvent reached excess flow level, a syphon is used to aspirate the solution of thimble-holder. The solution is discharged back into the distillation flask by the syphon. Next, this solution contains extracted solutes into the bulk liquid. Then, the solute stays in the distillation flask and the solvent moves back to the plant 's solid bed.

Aside from that, maceration technique which previously was applicable as homemade preparation of tonic and popular as a one of the cheapest ways to extract few essential oils and bioactive compounds from various plant materials. There are few steps in maceration process. Initially, the plant materials were ground into smallest particles to obtain biggest surface areas so that it will be blended with the solvent. Then, solvent known as menstruum is then placed in a closed vessel. Next, the liquid is drawn off, but the solid residue from the extraction process is pressed to retrieve significant amount of occluded solution. It was then separated and mixed from impurities through filtration. There are two ways of shaking in maceration technique which is firstly increased diffusion and secondly, remove the concentration solution from the sample surface to add fresh solvent to the menstruum to produce high extraction yield (Selvamuthukumaran et al., 2017).

Hydrodistillation (HD) also considered as a technique that used to extract natural antioxidant compound (Vankar,2004). Organic solvents are not included in this process, and it can be done before dehydration of plant materials. There are three types of HD which is water and steam distillation, distillation, and direct steam distillation. At first, a still compartment and the plant materials were packed. Then, an adequate amount of water is placed and boil it. Direct steam was introduced to the plant sample. The diluted mixture flows to a separator from the condenser, where oil and bioactive compounds are immediately removed from the water (Silva et al., 2005). Other than that, there are three main physiochemical processes of HD which are hydrodiffusion, hydrolysis, decomposition by heat. Some of the volatile components can be damage at the higher extraction temperature.

Therefore, the efficiency of extraction in any conventional method depends on the selected solvents. Usually, the polar solvent such as water, methanol, propanol, acetone, and other aqueous mixture are favourable solvent that has been used in extraction process. The polarity of the solvent was the most significant factors to extract the targeted compound. Several factors need to be considered when choosing the solvent for extracted natural antioxidants compounds for instance mass transfer of the solvent, the molecular affinity between the solvent and the solvent selected, environmental protection, toxicity, and economic viability (Cowan, 1999).

6.0 Non-conventional extraction method

There are several critical issues of traditional extraction method which are costly requirement, high purity of solvent required, longer extraction time, poor extraction selectivity, thermal decomposition of thermolabile compound, and need large amount of solvent to evaporate (Luque-de-Castro et al., 1998). Therefore, new extraction method known as non-conventional extraction method were introduced to solve the problem of the traditional method. Besides, by comparing to traditional methods, non-conventional extraction methods offer many advantages such as high efficacy, low energy and water consumption used, and allowing a higher amount of yield.

Hence, these non-conventional extraction methods refer to microwave-assisted extraction (MAE), ultrasound-assisted extraction (UAE), pulsed electric field (PEF) extraction, enzyme-assisted extraction (EAE), supercritical fluid extraction (SFE), and pressurised liquid extraction (PLE). In addition, some of these methods are known as green techniques because it satisfied the standards set by Environmental Protection Agency (2015). Moreover, these green techniques have the advantages of derivatives and catalysis reduction, the less dangerous chemical synthesis that enables the design of safer chemicals, enable to design for energy efficiency, and its use of sustainable feedstock.

6.1 Microwave assisted extraction (MAE)

Microwave is an electromagnetic of radiation (Xu et al., 2017). Microwave can supply energy solvent and plant matrix during microwave assisted extraction (MAE) method. Besides, the energy is absorbed by molecules within plants especially polar molecules. Microwave significantly alters the physical properties of cell walls eventually result in cell wall rupture and release of target components due to localise pressure, stress of mechanical, and severe thermal exposure (Zhang et al., 2011; Florez et al., 2015). Since the first time MAE method was applied in 1989, there have been various studies of the antioxidant's recovery from plant material using this method. MAE only applies to extraction of solvents which need to be capable of absorbing microwaves.

Besides, the selection of suitable solvent, time of irradiation, temperature of irradiation, solvent to material ratio, characteristics of matrix, and lasty the power of microwave were factor that affecting MAE method (Tatke et al., 2011; Pasrija et al., 2015). Therefore, various studies have shown the advantages method of MAE which are less time for extraction, lower solvent consumption, and produce greater extraction yield (Zhang et al., 2011, Routray & Orsat, 2012). MAE of antioxidants from *Achillea millefolium* dust was performed (Milutinovic et al., 2015). In order to extract antioxidant, researchers had optimised four parameters namely ethanol concentration, irradiation time, solvent solid ratio, and lastly microwave power. It was concluded that, conventional extraction method took 48 h and consumed 40% of ethanol to extract the antioxidant, while MAE only took 33 s and consumed 40 mL/g solvent to extract antioxidant. Moreover, increased of extraction yield under MAE conditions which are total flavonoid content from 30.82 ± 2.35 to 42.95 ± 1.32 mg quercetin equivalents (QE)/g, for total polyphenol content from 135.26 ± 1.72 to 237.74 ± 2.08 mg GAE/g, and lastly for 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging activity from 21.58% ± 0.88% to 71.72% ± 2.12%. Hence, it showed that MAE took shorter time with great extraction yields to extract the antioxidant compared to conventional method. Meanwhile, Shu et al. (2003) report that higher recovery of *Ginsonesides* from ginseng root by using MAE method was superior because it took only 15 minutes compared to conventional extraction method which took 10 hours.

MAE method for extraction of polyphenols compound from Quercus bark was also reported by Bouras et al. (2015). In this study, it used two solvent which are 0.38% methanol and 33% ethanol solvent. The condition for MAE method and conventional extraction method were the same which are at room temperature, pH is 10.75, 60 min, 45W, and 50 Hz. Compared to the conventional method, the MAE method had the microwave treatment, which resulted in the recoveries of antioxidant and total phenolic content increasing by three times.

Antioxidant compounds such as E- and Z-guggolsterone, tannin, and cinnamalydehyde were extracted from different types of plants by having optimal conditions and it has proved that MAE is a faster and compatible technique compared to the traditional extraction technique (Asghari et al.,2011). In the different study reported, Thirugnanasambandham et al., (2017) optimised the operating parameters such as mass of the sample, time for extraction, and temperature in MAE method to extract betalain content from dragon fruits peel using response surface methodology.

6.2 Ultrasound assisted extraction (UAE)

UAE has been used in the food and pharmaceutical industries over the last three decades as an effective extraction process (Esclapez et al., 2011). Besides, UAE method consist of ultrasound which is a special form of sound wave beyond human hearing and its frequency ranges between 20 kHz to 100 MHz (Selvamuthukumaran et al., 2017). The sound waves can flow across a medium by generating expansion and compression. Then, this process generates a phenomenon known as cavitation, which further leads to bubble formation, growth, and collapse. Over the course of a few cycles, the size of these bubbles expands to a critical stage, so these bubbles collapse and release a huge amount of energy that would produce intense pressure which is 1000 atmospheres and temperatures which is 5000 K at room temperature (Xu et al., 2017).

Furthermore, the efficiency of extraction yield using UAE method can significantly affect by the temperature, time, intensity, frequency of ultrasound, amount of solvent, the types of solvent, and the characteristics of the sample such as the sample's moisture content and particle size (Talmaciu et al., 2015). Thus, UAE method is known to be effective, productive technique, inexpensive, and high extraction yield due to used low temperatures which can enhance the efficiency of the conventional method (Altemimi et al., 2016). Thus, it indicated that with presence of energy of ultrasound, it will produce high energy transfer, low thermal gradients, and temperature for extraction, produced more effective mixing, easy to start up, faster response to process extraction control, and does not require process steps selective extraction.

Moreover, there a recent study has been conducted on UAE method. Sunflower oil was used as an alternative solvent to extract carotenoids from carrots based on biorefinery concept in UAE, while solvent of hexane was used for conventional method (Li et al., 2013). There are few parameters, including carrot to oil ratio (2:10), ultrasonic intensity (22.5 W), temperature (40 °C), and sonification time (20 min) were optimised to obtain the high extraction β-carotene yields in this research. The results showed that the UAE's solvent obtained highest β-carotene yield of 334.75 mg/L just in 20 min only while for conventional extraction method using hexane as solvent obtained the β-carotene yield of 321.36 mg/L after one-hour extraction. Whereas another study has been discovered in optimizing the extraction of phenolic compounds from peaches and pumpkin using the UAE method (Altemimi et al., 2016). The result shows the higher yield of antioxidants with high activity by DPPH radical compared to conventional method.

In other studies, UAE extraction is proved to be a potential technique to replace the traditional method on an industrial scale due to greater extraction yield, higher antioxidant activity, lower operating temperature, and shorter extraction time to extract lycopene from papaya processing waste (Li et al., 2015).

The conventional method took longer time compared to UAE and slow energy transfer due to no ultrasound treatment. Another study using UAE in extracting *C. japonica Hassk* flavonoids and these extracted flavonoids is a possible antioxidant agent to be used in medicinal products or used in food ingredients (Lu et al., 2015).

6.3 Pulsed electric field extraction (PEF).

PEF is applicable to enhance extraction, drying, pressing, and diffusion processes (Angersbach et al., 2000, Vorobiev & Lebovka, 2006). It contains a treatment chamber that contains two electrodes in which the plant materials are located. Puertolas et al., (2010) stated that PEF can be performed in either continuous or batch mode, depending on the treatment chamber design. PEF has its effectiveness whereby it is based on the process parameters such as pulse number, properties of the materials to be treated, specific energy input, the treatment temperature, and field strength (Heinz et al., 2003).

Therefore, during extraction process, the membrane structure plant materials can be improved and shorten the extraction time which can increase the mass transfer of extraction compounds. PEF was reported to improve the removal of intracellular compounds from plant tissue and increased permeability of cell membrane (Toepfl et al., 2006). Besides, the PEF destroyed the cell membrane of plant tissue with a slight increase in temperature at a moderate electric field of 500 V/cm and 1000 V/cm for 10^{-4} s to 10^{-2} s (Fincan and Dejmek, 2002; Lebovka et al., 2002). Thus, PEF can minimise the destruction of compounds that are sensitive to heat (Ade-Omowave et al., 2001). Besides, PEF used as a pre-treatment method compared of using conventional extraction which obtained low yield extraction (Lopez et al., 2009).

Luengo et al. (2013) revealed that polyphenols obtained from orange peels using PEF is much better compared to the conventional method where the extraction yields of hesperidin and naringin contents were increased from 1.3 to 4.6 mg/100 g and 1 to 3.1 mg/ 100 g, respectively. Besides, the extraction of polyphenols from defatted canola seed cake using MAE and PEF method was performed (Teh et al., 2015). In this study, MAE took 5 min while PEF took only 10 s and consumed 10% of ethanol to extract polyphenols. Thus, it shows that PEF took shorter time with less solvent usage to extract the polyphenols compared to MAE.

Meanwhile, the PEF method was superior in the extraction of polyphenol yield from *Borago Officinalis L. leaves* compared to the conventional method (Segovia et al., 2015) due to the increase of oxygen radical absorbance capacity (ORAC) value from 2 to 13.7 times and the total phenolic compound (TPC) value from 1.3 to 6.6 times. In addition, the permeabilisation of Merlot skin by using PEF shows the increment in the extraction of polyphenols and anthocyanin (Delsart et al., 2012).

Besides, the application of PEF treatment is not only applicable in the extraction of lipids and other cell ingredients from plants but also can be applied in algae

(Mercer and Armenta, 2011). Also, PEF is suitable to be used before the maceration step to minimize the time of maceration and to enhance the stability of bioactive compounds for instance polyphenols and anthocyanin during vinification (Lopez et al.,2008).

6.4 Enzyme assisted extraction (EAE)

Enzyme assisted extraction (EAE) is a green extraction process that have the potential in extraction method due to less impact on environment and mild extraction condition (Cheng et al., 2015). Moreover, this method contains the enzymes which are in high specificity and high efficiency properties. In order to improve the extraction of natural antioxidants compound, this enzyme would damage the integrity structure of plant cell wall and deform it composition. Besides, the different source of enzyme can be derived by fungi, bacteria, animal organ or vegetable and fruit extract (Liu et al., 2014). Therefore, EAE method has the potential to improve the efficiency of extraction method for antioxidants such as flavonoids, carotenoids, phenolics and anthocyanins.

There are several factors that influence the efficiency and yield in EAE method which are concentration, pH, types of enzymes, liquid to solid ratio, particle size, incubation temperature, and time (Liu et al., 2016). The extraction of phenolic compounds from watermelon rind using the mixture of α-amylase, β- glycosidase, protease, and pectinase was applied in EAE (Mushtaq et al., 2015). In this study, in order to get the optimum extraction of polyphenol, four variables were considered which are pH (6–9), time for treatment (30–90 min), temperature (25–75 °C) and concentration of enzyme (0.5–6.5%). As the result, it indicated the optimum value which are 6.58 pH, 30 min, 51.8 °C and 24% concentration of enzyme. Thus, EAE enhance the extraction of antioxidant phenolics up to 3 times relative to traditional solvent methods with level of 279.96 mg TE/g FW (TEAC), 112.27 mg/mL (DPPH radical scavenging ability (IC50)) and 173.70 mg GAE/g FW (total phenolics). Aside from that, the effect of enzyme treatment on the lycopene recovery from tomato and the effect of solvents in extraction method was studied by Ranveer et al. (2013). In that study, there are four different solvents were carried out (hexane, ethyl acetate, petroleum ether and the tri-mixture of hexane, acetone, and ethanol) and involved two step extraction procedures. For the first phase, waste samples were treated with enzymes, for example pectinase and cellulase, whereas in the second phase, solvent was used to extract lycopene.

In EAE, it is proven that enzyme treatment without control and the treatment of enzymatic had impacts on extraction of phenolic compound. This method needs more development for its industrial-scale application since it spends a high cost on enzymes which included the application and activity of enzymes with environmental factors such as temperature and availability of nutrients (Puri et al., 2012).

6.5 Supercritical fluid extraction (SFE)

There are several factors that influence the efficiency of extraction on supercritical fluid extraction (SFE) method such as extraction temperature, extraction time, flowrate of solvent, operating pressure, particle size, chemical components as well as pre-treatment conditions. The best selection of solvent which are propane, hexane, butane, ethane, pentane, and carbon dioxide is indicated by cost, toxicity, ability of solvation or technical viability in SFE method. The volume of solvent used in SFE is considerably smaller than the quantity recommended for any low-pressure extraction procedure. In addition, the advantages of SFE are that supercritical fluid consists of a higher coefficient of diffusion and lower surface tension and viscosity than liquid solvent, which allows the sample matrix and mass transfer to penetrate easily. Next, the chosen supercritical fluid is higher compared to liquid solvent when the solvation power can be modified by alternating pressure or temperature. Meanwhile, SFE only uses a little amount of organic solvent which is known to be environmentally friendly.

Therefore, there are recent studies on SFE method of antioxidants from food and medical plants have been published. For example, the extraction of flavonoids from *Calycopteris floribunda* leaves using supercritical fluid extraction method was performed (Liu et al., 2014). The result shows that, at lower temperature and higher pressure, the maximum extraction SFE yields were obtained. At 1.5 kg/h flowrate of CO_2, 300 min, 30 MPa, and 35 °C of SFE was contrasted with classical extraction (CE) with 40 % ethanol solution for 8 h at 70 °C. As the result, the CE approach achieved the highest yield up to 8.01%, while the efficiency separation of pachypodol from SFE extracts was 3.7 times higher than CE. Therefore, in the extraction process, SFE method could increase the selectivity of some flavonoid components.

In the case of anthocyanin and phenolic compounds from *Syzygium cumini* fruit pulp using SFE was performed (Maran et al.,2014). In this study, the pressure, temperature, and flowrate of co-solvent were optimised as independent variable to obtain higher extraction yields. It can be concluded that the higher yield of TPC and total monomeric anthocyanin content (TMAC) were extracted when the pressure increases from 100 to 162 bar, temperature increases from 40 to 50 °C, and the flow rate of co- solvent (99.9% ethanol) rising from 1 to 2 g/min. The TPC and TMAC obtained from mentioned conditions was 1143.051 ± 1.58 mg GAE/100 g and 231.28 ± 0.76 mg/100 g, respectively. In addition, eight differences bioactive phenolics and seven different anthocyanins were classified by HPLC analysis, when SFE was applied under optimum condition. Aside from that, in another study conducted to extract carotenoids from Persimmon (*Diospyros kaki L.*) reported that SFE has demonstrated higher extraction performance and lower extraction time relative to other methods (Zaghdoudi et al.,2016). Aside from that, pentacyclic triterpene selective recovery can be optimised by changing the pressure and temperature during the extraction phase. Hence, it concluded that the SFE is one of the best methods for the efficient extraction of pentacyclic triterpene α, β-amyrin from rosemary leaves (Bensebia et al.,2016).

6.6 Pressurised liquid extraction (PLE)

PLE is known as automated extraction method and simple in operation (Shang et al., 2014). This method used the solvent at high pressure and temperature to extract the yield from different matrices (Herrero et al., 2015). Besides, the temperature of the solvent in the liquid state can be above its boiling point at normal temperature by increasing the pressure, which can increase the rate of mass transfer and encourage the solubility of the analytes.

Moreover, it is possible to apply the huge temperature ranges in PLE from room temperature to 200 °C and pressure from 35 to 200 bar. In addition, PLE is also called sub-critical water extraction (SWE) when the extraction solvent is water. Hence, it can be preserved in the liquid state when the water is heated to 200–250 ° C in SWE, while the dielectric constant (ε) of water is reduced from 80 to 30–25, which is similar to the dielectric constant of certain organic solvents such as ethanol or methanol. The closed dielectric constants mean the organic solvent's comparable polarity. While not feasible for all applications, the use of SWE in some applications can be regarded as an important option to organic solvents.

In addition, to increase the extraction yield of different antioxidants from plant materials, such as carotenoid (Breithaupt, 2004), anthocyanins (Cai et al., 2016), flavonoids (Bozan & Altinay, 2014), and phenolic compound (Setyaningsih et al., 2016) were used in the PLE method. This method is a green extraction process because of shorter extraction time, fewer operating steps, light and oxygen-free environment and reduced the use of solvent. Besides, temperature, static time, pressure, number of cycles and pressure are the most relevant parameters in PLE (Fu, et al.,2011). Other than that, flush volume and purge are known as variables that capable to fix and enhance the extraction recovery of components. Thus, mixture of solvent used in PLE method is depending on the properties of the target compound. For instance, the extraction of polyphenols used ethanol as a solvent (Shang et al., 2014). Meanwhile, n-hexane is used as a solvent for the extraction of β-carotene (Sanagi et al., 2005).

Furthermore, PLE was found to significantly reduce time consumption and solvent usage compared to the conventional Soxhlet extraction (Richter et al., 1996). Therefore, PLE is considered as one of the potential alternative techniques to the SFE method for the extraction of polar compounds. Flavonoids was extracted from spinach using a mixture of ethanol and water (70:30) solvent at 50–150°C by PLE were more successful than water solvent at 50–130 °C (Kaufmann et al., 2002; Howard et al., 2008).

Another study on PLE was discovered to extract the antioxidant compounds from black bamboo leaves (Shang et al.,2014). The solvent used in this method is the mixture of ethanol and water. The result shows the best condition extraction for TPC were material of 4.75 mm size with 75% ethanol at condition 200 °C, 25 min and 1500 psi while, for flavonoid content, the best process of extraction were material of 0.425 mm size with 50% ethanol at 200 °C, 25 min, and 1500 psi. Besides, the best process of extraction for DPPH radical efficiency were material of 425 µm size with 25% ethanol at 200 °C, 25 min, and 1500 psi. Hence, the optimum PLE method shows that the upwards of twice efficiency of crude extract which were from 240 to 500 mg/1 g dry bamboo leaves (DL), from 1510 ± 3.2 to 2682 ± 0.9 mg/100 g for TPC contents, and for flavonoid contents from 182 ± 2.7 to 657 ± 1.7 mg/100 g. In addition, the extraction process of superheated of black bamboo leaves would increase the properties of antioxidant by decreasing the surface tension and solvent viscosity along with destroying of black bamboo leaves matrix. It also increases the bond between solvent and flavonoids and phenolics.

In another study, the extraction of sulphated polysaccharides (fucoidan) from brown seaweed *Saccharina japonica* using PLE method was performed (Saravana et al., 2016). In this study, at 140 °C with 50 bar, researchers found that the best crude fucoidan yield of 8.23 % was obtained. Luthria (2008) revealed parameters of temperature, pressure, particle size, flush length, static time, and solid-to-solvent ratio that have a significant influence on the

Table 2: Extraction methods and its applications

Year	Type of extraction	Sources	Compound extraction	Result	Reference
2015	MAE method	Quercus bark	Polyphenols	• MAE method: 0.38% methanol and 33% ethanol content, condition: room temperature, pH 10.75, 60 min, 45 W, 50 Hz • Conventional method: same extraction condition with no microwave treatment • Total phenolic content and antioxidant recoveries were increasing up to 3 times	Bouras et al., 2015
2015		Achillea millefolium dust	Antioxidants	• MAE method: ethanol 70%, condition: 33 s, 40 mL/g and 170 W • Conventional method: for 48 h and 40% ethanol at room temperature • Increased total flavonoid content from 30.82 ± 2.35 mg to 42.95 ± 1.32 mg quercetin equivalents (QE)/g, total polyphenol content from 135.26 ± 1.72 mg to 237.74 ± 2.08 mg GAE/g, 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging activity from 21.58 ± 0.88% to 71.72 ± 2.12% • MAE took shorter time with great extraction yields to extract the antioxidant compared to conventional method	Multinovic et al., 2015
2003		Ginseng root	Ginsonesides	• Higher recovery of Ginsonesides from ginseng root by using MAE method was superior because it took only 15 min compared to conventional extraction method which took 10 h	Shu et al., 2003
2013	UAE method	Carrot	Carotenoid	• UAE method: sunflower oil as solvent, condition: 20 min, 22.5 W, 40 °C • Conventional method: at room temperature for 1 h for hexane • β-carotene yield of 334.75 mg/L just in 20 min while the CSE method using hexane as solvent obtained the β-carotene yield of 321.36 mg/L after one-hour extraction	Li et al., 2013
2015		Papaya	Lycopene	• UAE method: 42.28% ethanol in ethyl acetate, condition: 26.09 min, 800 W, 40 kHz, 50.12 °C. • Conventional method: 405 ethanol in ethyl acetate (300 mL) 95 °C in a Soxhlet extractor • The lycopene recovery increasing from 68.3 ± 4.1 µg/g to 189.8 ± 4.5 µg/g	Li et al., 2015
2016		Blueberry wine pomace	Anthocyanins and phenolics	• UAE method: 0.01% hydrochloric acid and 70% ethanol, conditions: 23.67 min, 400 W, 61.03 °C • Conventional method: 0.01% hydrochloric acid and 70% ethanol, conditions: 35 min, 61 °C, no ultrasound treatment • Total of anthocyanins from 1.72 to 4.27 mg g C3G/g (2.5-fold) and total phenolics from 5.08 to 16.41 mg gallic acid equivalent (GAE)/g (about 3.2-fold)	He et al., 2016

PLE method of extracting antioxidants compounds from parsley (*Petroselinum crispum*) flakes. Then, the extraction of natural antioxidants compounds from marine sponges has been successfully applied using PLE (Ibanez et al., 2012).

The summary of the extraction methods discussed were tabulated in Table 2.

7.0 Conclusion

Natural antioxidants compounds play a significant role in human health. It can usually be found in

Table 2 *(Continued)*

Year	Type of extraction	Sources	Compound extraction	Result	Reference
2013	PEF method	Orange peel	Polyphenols	• PEF method: 5 bars for 30 min pressurisation, 0.06 to 3.77 kJ/kg, distilled water 5kV/cm and 60 µs. • Conventional method: extraction same without PEF treatment • Increased hesperidin content (1.3–4.6 mg/100 g) and naringin content (1.0–3.1 mg/100 g).	Luengo et al., 2013
2015		Borago officinalis L. leaves	Polyphenols	• PEF method: 0.04 to 61.1 kJ/kg, (pH 1.5) acidic water 1 to 7 kV/cm • Conventional method: extraction same without PEF treatment • Increased ORAC value (2-13.7 times) and the TPC value (1.3–6.6 times).	Segovia et al., 2015
2015		Defatted canola seed cake	Polyphenols	• PEF method: 10 s, 30 Hz, 30 V, and 10% ethanol. • Conventional method: liquid/ solid ratio of 6.0, 633.3 W, and 5 min for microwave processing. • Extraction time shorter and less solvent usage.	Teh et al., 2015
2013	EAE method	Tomato processing waste	Lycopene	• EAE method: ethanol/hexane/acetone (25:50:25v/v), Condition: 1.5% cellulase/2% pectinase at 4 h of incubation period. • Conventional method: no enzyme treatment. • The extraction of lycopene increases from below than 200 to 847.33 µg/g (cellulase treatment) and to 1262.56 µg/g (pectinase treatment).	Ranveer et al., 2013
2015		Wine making by-products	Phenolic	• EAE method: 2% viscozyme solution with 70% acetone enzyme treatment stirred for 12 h at 37 °C or 1 mg /mL pronase solution stirred for 1 h, then extraction with acetone 70% in a gyratory water bath shaker at 30 °C for 20 min. • Conventional method: same extraction process but no enzyme treatment. • Viscozyme and pronase reduce the content of insoluble bound phenolics while increase the content of soluble phenolic	Mushtaq et al., 2015
2016		grape skins	Flavonoid	• EAE method: the buffer solution contains appropriate amount of enzyme, condition: pH 2, 45 °C, 3 h and 10.52 mg/g Lallsyme EX-V. • Conventional method: 70% aqueous ethanol containing 1% formic acid for one day in the dark. • Improved recovery of anthocyanin contents (from 40,496.19 ± 58.18 mg/kg to 41,752.95 ± 76.10 mg/kg) and flavan-3-ol contents (from 329.32 ± 2.46 mg/kg to 345.94 ± 2.88 mg/kg).	Tomaz et al., 2016

medicinal herbs, fruits, vegetables, and plants. There are various techniques that have been introduced for the extraction methods of plant-based natural antioxidant compounds. The previously introduced conventional methods have been the starting point to the development of extraction technology. Improvements on the conventional methods have led to the existence of new methods known as non-conventional methods. These non-conventional methods were inspired to overcome the shortcomings of conventional methods where these methods generate significant quantities of yields and reduce the amount

Table 2 *(Continued)*

Year	Type of extraction	Sources	Compound extraction	Result	Reference
2014	SFE method	*Calycopteris floribunda* leaves	Flavonoids	• At lower temperature and higher pressure, the maximum extraction SFE yields were obtained. • At 1.5 kg/h flowrate of CO_2, 300 min, 30 MPa, and 35 °C of SFE was contrasted with classical extraction (CE) with 40% ethanol solution for 8 h at 70 °C. • CE approach to achieve the highest yield which is 8.01%, while the efficiency separation of pachypodol from SFE extracts was 3.7 times higher than that achieved by CE. • SFE method could increase the selectivity of some flavonoid components.	Liu et al., 2014
2016		Persimmon (*Diospyros kaki L.*)	Carotenoids	• SFE has demonstrated higher extraction performance and lower extraction time relative to other methods.	Zaghdoudi et al., 2016
2016		Rosemary leaves	Pentacyclic triterpene α, β-amyrin	• SFE is one of the best methods for the efficient extraction of pentacyclic triterpene α, β-amyrin from rosemary leaves.	Bensebia et al., 2016
2016		Myrtle leaves and berries	antioxidants	• Condition 45 °C, 23 MPa, flowrate 0.09 kg/h and 0.3 kg/h of CO_2 flow using absolute ethanol as co solvent. • Conventional method: 2 h to obtain by hydro-distillation using Clevenger- type apparatus. • Increased myricetin-3-O-rhamnoside content (about 110–170 times in fruit and about 130–210 times in leaves), antioxidant capacity (about 20–40 times), polyphenolic contents (about 2 times).	Pereira et al., 2016
2014	PLE method	Black bamboo leaves	Antioxidants	• PLE method: 75% ethanol for total flavonoid (TF) and 25% ethanol for DPPH radical scavenging ability: 50% ethanol for the total phenolic (TP), condition 200 °C, 25 min static time and 1500 psi • For conventional method: extraction method reflux (60 min, −90 °C,1 L solvent). • The extraction improves the product from 1510 ± 3.2 mg/100 g to 2682 ± 0.9 mg/100 g for TP contents, TF contents from 182 ± 2.7 to 657 ± 1.7 mg/100 g and from 240 to 500 mg/1 g Dry black bamboo leaves (DL).	Shang et al., 2014
2016		Brown seaweed Saccharina japonica	Sulfated polysaccharides (fucoidan)	• At 140 °C with 50 bar, researchers found that the best crude fucoidan yield of 8.23% was obtained.	Saravana et al., 2016
2008		Parsley (Petroselinum crispum) flakes	Antioxidants	• Parameters of temperature, pressure, particle size, flush length, static time, and solid-to-solvent ratio that have a significant influence on the PLE method.	Luthria, 2008
2016		Aerial parts of Dracoceph- alum kotschyi	Flavonoid and phenolics	• PLE method: 17.45 dynamic time, 11.33 static time, 0.7 mL/min solvent flow rate, 34 bar pressure and 74 °C. • According to the European Pharmacopeia, percolated with 1 L of methanol at room temperature (25 °C) improves recovery of total flavonoids from 5.042 ± 0.04 to 6.13 ± 0.07 QE mg/g, luteolin content from 9,550 ± 0.3 to 13,247 ± 0.2 µg/g and total phenolic from 22.29 ± 0.05 to 30.92 ± 0.03 GAE mg/g.	Kamali et al., 2016

of solvent used. Besides, the non-conventional method also implements a green solvent where it can minimize environmental damage. However, the contribution of the conventional method cannot be denied as both methods having their pros and cons. Therefore, understanding the process of the natural antioxidants compound extraction will be critically important if we are to reach the best potential methods and will in turn undoubtedly lead us to technological advancements in the extraction process.

Acknowledgement

The authors would like to send our gratitude to School of Chemical Engineering, College of Engineering, Universiti Teknologi MARA Shah Alam for its support.

References

Ade-Omowaye, B. I. O., Angersbach, A., Taiwo, K. A., & Knorr, D. (2001). Use of pulsed electric field pre-treatment to improve dehydration characteristics of plant-based foods. *Trends in Food Science & Technology*, *12*(8), 285–295. https://doi.org/10.1016/S0924-2244(01)00095-4

Ajila, C. M., Brar, S. K., Verma, M., Tyagi, R. D., Godbout, S., & Valéro, J. R. (2011). extraction and analysis of polyphenols: Recent trends. *Critical Review Biotechnology*, *31*(3), 227–249. https://doi.org/10.3109/07388551.2010.513677

Altemimi, A., Watson, D. G., Choudhary, R., Dasari, M. R., & Lightfoot, D. A. (2016). Ultrasound assisted extraction of phenolic compounds from peaches and pumpkins. *PLOS ONE*, *11*(2), e0148758. https://doi.org/10.1371/journal.pone.0148758

Amit, K., & Priyadarsini, K. I. (2011). Free radicals, oxidative stress, and importance of antioxidants in human health. *Journal of Medical & Allied Sciences*, *1*(2), 53-60. https://doi.org/10.4103/0973-7847.70902

Anel-lópez, L., Álvarez-rodríguez, M., García-álvarez, O., Álvarez, M., Maroto-morales, A., Anel, L., Paz, P. D., Garde, J. J., & Martínez-pastor, F. (2012). Reduced glutathione and Trolox (vitamin E) as extender supplements in cryopreservation of red deer epididymal spermatozoa. *135*, 37–46. https://doi.org/10.1016/j.anireprosci.2012.09.001.

Angersbach, U. A., Heinz, V., & Knorr, D. (2000). Effects of pulsed electric fields on cell membranes in real food systems. 135–149. https://doi.org/10.1016/S1466-8564(00)00010-2

Anwar, H. (2018). Antioxidants from Natural Sources. In E. S. a. G. M. Azzam (Ed.), *Antioxidants in Foods and Its Applications* (pp. 3–28). Intech Open. https://doi.org/https://doi.org/10.5772/intechopen.75961

Asghari, J., Ondruschka, B., & Mazaheritehrani, M. (2011). Extraction of bioactive chemical compounds from the medicinal Asian plants by microwave irradiation. *Journal of Medicinal Plants Research*, *5*(4), 495–506. https://doi.org/10.5897/JMPR.9000641

Baiano, A., & Del Nobile, M. A. (2016). Antioxidant compounds from vegetable matrices: biosynthesis, occurrence, and extraction systems. *Critical Reviews in Food Science and Nutrition*, *56*(12), 2053–2068. https://doi.org/10.1080/10408398.2013.812059

Belwal, T., Dhyani, P., Bhatt, I. D., Rawal, R. S., & Pande, V. (2016). Optimization extraction conditions for improving phenolic content and antioxidant activity in Berberis asiatica fruits using response surface methodology (RSM). *Food Chemistry*, *207*, 115–124. https://doi.org/10.1016/j.foodchem.2016.03.081

Bensebia, O., Bensebia, B., Allia, K., & Barth, D. (2016). Supercritical CO_2 extraction of triterpenes from rosemary leaves: Kinetics and modelling. *Separation Science and Technology (Philadelphia)*, *51*(13), 2174–2182. https://doi.org/10.1080/01496395.2016.1202977

Biswas, S. K., McClure, D., Jimenez, L. A., Megson, I. L., & Rahman, I. (2005). Curcumin induces glutathione biosynthesis and inhibits NF-kappaB activation and interleukin-8 release in alveolar epithelial cells: mechanism of free radical scavenging activity. *Antioxidant and Redox Signaling*, *7*(1–2), 32–41. https://doi.org/10.1089/ars.2005.7.32

Bouras, M., Chadni, M., Barba, F. J., Grimi, N., Bals, O., & Vorobiev, E. (2015). Optimization of microwave-assisted extraction of polyphenols from Quercus bark. *Industrial Crops and Products*, *77*, 590–601. https://doi.org/10.1016/j.indcrop.2015.09.018

Bozan, B., & Altinay, R. C. (2014). Accelerated solvent extraction of flavan-3-OL derivatives from grape seeds. *Food Science and Technology Research*, *20*(2), 409–414. https://doi.org/10.3136/fstr.20.409

Breithaupt, D. E. (2004). Simultaneous HPLC determination of carotenoids used as food coloring additives: Applicability of accelerated solvent extraction. *Food Chemistry*, *86*(3), 449–456. https://doi.org/10.1016/j.foodchem.2003.10.027

Cai, Z., Qu, Z., Lan, Y., Zhao, S., Ma, X., Wan, Q., Jing, P., & Li, P. (2016). Conventional, ultrasound-assisted, and accelerated-solvent extractions of anthocyanins from purple sweet potatoes. *Food Chemistry*, *197*, 266–272. https://doi.org/10.1016/j.foodchem.2015.10.110

Castro-López, C., Rojas, R., Sánchez-Alejo, G. N.-M. E. J., & Martínez-Ávila, G. C. G. (2016). Phenolic compounds recovery from grapefruit and by-products: An Overview of extraction methods.

Chen, A. Y., & Chen, Y. C. (2013). A review of the dietary flavonoid, kaempferol on human health and cancer chemoprevention. *Food Chemistry*, *138*(4), 2099-2107. https://doi.org/10.1016/j.foodchem.2012.11.139

Cheng, X., Bi, L., Zhao, Z., & Chen, Y. (2015, 2015/08). Advances in enzyme assisted extraction of natural products. Proceedings of the 3rd International Conference on Material, Mechanical and Manufacturing Engineering,

Cowan, M. M. (1999). Plant product as antimicrobial agents. *Clinical Microbiology Reviews*, *12*(4), 564–582. https://doi.org/10.1128/CMR.12.4.564

De Camargo, A. C., Regitano-d'Arce, M. A. B., Biasoto, A. C. T., & Shahidi, F. (2016). Enzyme-assisted extraction of phenolics from winemaking by-products: Antioxidant potential and inhibition of alpha-glucosidase and lipase activities. *Food Chemistry*, *212*, 395–402. https://doi.org/10.1016/j.foodchem.2016.05.047

De Groot, P., & Munden, R. F. (1990). Lung cancer epidemiology, risk factors, and prevention. *Radiologic clinics of North America*, *50*(5), 863–876. https://doi.org/10.1016/j.rcl.2012.06.006

Delsart, C., Ghidossi, R., Poupot, C., Cholet, C., Grimi, N., Vorobiev, E., Milisic, V., & Mietton Peuchot, M. (2012). Enhanced extraction of phenolic compounds from Merlot grapes by pulsed electric field treatment. *American Journal of Enology and Viticulture*, *63*(2), 205. https://doi.org/10.5344/ajev.2012.11088

Esclapez, M. D., García-Pérez, J. V., Mulet, A., & Cárcel, J. A. (2011). Ultrasound-assisted extraction of natural products. *Food Engineering Reviews*, *3*(2), 108. https://doi.org/10.1007/s12393-011-9036-6

Fincan, M., & Dejmek, P. (2002). In situ visualization of the effect of a pulsed electric field on plant tissue. *Journal of Food Engineering*, *55*(3), 223–230. https://doi.org/10.1016/S0260-8774(02)00079-1

Flórez, N., Conde, E., & Domínguez, H. (2015). Microwave assisted water extraction of plant compounds. *Journal of Chemical Technology & Biotechnology*, *90*(4), 590–607. https://doi.org/10.1002/jctb.4519

Fu, L., Xu, B. T., Xu, X. R., Gan, R. Y., Zhang, Y., Xia, E. Q., & Li, H. B. (2011). Antioxidant capacities and total phenolic contents of 62 fruits. *Food Chemistry*, *129*(2), 345–350. https://doi.org/10.1016/j.foodchem.2011.04.079

Greenlee, H. (2012). Natural products for cancer prevention. *Seminars in Oncology Nursing*, *28*(1), 29-44. https://doi.org/10.1016/j.soncn.2011.11.004

Han, S.-F., Jin, W., Yang, Q., El-Fatah Abomohra, A., Zhou, X., Tu, R., Chen, C., Xie, G.-J., & Wang, Q. (2019). Application of pulse electric field pre-treatment for enhancing lipid extraction from Chlorella pyrenoidosa grown in wastewater. *Renewable Energy*, *133*, 233–239. https://doi.org/10.1016/j.renene.2018.10.034

He, B., Zhang, L.-L., Yue, X.-Y., Liang, J., Jiang, J., Gao, X.-L., & Yue, P.-X. (2016). Optimization of ultrasound-assisted extraction of phenolic compounds and anthocyanins from blueberry (Vaccinium ashei) wine pomace. *Food Chemistry*, *204*, 70–76. https://doi.org/10.1016/j.foodchem.2016.02.094

Heinz, V., Toepfl, S., & Knorr, D. (2003). Impact of temperature on lethality and energy efficiency of apple juice pasteurization by pulsed electric fields treatment. *Innovative Food Science & Emerging Technologies*, *4*(2), 167–175. https://doi.org/10.1016/S1466-8564(03)00017-1

Herrero, M., Sánchez-Camargo, A. d. P., Cifuentes, A., & Ibáñez, E. (2015). Plants, seaweeds, microalgae, and food by-products as natural sources of functional ingredients obtained using pressurised liquid extraction and supercritical fluid extraction. *Trends in Analytical Chemistry*, *71*, 26–38. https://doi.org/10.1016/j.trac.2015.01.018

Howard, L., & Pandjaitan, N. (2008). Pressurized liquid extraction of flavonoids from spinach. *Journal of Food Science*, *73*(3), 151–157. https://doi.org/10.1111/j.1750-3841.2007.00658.x

Hui, C., Bin, Y., Xiaoping, Y., Long, Y., Chunye, C., Mantian, M., & Wenhua, L. (2010). Anticancer activities of an anthocyanin-rich extract from black rice against breast cancer cells in vitro and in vivo. *Nutrition and cancer*, *62*(8), 1128–1136. https://doi.org/10.1080/01635581.2010.494821

Ibañez, E., Herrero, M., Mendiola, J. A., & Castro-Puyana, M. (2012). Extraction and characterization of bioactive compounds with health benefits from marine resources: macro and micro algae, cyanobacteria, and invertebrates. In M. Hayes (Ed.), *Marine Bioactive Compounds: Sources, Characterization and Applications* (pp. 55–98). Springer US. https://doi.org/10.1007/978-1-4614-1247-2_2

Jomova, K., & Valko, M. (2013). Health protective effects of carotenoids and their interactions with other biological antioxidants. *European Journal of Medicinal Chemistry*, *70*, 102–110. https://doi.org/10.1016/j.ejmech.2013.09.054

Kamali, H., Khodaverdi, E., Hadizadeh, F., & Ghaziaskar, S. H. (2016). Optimization of phenolic and flavonoid content and antioxidants capacity of pressurized liquid extraction from *Dracocephalum kotschyi* via circumscribed central composite. *Journal of Supercritical Fluids*, *107*, 307–314. https://doi.org/10.1016/j.supflu.2015.09.028

Kaufmann, B., & Christen, P. (2002). Recent extraction techniques for natural products: microwave-assisted extraction and pressurised solvent extraction. *Phytochemical Analysis*, *13*(2), 105–113. https://doi.org/10.1002/pca.631

Kim, A. y., Jeong, Y.-j., Bok, Y., Lee, M.-k., Jeon, S.-m., McGregor, R. A., & Choi, M.-s. (2012). Dose dependent effects of lycopene enriched tomato-wine on liver and adipose tissue in high-fat diet fed rats. *Food Chemistry*, *130*, 42–48. https://doi.org/10.1016/j.foodchem.2011.06.050

Kurzawa-zegota, M., Najafzadeh, M., Baumgartner, A., & Anderson, D. (2012). The protective effect of the flavonoids on food-mutagen-induced DNA damage in peripheral blood lymphocytes from colon cancer patients. *Food and Chemical Toxicology*, *50*, 124–129. https://doi.org/10.1016/j.fct.2011.08.020

Kusuma, H. S., & Mahfud, M. (2016). Response Surface Methodology for Optimization Studies of Microwave assisted Extraction of Sandalwood Oil. *Journal of Materials and Environmental Science*, *7*(6), 1958–1971.

Lebovka, N. I., Bazhal, M. I., & Vorobiev, E. (2002). Estimation of characteristic damage time of food materials in pulsed-electric fields. *Journal of Food Engineering*, *54*(4), 337–346. https://doi.org/10.1016/S0260-8774(01)00220-5

Li, A.-N., Li, S., Xu, D.-P., Xu, X.-R., Chen, Y.-M., Ling, W.-H., Chen, F., & Li, H.-B. (2015). Optimization of ultrasound-assisted extraction of *Lycopene* from papaya processing waste by response surface methodology. *Food analytical methods*, *8*(5), 1207–1214. https://doi.org/10.1007/s12161-014-9955-y

Li, S., Tan, H. Y., Wang, N., Zhang, Z. J., Lao, L., Wong, C. W., & Feng, Y. (2015). The role of oxidative stress and antioxidants in liver diseases. *International Journal of Molecular Sciences*, *16*(11), 26087–26124. https://doi.org/10.3390/ijms161125942

Li, Y., Fabiano-tixier, A. S., Tomao, V., Cravotto, G., & Chemat, F. (2013). Green ultrasound-assisted extraction of carotenoids based on the bio-refinery concept using sunflower oil as an alternative solvent. *Ultrasonics Sonochemistry.*, *20*, 12–18. https://doi.org/10.1016/j.ultsonch.2012.07.005

Liu, J. J., Gasmalla, M. A. A., Li, P., & Yang, R. (2016). Enzyme-assisted extraction processing from oilseeds: Principle, processing, and application. *Innovative Food Science & Emerging Technologies*, *35*, 184–193. https://doi.org/10.1016/j.ifset.2016.05.002

Liu, X., Hu, Y., & Wei, D. (2014). Optimization of enzyme-based ultrasonic/microwave-assisted extraction and evaluation of antioxidant activity of orcinol glucoside from the rhizomes of Curculigo orchioides Gaertn. *Medicinal Chemistry Research*, *23*(5), 2360–367. https://doi.org/10.1007/s00044-013-0834-7

Liu, X., Yang, D. L., Liu, J. J., Xu, K., & Wu, G. H. (2014). Modeling of supercritical fluid extraction of flavonoids from Calycopteris floribunda leaves. *Chemical Papers*, *68*(3), 316–323. https://doi.org/10.2478/s11696-013-0451-4

López, N., Puértolas, E., Condón, S., Raso, J., & Alvarez, I. (2009). Enhancement of the extraction of betanine from red beetroot by pulsed electric fields. *Journal of Food Engineering*, *90*, 60–66. https://doi.org/10.1016/j.jfoodeng.2008.06.002

López, N., Puértolas, E., Condón, S., Álvarez, I., & Raso, J. (2008). Effects of pulsed electric fields on the extraction of phenolic compounds during the fermentation of must of Tempranillo grapes. *Innovative Food Science and Emerging Technologies*, *9*(4), 477–482. https://doi.org/10.1016/j.ifset.2007.11.001

Lu, J., Xu, Y., Yang, M., Fu, X., Luo, F., & Li, Z. (2015). Optimization of Ultrasound-Assisted Extraction of Flavonoids from *Cryptotaenia japonica* Hassk. and Evaluation of Antioxidant Activity. *Journal of Agricultural Science*, *7*(7). https://doi.org/10.5539/jas.v7n7p138

Luengo, E., Álvarez, I., & Raso, J. (2013). Improving the pressing extraction of polyphenols of orange peel by pulsed electric fields. *Innovative Food Science & Emerging Technologies*, *17*, 79–84. https://doi.org/10.1016/j.ifset.2012.10.005

Luque de Castro, M. D., & García-Ayuso, L. E. (1998). Soxhlet extraction of solid materials: an outdated technique with a promising innovative future. *Analytica Chimica Acta*, *369*(1), 1–10. https://doi.org/10.1016/S0003-2670(98)00233-5

Luthria, D. L. (2008). Influence of experimental conditions on the extraction of phenolic compounds from parsley (Petroselinum crispum) flakes using a pressurized liquid extractor. *Food Chemistry*, *107*(2), 745–752. https://doi.org/10.1016/j.foodchem.2007.08.074

Manach, C., Scalbert, A., Morand, C., Rémésy, C., & Jime, L. (2004). Polyphenols: food sources and bioavailability. *The American Journal of Clinical Nutrition*, *79*(5), 727–747. https://doi.org/10.1093/ajcn/79.5.727

Maran, J. P., Priya, B., & Manikandan, S. (2014). Modeling and optimization of supercritical fluid extraction of anthocyanin and phenolic compounds from Syzygium cumini fruit pulp. *Journal of Food Science and Technology*, *51*(9), 1938–1946. https://doi.org/10.1007/s13197-013-1237-y

Markom, M., Singh, H., & Hasan, M. (2018). Supercritical CO_2 fractionation of crude palm oil. *The Journal of Supercritical Fluids*, *20*(1), 45–53. https://doi.org/10.1016/S0896-8446(00)00104-2

Mercer, P., & Armenta, R. E. (2011). Developments in oil extraction from microalgae. *European Journal of Lipid Science and Technology*, *113*(5), 539–547. https://doi.org/10.1002/ejlt.201000455

Milutinović, M., Radovanović, N., Ćorović, M., Šiler-Marinković, S., Rajilić-Stojanović, M., & Dimitrijević-Branković, S. (2015). Optimisation of microwave-assisted extraction parameters for antioxidants from waste Achillea millefolium dust. *Industrial Crops and Products*, *77*, 333–341. https://doi.org/https://doi.org/10.1016/j.indcrop.2015.09.007

Mushtaq, M., & Sultana, B. (2014). RSM based optimized enzyme-assisted extraction of antioxidant phenolics from underutilized watermelon (*Citrullus lanatus Thunb*.) rind. *Journal of Food Science and Technology*, *52*(8), 5048–5056. https://doi.org/10.1007/s13197-014-1562-9

Nawaz, H., Shad, M. A., Rehman, N., Andaleeb, H., & Ullah, N. (2020). Effect of solvent polarity on extraction yield and antioxidant properties of phytochemicals from bean (Phaseolus vulgaris) seeds. *Brazilian Journal of Pharmaceutical Sciences*, *56*, e17129. https://doi.org/10.1590/s2175-97902019000417129

Nguyen, V. T., Sakoff, J. A., & Scarlett, C. J. (2017). Physicochemical Properties, Antioxidant and Cytotoxic Activities of Crude Extracts and Fractions from Phyllanthus amarus. *Medicines (Basel, Switzerland)*, *4*(2), 1–15. https://doi.org/10.3390/medicines4020042

Oroian, M., & Escriche, I. (2015). Antioxidants: Characterization, natural sources, extraction, and analysis. *Food Research International*, *74*, 10–36. https://doi.org/10.1016/j.foodres.2015.04.018

Pasaporte, M. S., Rabaya, F. J. R., Toleco, M. M., & Flores, D. M. (2014). Xanthophyll content of selected vegetables commonly consumed in the Philippines and the effect of boiling. *Food Chemistry*, *158*, 35–40. https://doi.org/10.1016/j.foodchem.2014.02.090

Pasrija, D., & Anandharamakrishnan, C. (2015). Techniques for extraction of green tea polyphenols: A Review. *Food and Bioprocess Technology*, *8*(5), 935–950. https://doi.org/10.1007/s11947-015-1479-y

Pereira, P., Cebola, M.-J., Oliveira, M. C., & Bernardo-Gil, M. G. (2016). Supercritical fluid extraction vs conventional extraction of myrtle leaves and berries: Comparison of antioxidant activity and identification of bioactive compounds. *The Journal of Supercritical Fluids*, *113*, 1–9. https://doi.org/10.1016/j.supflu.2015.09.006

Pojer, E., Mattivi, F., Johnson, D., & Stockley, C. S. (2013). The case for anthocyanin consumption to promote human health: A Review. *Comprehensive Reviews in Food Science and Food Safety*, *12*(2006), 483–508. https://doi.org/10.1111/1541-4337.12024

Poole, C. F. (2020). Chapter 1 - Milestones in the Development of liquid-phase extraction techniques. In C. F. Poole (Ed.), *Liquid-Phase Extraction* (pp. 1–44). Elsevier. https://doi.org/10.1016/B978-0-12-816911-7.00001-3

Puértolas, E., López, N., Saldaña, G., Álvarez, I., & Raso, J. (2010). Evaluation of phenolic extraction during fermentation of red grapes treated by a continuous pulsed electric fields process at pilot-plant scale. *Journal of Food Engineering*, *98*, 120–125. https://doi.org/10.1016/j.jfoodeng.2009.12.017

Puri, M., Sharma, D., & Barrow, C. J. (2012). Enzyme-assisted extraction of bioactives from plants. *Trends in biotechnology*, *30*(1), 37–44. https://doi.org/10.1016/j.tibtech.2011.06.014

Ranveer, R. C., Patil, S. N., & Sahoo, A. K. (2013). Effect of different parameters on enzyme-assisted extraction of lycopene from tomato processing waste. *Food and Bioproducts Processing*, *91*(4), 370–375. https://doi.org/10.1016/j.fbp.2013.01.006

Rasheed, A., Fathima, R., & Azeez, A. (2019). A Review on natural antioxidants. In *Traditional and Complementary Medicine*. Intech Open. https://doi.org/10.5772/intechopen.82636

Riccioni, G., Speranza, L., Pesce, M., Cusenza, S., D'Orazio, N., & Glade, M. J. (2012). Novel phytonutrient contributors to antioxidant protection against cardiovascular disease. *Nutrition and cancer*, *28*, 605–610. https://doi.org/10.1016/j.nut.2011.11.028

Richter, B. E., Jones, B. A., Ezzell, J. L., Porter, N. L., Avdalovic, N., & Pohl, C. (1996). Accelerated solvent extraction: A technique for sample preparation. *Analytical Chemistry*, *68*(6), 1033–1039. https://doi.org/10.1021/ac9508199

Roddy, E. (2014). Epidemiology of Gout. *Rheumatic Disease Clinics of North America*, *40*, 155–175. https://doi.org/10.1016/j.rdc.2014.01.001

Routray, W., & Orsat, V. (2012). microwave-assisted extraction of flavonoids: A review. *Food and Bioprocess Technology*, *5*, 409–424. https://doi.org/10.1007/s11947-011-0573-z

Sagar, N. A., Pareek, S., Sharma, S., Yahia, E. M., & Lobo, M. G. (2018). Fruit and vegetable waste: bioactive compounds, their extraction, and possible utilization. *Comprehensive Reviews in Food Science and Food Safety*, *17*(3), 512-531. https://doi.org/10.1111/1541-4337.12330

Sanagi, M. M., See, H. H., Ibrahim, W. A. W., & Naim, A. A. (2005). Determination of carotene, tocopherols and tocotrienols in residue oil from palm pressed fiber using pressurized liquid extraction-normal phase liquid chromatography. *Analytica Chimica Acta*, *538*(1–2), 71–76. https://doi.org/10.1016/j.aca.2005.02.028

Santos-buelga, C., Mateus, N., & Freitas, V. D. (2014). Anthocyanins. Plant pigments and beyond. *Journal of Agricultural and Food Chemistry*, *62*(29), 6879–6884. https://doi.org/10.1021/jf501950s

Santos, E. O. L., Kabeya, L. M., Figueiredo-rinhel, A. S. G., Marchi, L. F., Andrade, M. F., Piatesi, F., Paoliello-paschoalato, A. B., Elisa, A., Azzolini, C. S., & Lucisano-valim, Y. M. (2014). Flavonols modulate the effector functions of healthy individuals' immune complex-stimulated neutrophils: A therapeutic perspective for rheumatoid arthritis. *International Immunopharmacology 21*, 102–111. https://doi.org/10.1016/j.intimp.2014.04.014

Saravana, P. S., Cho, Y. J., Park, Y. B., Woo, H. C., & Chun, B. S. (2016). Structural, antioxidant, and emulsifying activities of fucoidan from Saccharina japonica using pressurized liquid extraction. *Carbohydrate Polymers*, *153*, 518–525. https://doi.org/10.1016/j.carbpol.2016.08.014

Segovia, F. J., Luengo, E., Corral-Pérez, J. J., Raso, J., & Almajano, M. P. (2015). Improvements in the aqueous extraction of polyphenols from borage (*Borago officinalis* L.) leaves by pulsed electric fields: Pulsed electric fields (PEF) applications. *Industrial Crops and Products*, *65*, 390–396. https://doi.org/10.1016/j.indcrop.2014.11.010

Setyaningsih, W., Saputro, I. E., Palma, M., & Barroso, C. G. (2016). Pressurized liquid extraction of phenolic compounds from rice (Oryza sativa) grains. *Food Chemistry*, *192*, 452–459. https://doi.org/10.1016/j.foodchem.2015.06.102

Selvamuthukumaran, M., & Shi, J. (2017). Recent advances in extraction of antioxidants from plant by-products processing industries. *Food Quality and Safety*, *1*, 61–81. https://doi.org/10.1093/fqs/fyx004

Shahkar, E., Yun, H., Kim, D.-j., Kim, S.-k., Ik, B., & Bai, S. C. (2015). Effects of dietary vitamin C levels on tissue ascorbic acid concentration, hematology, non-specific immune response and gonad histology in broodstock Japanese eel, Anguilla japonica. *Aquaculture*, *438*, 115–121. https://doi.org/10.1016/j.aquaculture.2015.01.001

Shang, Y. F., Kim, S. M., & Um, B.-H. (2014). Optimisation of pressurised liquid extraction of antioxidants from black bamboo leaves. *Food Chemistry*, *154*, 164–170. https://doi.org/10.1016/j.foodchem.2013.12.050

Sharmila, G., Nikitha, V. S., Ilaiyarasi, S., Dhivya, K., Rajasekar, V., Kumar, N. M., Muthukumaran, K., & Muthukumaran, C. (2016). Ultrasound assisted extraction of total phenolics from Cassia auriculata leaves and evaluation of its antioxidant activities. *Industrial Crops and Products*, *84*, 13–21. https://doi.org/10.1016/j.indcrop.2016.01.010

Shu, Y. Y., Ko, M. Y., & Chang, Y. S. (2003). Microwave-assisted extraction of ginsenosides from ginseng root. *Microchemical Journal*, *74*(2), 131–139. https://doi.org/10.1016/S0026-265X(02)00180-7

Silva, L. V., Nelson, D. L., Drummond, M. F. B., Dufossé, L., & Glória, M. B. A. (2005). Comparison of hydrodistillation methods for the deodorization of turmeric. *Food Research International*, *38*, 1087–1096. https://doi.org/10.1016/j.foodres.2005.02.025

Sikora, E., Cieslik, E., & Topolska, K. (2016). The sources of natural antioxidants. *Acta Scientiarum Polonorum*, *7*(1), 5–17.

Sitholé, B., Shirin, S., & Ambayec, B. (2010). Analysis and fate of lipophilic extractives in sulphite pulps. *Journal of Wood Chemistry and Technology*, *30*(1), 31–47. https://doi.org/10.1080/02773810903370404

Talmaciu, I., Volf, I., & Popa, V. I. (2015). A comparative analysis of the green techniques applied for polyphenols extraction from bioresources. *Chemistry and Biodiversity*, *12*, 1635-1651. https://doi.org/10.1002/cbdv.201400415

Tatke, P. A., & Jaiswal, Y. S. (2011). An overview of microwave assisted extraction and its applications in herbal drug research. *Research Journal of Medicinal Plant*, *5*, 21–31. https://doi.org/10.3923/RJMP.2011.21.31

Teh, S.-s., Niven, B. E., Bekhit, A. E.-d. A., Carne, A., & Birch, E. J. (2015). Microwave and pulsed electric field assisted extractions of polyphenols from defatted canola seed cake. *International Journal of Food Science & Technology*, *50*, 1109–1115. https://doi.org/10.1111/ijfs.12749

Thirugnanasambandham, K., & Sivakumar, V. (2017). Microwave assisted extraction process of betalain from dragon fruit and its antioxidant activities. *Journal of the Saudi Society of Agricultural Sciences*, *16*(1), 41–48. https://doi.org/10.1016/j.jssas.2015.02.001

Toepfl, S., Mathys, A., Heinz, V., & Knorr, D. (2006). Review: Potential of high hydrostatic pressure and pulsed electric fields for energy efficient and environmentally friendly food processing. *Food Reviews International*, *22*, 405–423. https://doi.org/10.1080/87559120600865164

Tomás-Barberán, F. A., & Andrés-Lacueva, C. (2012). Polyphenols and health: current state and progress. *Journal of Agricultural and Food Chemistry*, *60*(36), 8773–8775. https://doi.org/10.1021/jf300671j

Tomaz, I., Maslov, L., Stupić, D., Preiner, D., Ašperger, D., & Kontić, J. K. (2016). Recovery of flavonoids from grape skins by enzyme-assisted extraction. *Separation Science and Technology*, *51*(2), 255–268. https://doi.org/10.1080/01496395.2015.1085881

Tsuda, T. (2012). Dietary anthocyanin-rich plants: Biochemical basis and recent progress in health benefits studies. *Molecular Nutrition & Food Research*, *56*(1), 159–170. https://doi.org/10.1002/mnfr.201100526

Vaisi- Raygani, A., Rahimi, Z., Noroozian, M., & Pourmotabbed, A. (2007). Enzymatic and non-enzymatic antioxidant defense in Alzheimer's disease. *Acta Medica Iranica*, *45*(4), 271-276.

Vankar, P. S. (2004). Essential oils and fragrances from natural sources. *Resonance*, *9*(4), 30–41. https://doi.org/10.1007/BF02834854

Vorobiev, E., & Lebovka, N. I. (2006). extraction of intercellular components by pulsed electric fields. In J. Raso & V. Heinz (Eds.), *Pulsed Electric Fields Technology for the Food Industry: Fundamentals and Applications* (pp. 153-193). Springer US. https://doi.org/10.1007/978-0-387-31122-7_6

Wang, F., Li, Y., Zhang, Y. J., Zhou, Y., Li, S., & Li, H. B. (2016). Natural products for the prevention and treatment of hangover and alcohol use disorder. *Molecules*, *21*(1), 64. https://doi.org/10.3390/molecules21010064

Xu, D.-p., Li, Y., Meng, X., Zhou, T., Zhou, Y., Zheng, J., & Zhang, J.-j. (2017). Natural antioxidants in foods and medicinal plants: Extraction, Assessment and Resources. *International Journal of Molecular Sciences*, *18*, 20–31. https://doi.org/10.3390/ijms18010096

Yamagata, K., & Tagami, M. (2015). Chapter 41 - Prevention of ischemia-induced neuronal apoptosis by vitamin E in stroke-prone spontaneously hypertensive rats: cellular mechanisms of antioxidants. In R. R. Watson & V. R. Preedy (Eds.), *Bioactive Nutraceuticals and Dietary Supplements in Neurological and Brain Disease* (pp. 399–402). Academic Press. https://doi.org/10.1016/B978-0-12-411462-3.00041-2

Yousef, M. I. (2010). Vitamin E modulates reproductive toxicity of pyrethroid lambda-cyhalothrin in male rabbits. *Food and Chemical Toxicology*, *48*(5), 1152–1159. https://doi.org/10.1016/j.fct.2010.02.002

Zaghdoudi, K., Framboisier, X., Frochot, C., Vanderesse, R., Barth, D., Kalthoum-Cherif, J., Blanchard, F., & Guiavarc'h, Y. (2016). Response surface methodology applied to supercritical fluid extraction (SFE) of carotenoids from Persimmon (Diospyros kaki L.). *Food Chemistry*, *208*, 209–219. https://doi.org/10.1016/j.foodchem.2016.03.104

Zhang, H. F., Yang, X. H., & Wang, Y. (2011). Microwave assisted extraction of secondary metabolites from plants : Current status and future directions. *Trends in Food Science & Technology*, *22*, 672–688. https://doi.org/10.1016/j.tifs.2011.07.003