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Processing of health-promoting compounds in berries and fruits for therapeutic use

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Abstract

Health-promoting compounds (HPCs) are bioactive compounds that provide medical and health benefits, including the prevention and treatment of diseases. Some of these compounds are derived from horticultural plants, majorly fruits and berries, and they are renowned for providing benefits such as anti-ageing, protection against some chronic diseases, metabolic disorders like diabetes, degenerative diseases like cancer, protein deficiency, allergy problems and maintenance of body homeostasis. Many of the crops from which HPCs are derived, especially berries and fruits, are highly perishable and vulnerable to a number of factors, which may alter their chemical characteristics and subsequently impact on their bioactivity. One of the major factors is the processing and refining of these crops. The processing of HPCs in fruits and berries is usually done following several methods. These include traditional methods such as crushing, pressing, filtration, heat and cold treatments, and enzymatic treatments. Generally, crushing, pressing and filtration promote the extraction of fruit/berry constituents with retention of the exact chemical constituents. Heat and cold treatments destroy micro-organisms, enhance preservation and help to dissolve product components. Enzymatic treatments enhance bioactive compounds and stabilize yields. Moreso, crushing results in the disruption of the fruit/berry skins leading to chemical loss of bioactive compounds; heat and cold treatments destroy enzyme actions, while enzymatic treatments degrade cell walls and vacuolar membranes. Novel techniques in processing HPCs include ultrasound assisted extraction (UAE), microwave assisted extraction (MAE), accelerated solvent extraction (ASE), and pulsed electrical field (PEF) extraction. In the up-coming years, it is anticipated that there will be breakthroughs in the effective processing of horticultural products of therapeutic importance through the combination of novel techniques, sophisticated omics tools with automation-related software technologies.

Keywords: Bioactive compounds; Berries; Fruits; Health-promoting compounds; Novel techniques; Traditional techniques; Therapeutics.

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Introduction

Health-promoting compounds (HPCs) are bioactive compounds that provide medical and health benefits, including the prevention and treatment of diseases. Earlier reports show that HPCs serve as health promoters when they function as cofactors or inhibitors in enzymatic reactions, substrates in biochemical reactions, absorbents for the removal of undesirable compounds, and as scavenging agents for reactive and toxic chemicals (Kris-Etherton *et al*., 2002). These compounds also provide several pharmacological benefits such as anti-ageing, protection against some chronic diseases, metabolic disorders like diabetes, degenerative diseases like cancer, protein deficiency, allergy problems, etc. and maintenance of body homeostasis. HPCs are commonly derived from horticultural plants, majorly fruits and berries (Bansal *et al*., 2023).

The HPCs in plants (fruits and berries) are classified according to various criteria, based on: (i). Clinical function i.e., pharmacological or toxicological effects; (ii). Biological effects; and (iii). Botanical categorisation which is based on families and genera of closely related plant species producing the bioactive compounds (Kårlund *et al*., 2014). Some examples of these group of compounds are: glycosides which are majorly present in plants of *Scrophulariaceae (figwort family)*; saponins are present in a range of plant families such as *Liliaceae (lily family)*; flavonoids and proanthocyanidins are produced by species of *Fabaeceae (bean family)*; tannins are produced by species of *Fagaceae (beech familiy) and Polygonaceae (knotweed family).* Other groups of health-promoting compounds are resins, lignans, alkaloids, proteins and peptides, ascorbic acid, anthocyanins and polyphenols (Kårlund *et al*., 2014)

Nowadays, there is a growing consumer demand for natural and tasty functional and low-calorie foods, and this will be an impetus guiding product and process development for health-promoting compounds (Tiitinen *et al*., 2006; Ventura *et al*., 2013). Berries and fruits products with high active content of health-promoting compounds serve as a source for derived natural and tasty functional, low-calorie foods and health promoters. For example, carrots, apple, oranges, tomatoes, and blackcurrant residues contain substantial amounts of flavanols, flavonols, sterols and fibers and are ideal biomaterial for a variety of health-promoting compounds (Sandell *et al*., 2009). Scientists and food industry experts are cooperating to encourage more effective use of berry and fruit processing residues rich in valuable components (Loncaric *et al*., 2014). Over the years, the different berry and fruit processing residues rich in valuable components were majorly processed by traditional techniques. Recently, less energy-intensive novel methods evoking minimal effects on berry/fruit product have replaced the traditional thermal and dehydration treatments (Chen *et al*., 2013).

Although, traditional processing and refining methods enhance preservation of bioactive compounds and stabilize yields. Factors such as using samples in low quantities, higher selectivity of the method, conformance with the automation and minimization of solvent consumption and wastes that may lead to environmental problems render their application quite uneconomical (Cravotto *et al*., 2011). These underlying drawbacks have triggered research that explored more cost-effective and novel techniques for processing and refining berry/fruit products for bioactive compounds. Promising features of novel techniques for processing and refining methods include its potential to limit the use of toxic organic pollutants, faster extraction rate, comparable yields, and utilization of food-grade organic modifiers. Meanwhile, the ways that many novel methods are best applied still require further optimization (Sarkis *et al*., 2013). Future progress will lie in the clarification of the selection of special-target-specific health-promoting compounds that will be optimized for processing in fruits and berries (Mazur *et al*., 2014). The present study reviewed the traditional and novel processing methods for extraction of bioactive compounds from fruits and berries.

Materials and Methods

The information and data provided in this study were sorted from indexed and non-indexed journals by using online bibliographic databases such as Google Scholar, Bing, PubMed, Scopus, Google, Web of Science, University Grants Commission-Consortium for Academic and Research and Ethics (UGC-CARE), Emerging Sources Citation Index (ESCI), Directory of Open Access Journals (DOAJ), Institute for Scientific Information (ISI), Web of Knowledge and other online library sources. Comprehensive and consummate information about the methods used in the processing of health-promoting compounds were collated from over 20 previously published reports, reviews and research articles on related studies.

Results and Discussion

Processing Methods for Bioactive compounds in Fruits and Berries: Processing methods for bioactive compounds in fruits and berries involve separating the medicinally active mixture of many health-promoting compounds, usually contained inside the plant materials, using standard procedures (Handa, 2006). It can also be the treatment of the plant material with solvent, whereby the health-promoting compounds constituents are dissolved and most of the inert matter remains undissolved. The product obtained is usually a relatively complex mixture of metabolites, in liquid or semisolid state or (after removing water) in dried powder form, which is intended for oral and external use. Over the years the processing of health-promoting compounds in fruits and berries are usually carried out either by traditional and/or novel methods (Hussain *et al*., 2019).

Traditional Processing Methods: Traditional processing and refining methods involve crushing, pressing, filtration, heat and cold treatments and enzymatic treatments. The commonly employed traditional processing methods, which have long been used, are primarily based on liquid-solid extraction. They are ordinarily easy to operate and are based on heat and/or solvents with different polarities. Traditional techniques involve application of solid-liquid extraction, simply by means of solvent application and leaching. These methods are majorly used for extracting bioactive compounds (Shahbaz *et al*., 2016a, 2016b) and have been utilized for more than a century. Common traditional processing methods include maceration, crushing, pressing, filtration, heat and cold treatments and enzymatic treatments (Hussain *et al*., 2019).

Maceration is the process of soaking the plant materials (coarse or powdered) in a closed stoppered container in a solvent and allowing it to stand at room temperature for 2 – 3 days with frequent stirring to obtain plant extracts. Maceration is intended to soften and break the plant's cell walls to release the soluble phytoconstituents. The mixture is then pressed or strained by filtration or decantation after a specific time (Olsson *et al*., 2004). Maceration is the simplest and most widely used traditional procedure. The extraction procedure in this stationary process works on principle of molecular diffusion, which is a time-consuming process. Maceration ensures dispersal of the concentrated solution accumulation around the particles' surface and brings fresh solvent to the surface of particles for further extraction (Wu *et al*., 2004).

Pressing is a basic step in juice production leading to the formation of a juice and fruit/berry press as the residue. Pressing mechanisms involves squeezing out of the constituents by applying pressures on the plant material. The food and agricultural industries utilize several kinds of pressing procedures, i.e., altering mechanisms, pressures, pressing times and filters. Several kinds of pressing procedures include press-cakes, pressing with a membrane press, wine press and juice extractor. Press-cakes hold a significant portion of the phenolic compounds, hence, pressing may decrease total phenols for example in blueberry (Lee *et al*., 2002) and blackcurrant juices (Holtung *et al*., 2011). Pressing with a membrane press has been found to be one of the most destructive steps leading to a loss of ascorbic acid in strawberry juice and nectar (Patras *et al*., 2009). However, the ascorbic acid content of strawberries was not affected by juice extraction in a domestic juice extractor (Hartmann *et al*., 2008; Wang *et al*., 2019). The total acetonitrile (ACN) content in pressed, non-clarified strawberry juice and paste made of thawed berries were found to be similar. With different pressing times (5.5 – 25 minutes) and pressure conditions (1.2 – 4.8 bar), total phenolic contents were higher when higher pressures were used (Türkyılmaz *et al*., 2013).

Enzymatic treatments are generally used to enhance juice flavor, stability and yields. Enzymatic treatments are applied to digest the plant cell wall, lower the viscosity and reduce the water binding capacity of enzyme-treated mashes. Commercial enzyme preparations may differ in their ability to degrade cell walls and vacuolar membranes of the plant matrix and to release compounds such as aglycones from flavonol glycosides. Mixing different enzyme products may be one way to increase the levels of different phenolic compounds in the final products (Laaksonen *et al*., 2012). Enzymatic treatments have been used to release polyphenols, from strawberry and blackcurrant matrices, increase the yields of hydroxycinnamic acid derivatives and flavonol glycosides in the juice processing final products, and also the enzyme pectinase have been used to increase the total phenolic content in pomegranate juices (Rinaldi *et al*., 2013). Enzymatic treatments and their pre-treatments can be largely customized to meet the requirements of specific raw material, and the chemical composition of final products can be somewhat tailored by modifying this processing step.

The food industry often utilizes procedures that involve temperature associated steps, such as freezing, thawing, many kinds of heat treatments and cooling. Freezing generally enhances preservation of raw materials and products, but then thawing is required to enable subsequent processing of frozen fruits and berries. Heat treatments may be applied to help to dissolve product components and/or to destroy harmful enzymes and microorganisms. Cooling is often used between the manufacturing steps or prior to packing and storage of the product. The different kinds of temperature-related steps involved in the production of juices, purees, jams, nectars and wines can reduce the levels of bioactive compounds in fruit products (Hartmann *et al*., 2008). Heat and cold treatments have been used to reduce total phenol levels in strawberries during jam production, increase amounts of acetonitrile (ACN) compounds in raspberry pastes, raspberry jam processing, pasteurization, and heat treatments resulted in loss of monomeric ACNs in canned berry products (Kim *et al*., 2004; Abouelenein *et al*., 2021).

Novel techniques: Novel techniques are modern techniques of processing health-promoting compounds, and involve special skills of separating soluble plant metabolites, leaving behind the insoluble cellular marc known as residue (Vepsäläinen *et al*., 2012). Novel techniques are commonly advanced techniques with the most recently developed extraction technology. Some of these techniques are also considered as green techniques as they agree with standards set by Environmental Protection Agency (EAP), USA (http://www.epa.gov/greenchemistry/ pubs/about_gc.html). These standards include, the use of less hazardous chemical synthesis, safe solvents auxiliaries, and safer chemicals, design for energy efficiency, reduction of derivatives, use of renewable feedstock, catalysis, design to prevent degradation, atom economy and time analysis for pollution prevention and inherently safer chemistry for the prevention of accident. Some novel techniques currently used are ultrasound assisted extraction (UAE), microwave assisted extraction (MAE), accelerated solvent extraction (ASE) and pulsed electrical field (PEF) extraction (Hussain *et al*., 2019).

Ultrasound waves propagate through a medium with a frequency range between 20 kHz to 100 MHz, beyond human hearing (Chemat *et al*., 2011). The basic mechanism of an ultrasound assisted extraction (UAE) device depends on some components such as the ultrasonic electric generator which creates a signal (usually around 20 kHz) that powers the transducer; the transducer whose function is to convert a specific type of energy into another form; the sonicator which enables the amplification of these vibrations until they pass through to the probe; and the probe whose function involves in transmission of the vibration to the solution being sonicated (Figure 1). Ultrasound assisted extraction has been used for processing of several aromatic compounds ranging from tea, wine (Cabredo-Pinillos *et al*., 2006) and aged brandies (Caldeira *et al*., 2004). The use of UAE is more advantageous over other novel methods by providing the best mass and heat transfer efficiency, lowest energy consumption and carbon emission. The most noticeable disadvantage of the procedure is the occasional deleterious effect of ultrasound energy through the formation of free radicals and consequently undesirable changes on the bioactive compounds (Hussain *et al*., 2019).

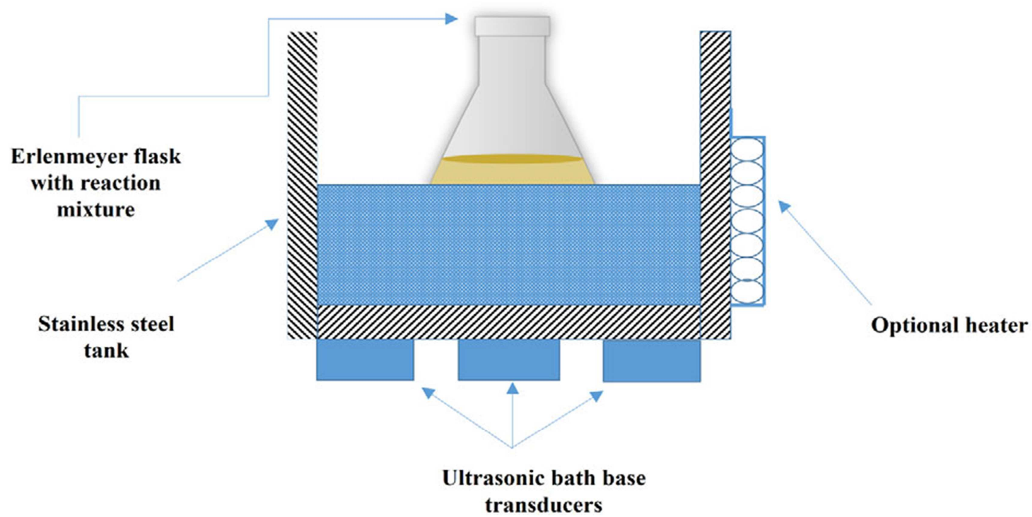

Figure 1. Schematic diagram of an ultrasound assisted extractor (Amer *et al*., 2017).

Microwaves are a type of electromagnetic radiation of light, with a range of 300 MHz to 300 GHz, and wavelengths of these waves range from 1 cm^{-1} to 1 m^{-1} (Yang *et al*., 2013). A microwave assisted extractor is composed of two oscillating fields such as electric and magnetic fields perpendicular to each other (Figure 2). MAE is based on the conversion of electromagnetic energy into heat energy by dipole rotation and ionic conduction mechanisms (Jain *et al*., 2009). This procedure has demonstrated various benefits like ease to handle and understand, and steadiness. Many studies reported that MAE leads to higher yields and is significantly faster than other novel methods for extracting active substances from plant materials (Chan *et al*., 2011; Gupta *et al*., 2012; Azmir *et al*., 2013). MAE can be presented as a potential alternative to the traditional solid-liquid extraction techniques. Some advantages of MAE are that they have shorter extraction time; it is favorable for thermolabile constituents; it requires a lesser amount of solvent; it can provide stirring, by which mass transfer phenomenon is improved, and it also improves extraction yield. Some of the disadvantages of using MAE is that it needs special equipment to be functional, constant electricity to produce waves, higher investments and higher operating costs than other novel methods (Little and Holmes, 2000).

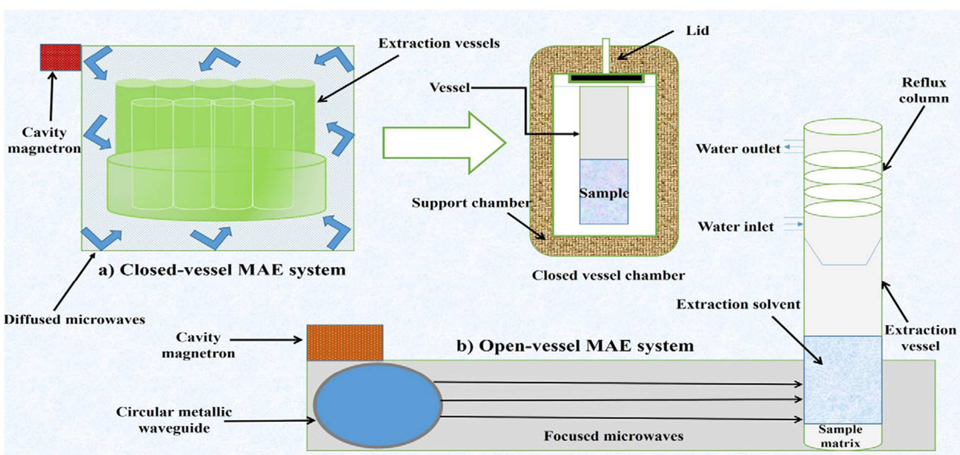

Figure 2. Schematic diagram of microwave assisted extraction (MAE) technique (Amer *et al*., 2017).

Accelerated solvent extraction (ASE) is also known as pressurized liquid extraction (PLE) because the extraction is carried out with solvents at a temperature and pressure lower than their critical points. ASE provides an effective penetration of the solvent into plant tissue at elevated temperature and pressure under nitrogen atmosphere and thereby hinders the degradation of phenolic compounds. The equipment used for ASE basically consists of an electrovalve, thermostatted extraction chamber, a pump, a pressurizing unit and a collector. ASE has been reported a superior technique to other novel methods due to shorter extraction time and less consumption of solvent (Giergielewicz-Możajska *et al*., 2001). As reported by Lee and Kim (2010), ASE has been used for the processing of bioactive lignans at 125°C in a 5 minute static time which is substantially shorter compared to UAE (3 hours). Moreso, ASE enhanced mass transfer of bioactive compounds and their solubility can be achieved at higher temperatures than the atmospheric boiling point of the solvent.

Pulsed electric field (PEF) extraction is the process in which the plant materials that are required for the processing for bioactive compounds is placed between two electrodes with electric current being allowed to pass along a period of 1 – 100 microseconds producing a field intensity varying from 1 to 80 kV/cm (Seçkin and Özgören, 2011) (Figure 3). Within a short duration of intense electric current, a considerable change in pressure along the cell wall can be ensured. When the sample is exposed to the current exceeding a certain critical value, the membrane of the cell wall is torn which enables the permeability. The continuous process results in pore formation which is defined as electro-poration. The major advantage of using PEF for processing of bioactive compounds is that it is less time consuming and has less detrimental effects on the chemical, physical and sensory characteristics of the food matrix compared to the other novel techniques. On the other hand, its use has been restricted to liquid samples with specific electrical conductivity, to prevent the degradation of the cell and the extraction of components from the intracellular vacuoles (Hellström *et al*., 2013). PEF extraction is considered to be best in increasing yield and decreasing the time needed for extraction, because it can increase mass transfer by destroying membrane structures during the processing (Hellström *et al*., 2013).

Conclusion: Extraction of bioactive compounds in fruits and berries is the first crucial step in preparation of their formulations for therapeutic use. The processing of health-promoting compounds in fruits and berries involves separation and extraction of bioactive compounds present in the botanicals and herbals. Both traditional and novel methods/techniques of processing health promoting compounds are effective in separating and extracting the bioactive constituents present in fruits and berries, each with its merits and demerits. Overall, the development of novel methods/techniques has significant advantages over traditional methods for the extraction and analysis of health-promoting compounds. Novel methods ensure availability of high-quality herbal products to consumers worldwide, increasing yield and decreasing the time needed for extraction. Despite its advantages, special skills and specialized equipment are needed for these novel methods, when compared to the traditional methods. However, understanding every aspect of various extraction methods is vital for proper extraction efficiency. The increasing economic significance of health promoting compounds may lead to more sophisticated extraction methods in future.

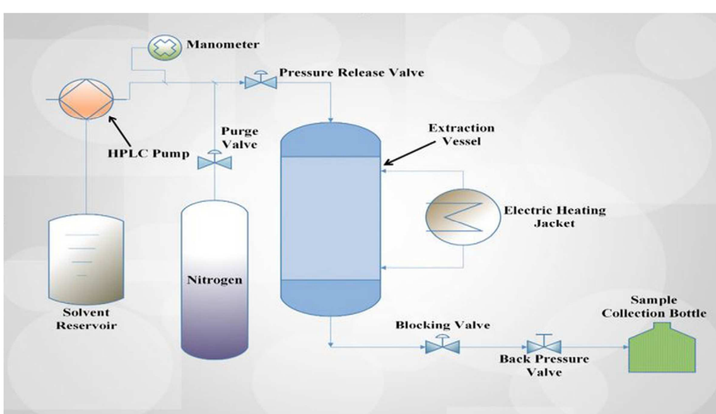

Figure 3. Schematic diagram of pulsed electrical field (PEF) extraction technique (Barišić, *et al*., 2022).

Conflicts of Interest

Authors declare no conflict of interest

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