Critical Reviews in Food Science and Nutrition

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/bfsn20

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To cite this article: Xinyi Huang, Chenyue Li & Jun Xi (2023) Dynamic high pressure microfluidization-assisted extraction of plant active ingredients: a novel approach, Critical Reviews in Food Science and Nutrition, 63:33, 12413-12421, DOI: 10.1080/10408398.2022.2101427

To link to this article: https://doi.org/10.1080/10408398.2022.2101427

CRITICAL REVIEWS IN FOOD SCIENCE AND NUTRITION
2023, VOL. 63, NO. 33, 12413–12421
https://doi.org/10.1080/10408398.2022.2101427

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REVIEW

Dynamic high pressure microfluidization-assisted extraction of plant active ingredients: a novel approach

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ABSTRACT

The extraction method has a great influence on the yield, quality, chemical structure, and biological activities of active ingredients. Safe and efficient extraction of active ingredients is one of the important problems facing the food and pharmaceutical industry. As a pretreatment approach for the extraction of active ingredients, dynamic high pressure microfluidization (DHPM) is a promising strategy that can not only effectively increase the yield of active ingredients but also strengthen the bioactivities of active ingredients, and take the advantages of mild operating temperature and environmental friendliness. In this review, the research progress of DHPM-assisted extraction of active ingredients from plant materials in recent ten years is overviewed. The DHPM equipment, strengthening mechanism, operating procedure, critical factors and application of DHPM-assisted extraction are introduced in detail, together with the advantages and disadvantages. Furthermore, its future development trend is discussed at the end. DHPM-assisted extraction is considered as the ideal technique of better homogenization effects, less solvent consumption, more reliable operation, and so on, making it a promising method to acquire active ingredients efficiently. Therefore, this technique is worthy of further theoretical research and experimental operation.

KEYWORDS

DHPM equipment; strengthening mechanism; critical factors; application strategies; homogenization effects; efficient extraction

Introduction

Plant materials contain a variety of substances, such as polysaccharides, flavonoids, phenols, proteins, and so on, which have various precious medicinal values (Slima et al. 2018; Panche, Diwan, and Chandra 2016; Qasim et al. 2017; Zhang, Zhang, and Chi 2016). For example, flavonoids have many pharmacological effects such as regulating platelet functions, inhibiting thrombosis, treating leukopenia, and fighting diabetes (Olas 2021; Qu et al. 2021; Bule et al. 2019). Proteins have antioxidant activity, and they can improve cardiovascular health and promote bone metabolism (Chi et al. 2015; Ramdath et al. 2017). Therefore, the isolation of these active compounds from plant materials has become an important research field in modern food and pharmaceutical industry.

Extraction is a crucial step in the separation of plant active ingredients (Jha and Sit 2022). Different extraction methods have important effects on the yield, purity, chemical structure and biological activity of active compounds, so appropriate extraction methods should be selected according to the physical and chemical properties of active molecules (Muthusamy, Udayakumar, and Narala 2021; Garcia-Salas et al. 2010). At present, there are many extraction methods, which can be divided into conventional methods and unconventional methods. Conventional methods include maceration, hot water extraction, alkaline extraction, acid extraction, Soxhlet, and so on (Muthusamy, Udayakumar, and Narala 2021; Sun et al. 2018; Azmir et al. 2013). They are mature industrial methods taking the advantages of convenient operations and low installation costs (Rocchetti et al. 2019; Fernández-Delgado et al. 2022). However, the main challenges associated with them are long extraction time, low extraction selectivity, high temperature, large amounts consumption of organic solvents, and possible loss of extracts due to additional cleaning steps (Barba et al. 2016; Chan et al. 2011), and so on. To overcome these shortcomings, many unconventional technologies have been proposed, including microwave-assisted extraction (Chan et al. 2011), ultrasonic-assisted extraction (Perera and Alzahrani 2021), enzyme-assisted extraction (Das, Nadar, and Rathod 2021), subcritical water extraction (Zhang et al. 2020), infrared-assisted extraction (Xiang et al. 2022), negative pressure cavitation (Roohinejad et al. 2016), dynamic high pressure microfluidization (DHPM) (Jing et al. 2016), and so on. These methods have the advantages of shorter operation time, higher yield, and more environmentally friendly by reducing the use of organic and synthetic chemicals (Azmir et al. 2013). DHPM technology is an emerging technology which uses the collective forces of high velocity impact, high-frequency vibration, instantaneous pressure drop, intense shear, cavitation, and ultra-high pressures up to 200 MPa with a short treatment time (less than 5 s) (Guo et al. 2020; Jing et al. 2016). It is directly pressurized to a predetermined pressure, uses the microfluidizer to generate jet collision and release the pressure, thus improving the treatment efficiency (Guo et al. 2020). At present, DHPM has been

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widely used in modification of macromolecules such as protein (Guo et al. 2020; Zhao et al. 2021), dietary fiber (Liu et al. 2016; Wang et al. 2021), and enzymes (Liu et al. 2010; Liu et al. 2012.).

DHPM for extraction is a new application. Studies have shown that it is an effective method to extract bioactive compounds such as flavonoids (Guo et al. 2017; Jing et al. 2016; Li et al. 2010; Tu et al. 2018; Sun et al. 2013) and polysaccharides (Tu et al. 2010; Huang et al. 2012; Qin et al. 2019; Kou 2013) from natural resources. However, there is no review provide adequate details for DHPM-assisted extraction. Therefore, this review aims to provide insight into DHPM-assisted extraction, including its equipment and mechanisms, operation procedures, important operating conditions, applications, advantages and disadvantages, and future development trends. Interested parties can rely on the useful information provided by this review to select appropriate extraction techniques for their respective target compounds.

DHPM system and strengthening mechanism

DHPM system

A typical DHPM system consists of inlet reservoir, constant high-pressure intensifier pump, interaction chamber, pressure gauge, and cooling jacket, as shown in Figure 1a (Guo et al.

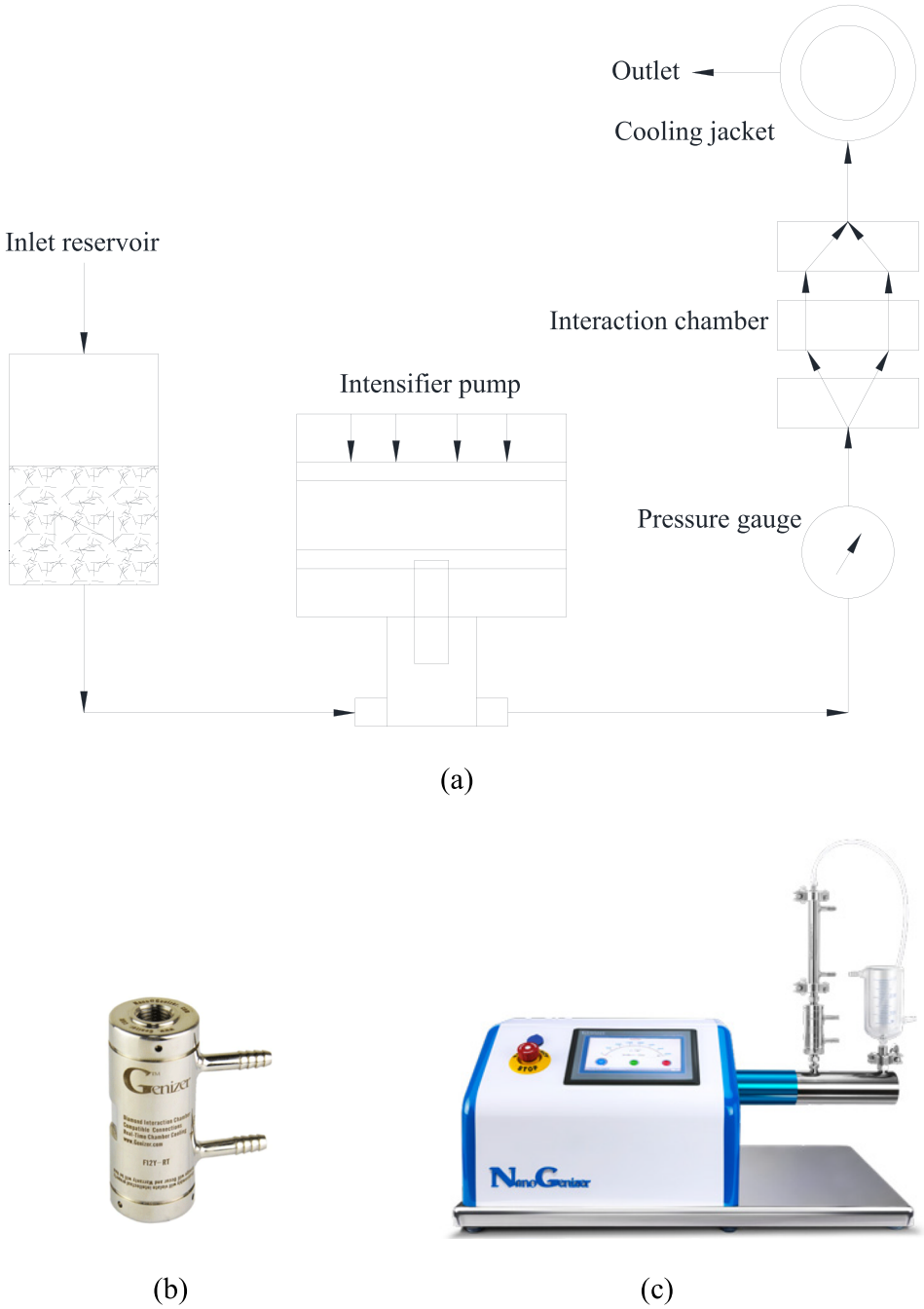

Figure 1. The scheme of DHPM equipment (Guo et al. 2020) (a), diamond interaction chamber (b), DHPM physical drawing of ProdGenizer (Genizer, USA, https://www.genizer.com/ 2022) (c).

2020; Karagiannidis et al. 2017; Sutradhar and Amin 2013). Among them, the interaction chamber is the core component, and its role is to reduce the particle size of materials, accompanied by superb homogenization effects such as stability, homogeneity and transparency (Chen et al. 2016). Figure 1b shows a physical view of the diamond interaction chamber. The fixed geometry within the diamond interaction chamber is intended to create a uniform processing profile so that all materials will be processed with equal disruptive forces (https://www.genizer.com/ 2022). The interaction chamber has two fixed geometric shapes, which is Y-chamber and Z-chamber, as shown in Figure 2 (Nekkanti, Vabalaboina, and Pillai 2012). The Y-chamber is used for liquid-to-liquid dispersion applications such as nanoemulsions, lipid nanoparticles, vaccine adjuvants, encapsulation, liposomes and polymer particles. The Z-chamber is recommended for the suspension of a solid into a liquid, in applications such as cell disruption, deagglomeration and particle size reduction (https://www.microfluidics-mpt.com/ 2022). The Y-type interaction chamber (Figure 2a), regarded as one of the most powerful chambers to date, has been used by several manufacturers, including Microfluidics (Y-type interaction chamber) (https://www.microfluidics-mpt.com/ 2022) and Nanomizer (collision-type generator) (https://nanomizer.co.jp/ 2022). In the Y-chamber, the flow stream is split into two channels that are redirected over the same plane at right angles and propelled into a single flow stream. The high pressure produces a high speed at the crossover of the two flows, resulting in high shear, turbulence, and cavitation over the single outbound flow stream (https://www.genizer.com/ 2022). In the Z-chamber, the liquid collides with the wall to obtain a smaller particle size, as shown in Figure 2b. In laboratory research and industrial production, multiple microchannels are simply placed in parallel to ensure that the material is processed under the same high velocity shear rate and impact force per microliter. The detailed operation process is as follows. First, the sample is poured into the inlet reservoir. Then, a motor drives the constant high-pressure intensifier pump to force the sample through the interaction chamber, where the sample is pushed through the microchannel at the speed of up to 500 m/s, which allows for subsequent fluid collisions. The high-speed feed liquid is divided into two or more streams in the microchannel and collides with the chamber wall or each other, producing shear forces, impact forces, and energy dissipation forces, which can damage to cells. Afterwards, the streams converge and flow out under high pressure. In the process of outflow, the tube diameter expands and the fluid velocity decreases. At last, the finished product is cooled in a heat exchanger or outlet cooling jacket in order to control the temperature of the sample (Strydom et al. 2013).

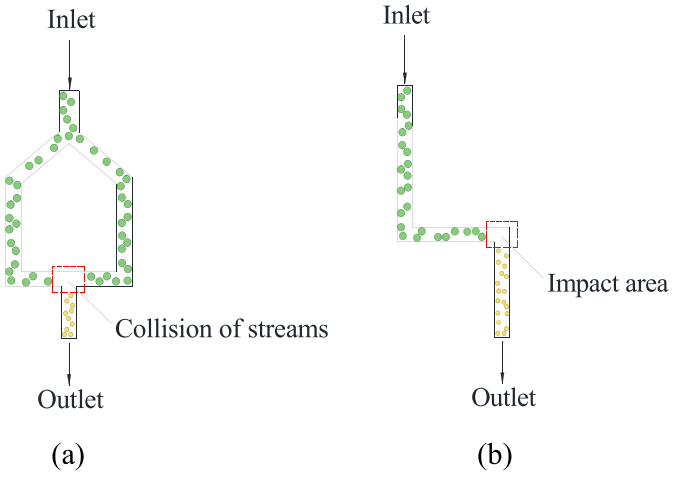

Figure 2. Geometry of interaction chamber of Y-type (a) and Z-type (b).

The physical figure of DHPM system is shown in Figure 1c. It is ultrahigh pressure microfluidizer of ProdGenizer series (Genizer, USA), which is operated with the touch screen and controlled intelligently by program. A constant flow is provided at a pressure of up to 45,000 psi (3100 bar).

Strengthening mechanism

In general, the DHPM process can generate many mechanical effects such as strong shear, high frequency vibration, high speed impact, instantaneous pressure drop and cavitation, which make particles and cells highly broken, and generate strong turbulence in solution, thus effectively speeding up the solvent penetration, strengthening the diffusion effect, and reducing the mass transfer resistance (Tu et al. 2010). The process of gradual destruction of cell structure could be observed by scanning electron microscope (SEM) images obtained by Huang et al. (2013), as shown in Figure 3. As could be seen from Figure 3B, DHPM treatment at 60 MPa caused the cell structure on the material surface to tear up and the integrity of the cell wall to be destroyed. With the increase of pressure, the cell structure was teared up more and the cell surface area also increased (Figure 3C and D). Figure 3E showed that eventually the cell structure was destroyed completely and the released cell contents were compressed into smaller particles.

Procedure of DHPM-assisted extraction

The procedure of DHPM-assisted extraction included sample preparation, DHPM treatment, and extraction step, which was shown in Figure 4.

Sample preparation

As shown in Figure 4, sample preparation starts from drying the required parts of the plant to remove moisture. The drying temperature is usually maintained at 50 or 60 °C (Li et al. 2010; Sun et al. 2013; Li et al. 2010; Huang et al. 2012; Jing et al. 2016) to avoid thermal degradation. The dried sample is then smashed and sieved through a mesh screen (Li et al. 2010; Sun et al. 2013; Kou 2013; Li et al. 2010; Huang et al. 2012; Jing et al. 2016; Huang et al. 2013; Guo et al. 2017) to facilitate extraction. In order to keep the sample pure, the sample is usually immersed in ethyl ether or petroleum ether and other solvents, and use Soxhlet or reflux method to remove lipids, pigments and fat-soluble impurities. After that, the sample is dried and stored in a dry place at room temperature until later use.

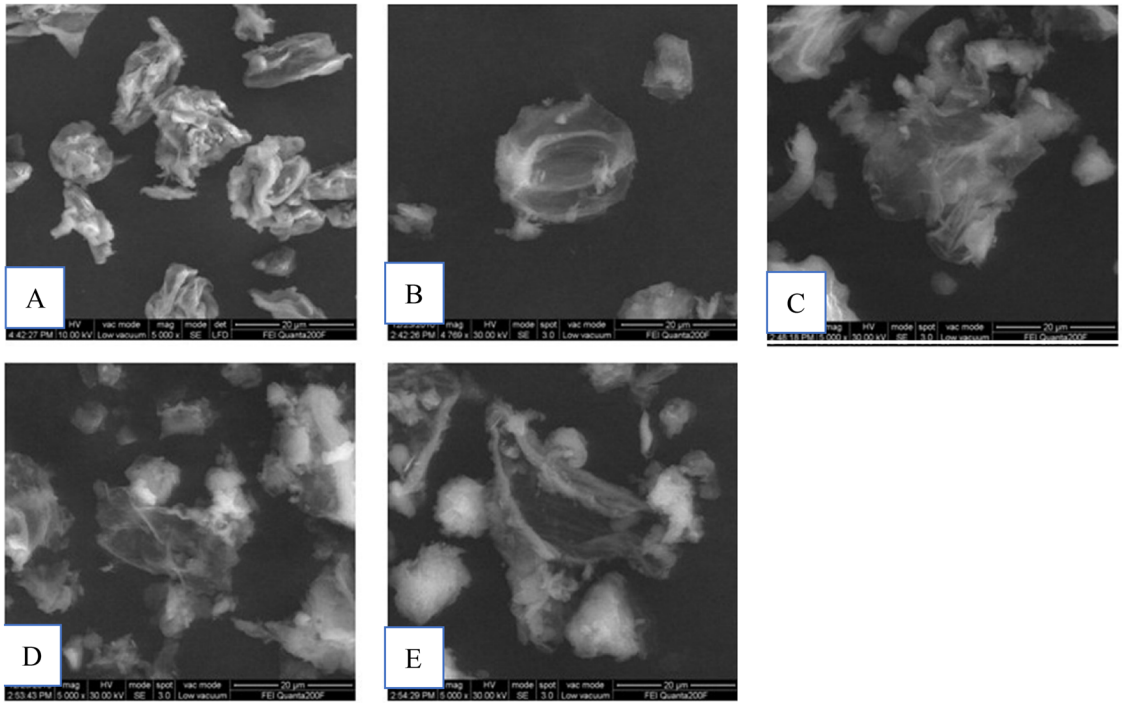

Figure 3. SEM images of sweet potato leaves powder by different treatment with 5000 enlargement (Huang et al. 2013) (A) before extraction, (B) treated by DHPM at 60 MPa, (C) treated by DHPM at 100 MPa, (D) unfolded cell treated by DHPM at 140 MPa, and (E) folded cell treated by DHPM at 140 MPa.

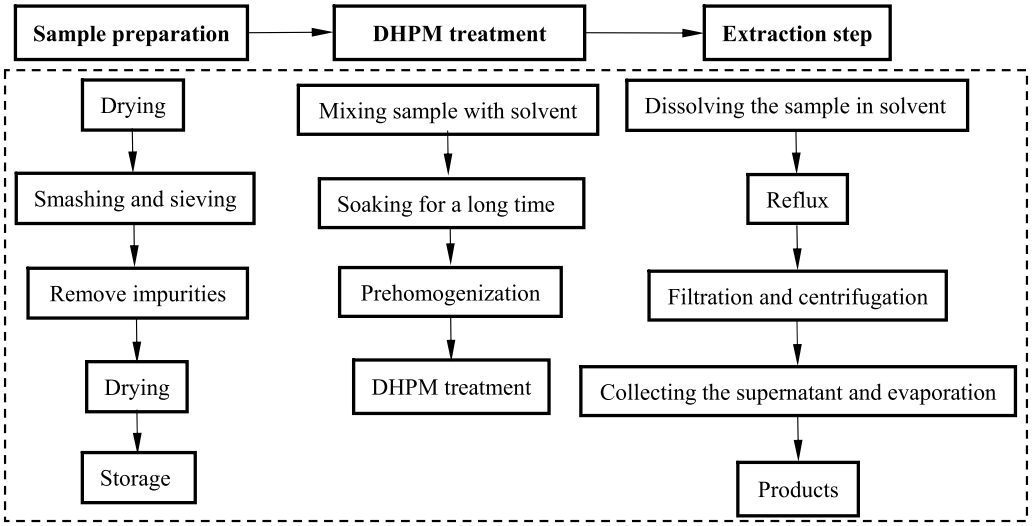

Figure 4. Schematic procedure of DHPM assisted extraction.

DHPM treatment

DHPM treatment of samples before extraction can improve extraction efficiency. It can accelerate solvent penetration, strengthen diffusion and reduce mass transfer resistance through comprehensive forces. A valve homogenizer and a microfluidizer are usually used in the experiment.

Firstly, the sample is soaked with extraction solvents for a long time. Secondly, a prehomogenization process of the sample is needed before DHPM treatment. Since the size of the interaction chamber of DHPM is usually small (tens to hundreds of microns), which lead the sample particles easily to clog the microfluidizer (Guo et al. 2020), an auxiliary crushing equipment such as valve homogenizer is applied in the early stage to make the material superfine crushing by making use of the strong hydraulic shear action, cavitation, and impact action in the gap (Putri et al. 2022). Finally, the sample is poured into the microfluidizer for treatment.

Extraction step

Place the treated sample in the container, add the solvent and open the reflux system to extract target compounds. After extraction, the extract is filtered, and the container is cleaned with the extraction solvent to prevent loss of the

active compound. The filtrate is collected and centrifuged at 500–4000 rpm for 10–15 min (Qin et al. 2019; Guo et al. 2017; Huang et al. 2012; Jing et al. 2016; Huang et al. 2013). Then the supernatant is collected and evaporated. Thus, the product is acquired and stored for subsequent analysis.

Critical factors

The efficiency of DHPM-assisted extraction is largely dependent on the selection of operating conditions, so it is important to understand the influences of these factors on the extraction process so as to select the appropriate parameters. This section introduces several main factors affecting extraction process, provides some guidelines on the selection of operating conditions, and summarizes best operating conditions for various studies. Three-dimensional response surface plots and contour diagrams are usually used in studies to show the relationships between the response of each variable and the experimental level as well as interactions between the two test variables. For example, in the study of Huang et al.'s extraction of lentinan (Huang et al. 2012), the three-dimensional surface plot showed that solid-liquid ratio, pressure, and temperature had significant effects on the extraction yield, and it could be seen from the contour diagram that the yield did not change much with the interaction between variables, so the interaction between variables was not significant (Huang et al. 2012), which was consistent with the conclusions obtained in other reports.

Solvent properties

The choice of solvent depends on the solubility of the target component, solvent's penetration and interaction with sample matrix and the dielectric constant of the solvent. Some extractions require an aqueous solution of a certain organic solvent, because certain amount of water can promote the mass transfer process by increasing the relative polarity of the solvent, thereby improving the permeability of the solvent in the sample matrix and increasing the surface area for solute to interact with solvent through effective expansion of the plant material (Mandal and Mandal 2010). Other organic solvents such as ethanol, methanol, and acetone have also been found to be effective extraction solvents. For example, the extraction yield of phenolic compounds from grape skins and seeds with methanol is higher than that extracted with ethanol, but the latter extract has stronger antioxidant properties (Casazza et al. 2010). Attention should also be paid to the toxicity of solvents in selecting suitable solvents. In the extraction of oleanolic acid from *Gymnema sylvestre*, ethanol is chosen because it is nontoxic, even though *n*-butanol can provide a higher extraction yield (Mandal and Mandal 2010). In short, ethanol is currently the most commonly solvent for the extraction of a variety of active compounds from plants.

Solid–liquid ratio

After selecting the solvent, the next step is to determine the solid-liquid ratio, because it can affect the extraction yield in most cases. If the solvent proportion in the solid is low, the distribution of the active compound is concentrated in a certain area, which restricts the movement of the compound from the cell matrix to the solvent and impedes the mass transfer process (Chan et al. 2011). In addition, as described by Ruan and Li (2007), solid-liquid ratio and container volume have an impact on extraction efficiency. In the circumstance of the same ratio of solid to liquid, the smaller container can speed up the extraction because of the high internal pressure, but this is not suitable for unstable active compounds, which can be decomposed or converted to other compounds under high pressure.

Pressure

In the extraction of polysaccharides from maize pollen, Tu et al. (2010) reported that the ability of microfluidization treatment to reduce the particle size of plants was better than that of homogenizer, and appropriate pressure could reduce particle size and disperse evenly. The effect of microfluidization on cell fragmentation was better than that of dry comminution, and the degree of cell fragmentation increased with the increase of pressure. With the pressure increases, the rupture degree of cells in the sample solution became progressively severe, and the resistance to the dissolution of active components in cells decreased, which was beneficial to the diffusion and dissolution of the active compounds in plants. At the same time, DHPM treatment also made the sample particles disperse in the solvent more quickly and evenly, so as to obtain a high yield, but when the pressure exceeded a certain value, with the further increase of pressure, there was no significant difference in the extraction yield. In the process of the extraction of some active compounds, the continue rise of pressure even causes the yields to decrease slightly, which may be due to the high-frequency oscillation resulting from excessive pressure, similar to the ultrasonic, damages the structure of a small number of dissolved compounds, or may be due to oscillations, cavitation and vortex change the existence state of dissolved oxygen in the extract, promote the oxidation and destroy the structure of the compound. Its mechanism needs further study.

Temperature

The selection of extraction temperature is contingent on the stability of the active compound and the expected extraction yield. In the extraction process of flavonoids, Li et al. (2010) reported that the yield of flavonoids increased with the increase of temperature. The optimal extraction temperature was 70 °C and further increasing the extraction temperature would reduce the yield. This confirmed the importance of appropriate temperature for plant extractions. Overall, the growth of temperature is favorable to the mass transfer rate of molecules, the

increment of solubility of active compounds in the solvent, and the decrease of solvent viscosity (Huang et al. 2012) However, excessive temperature will pose a risk of thermal degradation and oxidation of active compounds, and may result in protein denaturation and an increase of solution viscosity (Li et al. 2010). In which case, active compounds tend to be difficult to dissolve, generating lower solubility and lower yield. A large number of experiments show that the optimal extraction temperature of DHPM is about 70 °C.

Application

Table 1 summarizes the application of DHPM for extracting active ingredients from various plants based on reports in the open literatures. As can be seen from Table 1, current studies mainly focus on the extraction of flavonoids (Jing et al. 2016; Li et al. 2010; Sun et al. 2013; Tu et al. 2018; Guo et al. 2017) and polysaccharides (Qin et al. 2019; Tu et al. 2010; Huang et al. 2012; Kou 2013). The operational extraction pattern for optimizing yield by DHPM can be observed from the Table 1. The first operation mode emphasizes the setting of pressure, usually between 100 and 180 MPa, to provide shock energy for cell wall rupture during extraction. The second operation mode focuses more on the temperature than pressure and usually sets the temperature at a desired value, such as 65–90 °C, which is suitable for the extraction of heat-sensitive compounds.

Table 1. Application of DHPM in optimized operating conditions.

Material	Active ingredient	Operating conditions	Results	References
Cyperus esculentus leaves	Flavonoids	Pressure: 120 MPa Solvent: 60% aqueous ethanol Extraction temperature: 80 °C Extraction time: 90 min	-The flavonoids yield was 1.46%. -DHPM exhibited not only higher yield than reflux, ultrasonic, microwave, and ultrasonic followed by microwave, but also stronger scavenging activity.	Jing et al. (2016)
Sweet potato leaves	Flavonoids	Pressure: 100 MPa Solvent: 70% aqueous ethanol Extraction temperature: 75 °C Extraction time: 120 min	-The flavonoids yield was 5.75%. -The flavonoids yield of DHPM was higher than that of traditional reflux.	Li et al. (2010)
Radix Tetrastigmae leaves	Flavonoids	Pressure: 120 MPa Solvent: 75% aqueous ethanol Extraction temperature: 70 °C Extraction time: 90 min	-The flavonoids yield was 3.49%. -DHPM showed higher extraction efficiency than traditional reflux.	Sun et al. (2013)
Gynura procumbens leaves	Flavonoids	Pressure: 80 MPa Solvent: 80% aqueous ethanol Extraction temperature: 65 °C Extraction time: 120 min Solid-liquid ratio: 1:15g/mL	-The flavonoids yield was 1.95%. -Under the optimum conditions, the flavonoids yield of DHPM was higher than that of reflux.	Tu et al. (2018)
Cyperus esculentus	Flavonoids	Pressure: 120 MPa Solvent: 80% aqueous ethanol Extraction temperature: 80 °C Extraction time: 90 min	-The flavonoids yield was 1.46% and IC_{50} for DPPH scavenging activity was 0.17 ± 0.02 mg/mL. -Compared to traditional reflux, DHPM exhibited the better performance in both flavonoids yield and antioxidant activities.	Guo et al. (2017)
Auricularia auricula	Polysaccharides	Pressure: 140 MPa Solvent: Distilled water Extraction temperature: 90 °C Extraction time: 120 min Solid-liquid ratio: 1:40 g/mL	-The polysaccharides yield by DHPM was 22.13%, which was higher than that of hot water, ultrasonic and microwave.	Qin et al. (2019)
Maize pollen	Polysaccharides	Pressure: 120 MPa Solvent: Distilled water Extraction temperature: 70 °C Extraction time: 2.5h Solid-liquid ratio: 1:20 g/mL	-The polysaccharides yield was 7.545%. -The polysaccharides yield by DHPM was 1.023% higher than that of dry comminution extraction.	Tu et al. (2010)
Lentinus edodes	Lentinan	Pressure: 140 MPa Solvent: Distilled water Extraction temperature: 80 °C Extraction time: 1 h Solid-liquid ratio: 1:60 g/mL	-The lentinan yield of DHPM was 6.76%, while hot water extraction was 3.27%. -Compared to hot water extraction, the lentinan extracted by DHPM had better scavenging capacity of hydroxyl radical, superoxide anion free radical, DPPH radical and nitrite. -DHPM was a promising method to enhance the yield and antioxidant activity of lentinan.	Huang et al. (2012)
Lotus leaf	Polysaccharides	Pressure: 180 MPa Solvent: Distilled water Extraction temperature: 76 °C Extraction time: 50 min Solid-liquid ratio: 1:35 g/mL	-The polysaccharides yield by DHPM was 6.31%, which was higher than that by hot water extraction (2.95%). -The polysaccharides yield by DHPM is 2 times higher than that of hot water extraction, while the time of hot water extraction is 1.72 times longer than that of DHPM.	Kou (2013)

Flavonoids

Studies have proved that flavonoids have considerable anti-cancer effects. Besides, it has been shown to be effective in improving cardiovascular, digestive, and nervous system diseases (Khan et al. 2021). Therefore, it is of great significance to extract flavonoids from plant materials for the development of high value-added products. Currently, some researchers have applied DHPM to the extraction of flavonoids from *Cyperus esculentus L.* leaves (Jing et al. 2016), Sweet potato leaves (Li et al. 2010), *Radix Tetrastigmae* leaves (Sun et al. 2013), *Gynura procumbens* leaves (Tu et al. 2018), and *Cyperus esculentus* (Guo et al. 2017). The most commonly used solvent for flavonoids is ethanol, with the concentration between 60% and 80%. For optimal efficiency, the solid-liquid ratio is usually between 1: 15 and 1: 65 g/mL. Additionally, the optimal extraction time of an active substance can be as short as 50 min (Jing et al. 2016; Li et al. 2010; Sun et al. 2013; Tu et al. 2018; Guo et al. 2017).

For example, Jing et al. (2016) used DHPM-assisted extraction to extract flavonoids from *Cyperus esculentus L.* leaves, and compared it with traditional reflux method, ultrasonic-assisted extraction, microwave-assisted extraction, and ultrasonic treatment followed by microwave treatment. Under the optimized operating conditions, the flavonoids recovery was 1.46%, 0.64%, 0.78%, 1.34%, and 1.38%, respectively. The results showed that DHPM significantly improved the extraction yield of flavonoids compared with the other four methods. Moreover, flavonoids extracted by DHPM had stronger free radical scavenging activity and antioxidant capacity.

Polysaccharide

Polysaccharide compounds are one of the most important secondary metabolites in plants (Benchamas et al. 2021). Dozens of natural polysaccharides are used in biomedicine, food industry, clinic, and other fields (Fan et al. 2021; Bilal et al. 2021; Giavasis 2014). For example, starch extracted from avocado seeds contains high levels of polysaccharides, and can be used to produce bioethanol, a promising alternative to fossil fuels (Araújo et al). Polysaccharide biomolecules, such as starch and pectin, extracted from mango by-products can be used to develop viable and sustainable biopolymer packaging films (Oliver-Simancas et al. 2021). Consequently, the improvement of polysaccharide extraction technology has enormous economic and environmental benefits.

It is found that DHPM is more efficient in extraction of polysaccharide. Not only can DHPM improve the yield, but also save time. Kou (2013) extracted polysaccharides from lotus leaves under the optimal conditions of solid-liquid ratio of 1:35 g/mL, extraction temperature of 76 °C, extraction time of 50 min, and extraction pressure of 180 MPa, and the polysaccharides yield obtained by DHPM was 6.31%. However, under the conditions of solid-liquid ratio of 1:35 g/mL, extraction temperature of 77 °C, and extraction time of 86 min, the polysaccharide yield was only 2.95% obtained by hot water extraction. It can be seen that although there is little difference in temperature between the two methods, the extraction yield by DHPM is 2 times higher than that of hot water extraction, while the time of hot water extraction is 1.72 times longer than that of DHPM. Huang et al. (2012) also carried out experiments of lentinan extraction with DHPM and hot water extraction under the same conditions, and the yield was 6.76% and 3.27%, respectively. Furthermore, compared to hot water extraction, the lentinan extracted by DHPM had better scavenging capacity of hydroxyl radical, superoxide anion free radical, DPPH radical and nitrite.

Advantages and disadvantages

Many reports on the applications and performances of DHPM-assisted extraction indicate that it is a reliable method for the extraction of active ingredients from plants. Its advantages are summarized as follows: (1) It has good homogenization effects. The processed products have no precipitation, high gel shape, and high stability. (2) Compared with the traditional methods, its extraction time can be significantly shortened. (3) It does not destroy the structure of the compound, but change the composition proportion of the compound, which can enhance the dissolution of antioxidant compounds, thus obtaining products with strong antioxidant activity. (4) It can be carried out at room temperature, which is beneficial to protect the active ingredients in the sample and ensure the quality. (5) The operation is done in the closed system to protect the samples from external pollution and prevent leakage of samples, so it is safe and environmentally friendly. (6) The working parameters of the equipment are easy to control and the device is easy to clean.

Although DHPM has many advantages, it has some disadvantages that limit its use: (1) Compared with the emerging extraction methods (such as microwave-assisted extraction and ultrasonic-assisted extraction), the extraction time has no vantage. (2) The interaction chamber is too small to handle large particles directly, which will otherwise block the microfluidizer. (3) It has small flows and low processing capacity. (4) The equipment cost is relatively high.

Conclusion and future trends

Compared with other technologies, DHPM-assisted extraction has significant advantages of better homogenization effects, less solvent consumption, more reliable operation, and so on. As an emerging technology, it can play a better role in ultra-fine and homogenization. However, how to optimize the process to further shorten its extraction time is worthy of researchers' attention. Due to the limitations of small interaction chamber and low processing capacity, the practical application of DHPM is not as extensive as ordinary valve homogenization. Therefore, great efforts should be

made to solve these problems. Besides, more researches on DHPM treatment are needed. It is worthwhile to combine DHPM with other technologies for extraction. In addition, the application of DHPM-assisted extraction should not be limited to flavonoids and polysaccharides, and the extracts scope should be extended to anthocyanins (such as retention of chromogenic compounds), antioxidants, phenolic compounds, and so on.

Disclosure statement

The authors declare that they have no conflict of interests.

Funding

This work is financially supported by the National Natural Science Foundation of China (No. 21376150) and Postdoctoral Science Foundation of China (No. 2013M530400, 2014T70871).

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