

Applications and Prospects of Ultrasound-Assisted Extraction in Chinese Herbal Medicine

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ABSTRACT

Ultrasound-assisted extraction method has become more attractive due to its several advantages such as low energy consumption, less extraction time, less active compound damage and high extraction yields as compared with conventional extraction methods. Ultrasound-assisted extraction has been successfully used in the extraction of various medicinal compounds including alkaloids, flavonoids, glycosides, phenolic compounds and polysaccharides from plants in laboratory investigations. The mechanisms, regulatory factors, advantages and disadvantages of ultrasound-assisted extraction method are discussed in this paper. It is expected that ultrasound-assisted extraction method will become popular in Chinese herbal medicine industries in the near future.

KEYWORDS: Ultrasound-assisted extraction; Medicinal compounds; Chinese herbal medicine

INTRODUCTION

Extraction of medicinal compounds from plants is a critical step in medical research, drug manufacture and clinical applications in Chinese herbal medicine. Traditional methods including impregnation, percolation, decoction, reflux extraction, continuous reflux extraction, steam distillation, sublimation and press method are commonly used in the extraction of medicinal compounds from plants Seidel [1]; Chua [2]; Al-Ramahi et al. [3]; Kong [4]. The disadvantages of these methods include time-consuming process, poor purity and low efficiency Mandal [5]; Dewanjee [6]; Lu [7]; Mura [8]. Ultrasound-assisted extraction (UAE) was first used in the isolation of alkaloids from *Cinchona succirubra* Head et al. [9] and has been increasingly used in the extraction of medicinal compounds from plants Zhao et al. [10]; Florez-Fernandez [11]; Jibril [12]. In this paper, recent advances in applications and prospects of ultrasound-assisted extraction in Chinese herbal

medicine are discussed. It is expected that this method will be commercially used in the extraction of medicinal compounds from plants for drug manufacture and clinical applications in Chinese herbal medicine in the near future.

MECHANISMS OF ULTRASOUND-ASSISTED EXTRACTION

To extract medicinal compounds from plants, both cell wall and cell membrane must be destroyed. For this purpose, ultrasounds are used for cell disintegration in ultrasound-assisted extraction Lee [13]; Barba [14]. Ultrasounds are sound waves with frequencies from 20 kHz up to several gigahertz, which are higher than the upper audible limit of human hearing Podder [15]. Ultrasound treatment has thermal effects Feng [16]; Kumcuoglu [17]; Wang [18]; plant materials and solvent absorb the energy

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of the ultrasound waves and convert them into heat energy. The frequency, intensity and duration of ultrasound treatment affect the amount of heat generated in plant materials. This heat energy denatures proteins, destroys plant cells and increases the release of medicinal compounds from plant cells.

Ultrasound treatment also produces mechanical effects caused by the interaction between the ultrasonic waves, and the plant tissues and solvent Feng [16]. The mechanical effects of ultrasound include high-frequency vibration, radiation pressure and shear forces Sarvazyan [19]. They damage plant cells and tissues and denature proteins Riesz [20]; Altemimi [21]. Thus, these mechanical effects facilitate a more complete penetration of solvent into the plant tissues and cell compartments, and extraction of medicinal compounds from plant cells.

In addition, ultrasonic waves generate cavitation and thus destroy cell wall and cell membrane, facilitating the release of medicinal compounds from plant cells and tissues Riesz [20]; Wu [21]; Kumcuoglu [17]; Bashi [22]. The ultrasonic waves generate alternating high-pressure and low-pressure cycles in liquid media. During the low-pressure cycle, high-intensity ultrasonic waves produce small vacuum bubbles in the liquid. During the high-pressure cycle, small vacuum bubbles collapse destructively. This phenomenon is called cavitation Xu et al. [23]. Implosion of cavitation bubbles may also generate liquid jets with a high speed of up to 280 m/s, resulting in shear forces Williams [24]. The shear forces break the cell wall and cell membrane mechanically, and thus promote cellular component release.

CHARACTERISTICS OF ULTRASOUND-ASSISTED EXTRACTION

As stated above, ultrasound treatment has thermal, mechanical and cavitation effects in ultrasound-assisted extraction. Thus, this method may have unique features and advantages as compared with the traditional methods in the extraction of medicinal compounds from plants.

High efficiency

Ultrasound-assisted extraction has high extraction efficiency in the extraction of medicinal compounds from plants Xu et al. [25]; Zhang [26]. The traditional methods usually take a couple of days, whereas ultrasound-assisted extraction could be finished within several hours for the extraction of medicinal compounds from plants Florez-Fernandez, [11]. For example, ultrasound-assisted extraction has higher extraction efficiency in the extraction of isoflavone from *Puerariae Lobatae Radix* than the traditional methods Wu [27].

Low energy consumption

The energy consumption of ultrasound-assisted extraction is less by far than the traditional methods in the extraction of medicinal compounds from plants Petigny [28]; Kazemi [29]; Zhu et al. [30].

High qualities

The medicinal compounds extracted from plants by ultrasound-assisted extraction have better qualities Petigny [28]. In

comparison with the traditional methods, the ultrasound-assisted extraction takes less time and thus keeps minimal degradation and contamination of medicinal compounds during extraction. For example, ultrasound-assisted extraction of essential oil from fresh garlic (*Allium sativum*) cloves resulted in less degradation of thermal-sensitive molecules as compared with the traditional distillation extraction methods Kimbaris [31].

High yields

The yields of plant medicinal compounds extracted by ultrasound-assisted extraction are usually higher Petigny, [28]; Kazemi [29]; Dhanani [32]. Ultrasound treatment generates mechanical and cavitation effects, leading to the efficient disintegration of plant cells and increased release of medicinal compounds.

Extensive application

The choice of specific traditional method used in the extraction of medicinal compounds from plants depends on the molecular weight, solubility and heat-stability of targeted medicinal component. Ultrasound-assisted extraction, however, may be used in the extraction of varieties of targeted medicinal compounds such as alkaloids Wang [33], anthraquinones Jibril [12], flavonoids Zhou [34]; Pinela [35], glycosides Dong [36], oil Senrayan [37], pectin (Grassino [38]), phenolic compounds Um [39]; Wang [40] and polysaccharides Wang [33]; Cheng et al. [41], and thus has an extensive application in the extraction of medicinal compounds from plants.

Automation

Ultrasound parameters such as frequency, intensity and duration can be easily adjusted and controlled in ultrasound-assisted extraction Altemimi [21]; Kazemi [29]. Therefore, ultrasound-assisted method may be automated in the extraction of medicinal compounds from plants Zhang [42].

High standard

The facilities used in ultrasound-assisted extraction are of high quality and may meet the requirement of Good Manufacturing Practice (GMP) in the extraction of medicinal compounds from plants in medical industry (Gambaro [43]; Singanusong [44].

FACTORS ASSOCIATED WITH ULTRASOUND-ASSISTED EXTRACTION

The ultrasound-assisted extraction has unique features and advantages as compared with the traditional methods in the extraction of medicinal compounds from plants. Nevertheless, several important factors significantly affect the quality and yield of the extracted medicinal compounds from plants.

Ultrasonic frequency

The ultrasonic frequency impacts the efficiency of ultrasound-assisted extraction in the extraction of medicinal compounds from plants Dranca [45]. In general, the low ultrasonic frequency generates greater mechanical and cavitation effects, leading to increased efficacies of ultrasound-assisted extraction Tran [46]; Xin [47]. An exception has been reported when use of higher ultrasonic

frequency resulted in better efficiency of ultrasound-assisted extraction of phenolic compounds from *Phyllanthus emblica* Tsai [48]. The optimal ultrasonic frequencies differ for different plant tissues in ultrasound-assisted extraction of specific medicinal components. An ultrasonic frequency of 40 kHz is suitable for the ultrasound-assisted extraction of apigenin, baicalin and luteolin compounds from the air-dried whole plants of *Scutellaria barbata* D. Don Wei [49]. An ultrasonic frequency of 60 kHz is better than 20 kHz and 100 kHz for ultrasound-assisted extraction of hesperidin from Penggan (*Citrus reticulata*) peel Ma [50].

Duration of ultrasound treatment

The duration of ultrasound treatment in the ultrasound-assisted extraction is usually much shorter than the traditional methods Celli [51]. Generally, the duration of ultrasound treatment is 20-45 minutes in the ultrasound-assisted extraction of medicinal compounds from plants. An ultrasound treatment for 30 min is suitable for the ultrasound-assisted extraction of apigenin, baicalin and luteolin compounds from *Scutellaria barbata* D. Don Wei [49]. Ultrasound treatment for 44.85 min is the optimal condition for total monomeric anthocyanin extraction from eggplant (*Solanum melongena* L.) peel, whereas 57.5 min is the optimal extraction time for phenolic compounds extraction from eggplant peel Dranca [45].

Duty cycle of ultrasound

The duty cycle of ultrasound refers to the percentage of time that ultrasound is being generated (pulse duration) over one pulse period. The duty cycle of ultrasound dramatically impinges on the cavitation effects and thus affects the efficiency of ultrasound-assisted extraction Dey [52]. A duty cycle of 75% (intermittent sonication, 90s of pulse followed by 30s of no pulse) is suitable for the ultrasound-assisted extraction of apigenin, baicalin and luteolin compounds from *Scutellaria barbata* D. Don Wei [49], whereas a duty cycle of 50% is more efficient for ultrasound-assisted extraction of phenolic compounds from pomegranate peel Kazemi [29].

Solvent

Different medicinal compounds have different solubilities in different solvents. For instance, saponins and polysaccharides have good solubility in water Xie et al. [53]; Zhang, Qiao [54], whereas phenolic compounds such as anthocyanins and chlorogenic acid have good solubility in ethanol (Liu, Wei et al. 2013; Tan, Wang et al. 2014). Thus, the choice of solvent depends on the solubility of targeted medicinal compounds in ultrasound-assisted extraction. An ethanol concentration of 60% (v/v) is suitable for the ultrasound-assisted extraction of apigenin, baicalin and luteolin compounds from *Scutellaria barbata* D Don Wei et al. [49]. Methanol is the best solvent for ultrasound-assisted extraction of hesperidin from Penggan (*Citrus reticulata*) peel compared with ethanol or isopropanol Ma [50].

Features of plant materials

It has been documented that the parameters for extracting medicinal compounds from various plants are different. These differences may be due to the unique features of different plant materials including tensile strength, flexibility, shape,

density, and surface morphology. The unique features of plant materials are determined by the plant cell wall structures, which are composed of cellulose, hemicelluloses, lignin, and pectin. Different plant materials contain different types and amount of cellulose, hemicelluloses, lignin, and pectin. These differences affect the efficiency of ultrasound-assisted extraction of medicinal compounds from plants.

Size of plant materials

Plant materials are usually minced into tiny granules before they are used in ultrasound-assisted extraction. In general, the smaller the granules of plant materials the higher the efficiency of ultrasound-assisted extraction. The granules of plant materials with 0.250-0.149 mm in diameter are appropriate for ultrasound-assisted extraction of medicinal compounds from plants. A mean plant particle size of 0.355 mm is suitable for the ultrasound-assisted extraction of apigenin, baicalin and luteolin compounds from the air-dried whole plants of *Scutellaria barbata* D. Don Wei [49].

Immersion time

The immersion time of plant tissues in the solvent affects the efficiency of ultrasound-assisted extraction. Short-time immersion makes incomplete extraction of medicinal compounds from plant tissues, whereas a prolonged period of immersion time also hinders the transfer of medicinal compounds from plant cells into the solvent and impedes the efficiency of ultrasound-assisted extraction. The optimal immersion time for different plant tissues and specific medicinal component in ultrasound-assisted extraction should be determined experimentally.

Extraction temperature

Ultrasound treatment has thermal effects, which influence the efficiency of ultrasound-assisted extraction of medicinal compounds from plants. Extraction temperature itself also affects the extraction efficiency. Therefore, the extraction temperature may be different for ultrasound-assisted extraction of different medicinal compounds from different plants. For instance, 80 °C is optimal to achieve maximum yield of flavonoids from *Sophora flavescens* Zhou [34], and 50 °C to extract arabinoxylan from wheat bran Sun [55].

APPLICATIONS OF ULTRASOUND-ASSISTED EXTRACTION

Ultrasound-assisted extraction may have several advantages in the extraction of medicinal compounds from plants as compared with the traditional methods Petigny [28]; Kazemi [29]; Zhang et al. [26]. Thus, ultrasound-assisted extraction has great applications in Chinese herbal medicine.

Extraction of alkaloids

Alkaloids are a group of chemical compounds containing basic nitrogen atoms, which are naturally present in plants, animals and other organisms Derosa [56]. They have various medicinal activities such as antibacterial, antimalarial, antiasthma and anticancer Imperatore [57]; Pervaiz et al. [58]; Promchai [59].

Alkaloids are usually extracted from different plants by acid-base extraction Rujjanawate [60]; Vieira [61]. However, ultrasound-assisted extraction of fangchinoline and tetrandrine alkaloids from *Stephaniae tetrandrae* has a much shorter extraction time (from 6 h to 40 min) and significantly increased efficiency (approximately 30% improvement) as compared with traditional reflux extraction method Zhang [62]. Ultrasound-assisted extraction is the most suitable method for steroidal alkaloids from potato peel waste Hossain [63] and for the extraction of ergot alkaloids from seeds of the genus *Ipomoea* plants Nowak [64].

Extraction of artemisinin

Artemisinin is a sesquiterpene lactone containing an unusual peroxide bridge and has a therapeutic activity against *Plasmodium falciparum* malaria Klayman [65]; White [66]. It was isolated from the plant *Artemisia annua* L. Klayman [67]. Ultrasound-assisted extraction is an effective method in the isolation of artemisinin from *Artemisia annua* leaves Chemat [68].

Extraction of carotenoids

Carotenoids are one of plant pigment classes and the dominant pigment in autumn leaf coloration of 15-30% of trees. Their functions include absorption of light energy for use in photosynthesis and protection of chlorophyll from photo damage Chen [69]; Niedzwiedzki [70]. Carotenoids have also antioxidation activities Rangani [71]. It has been reported that ultrasound-assisted extraction using vegetable oils could be used in the extraction of carotenoids from peach palm fruit and pomegranate peels Ordonez-Santos et al. [72]; Goula [73].

Extraction of coumarins

Ultrasound-assisted extraction method is also used in the extraction of coumarins from plants. Ultrasound-assisted extraction of total coumarins from *Cortex Fraxini*, the barks of *Fraxinus chinensis* Roxb, is much better than the classic Soxhlet extraction in terms of processing time, energy cost and extraction efficiency Xiong [74]. The optimal conditions for the extraction of total coumarins from *Cortex Fraxini* include 60% ethanol, a ratio of solid to liquid 1:10 (W/V), ultrasonic frequency 175 W, extraction temperature of 50°C and extraction time of 40 min. The extraction rate of total coumarins is 6.283% under the optimal extraction conditions.

Extraction of flavonoids

Flavonoids, which belong to a polyphenolic subgroup, are usually present in plants and fungi. So far, more than 6,000 flavonoids have been identified, and quercetin, kaempferol, catechins and anthocyanidins are examples of the best-known flavonoids Konrad [75]. They may be divided into six subgroups: chalcones, flavones, flavonols, flavanones, anthocyanins and isoflavonoids Konrad [75]; Jiang [76]. Flavonoids have antioxidant, anti-inflammatory, and anti-cancer biological activities and provide vibrant food coloring Nakatsuka [77]; Martinez-Perez [78]; Konrad [75]. They have also great implications in Chinese herbal medicine Tang et al. [79]; Zheleva-Dimitrova [80]. Ultrasound-assisted extraction is often used in the extraction of flavonoids from plants Pan [81]; Wang [82]; Tomaz [83].

Extraction of anthocyanins: Anthocyanins belong to a subgroup of flavonoids Hassellund [85]. Anthocyanins have been found to improve heart health, boost cancer defense, fight free radicals, inhibit virus and suppress inflammation (Hassellund [85]; Sehitoglu [85]; Cassidy [86]. Ultrasound-assisted extraction is an effective method for the extraction of anthocyanins from mulberry using 63.8% methanol with 1% (v/v) trifluoroacetic acid (TFA), 43.2°C extraction temperature, 23.8 (v/w) liquid-to-solid ratio, and 40 min extraction time Zou [87]. Ultrasound-assisted extraction is also a suitable method for the extraction of anthocyanins from plant materials such as blueberry He [88], haskap berries Celli [51] and *Nitraria tangutorun* Bobr. seed meal Sang [89].

Extraction of baicalin: Baicalin is a flavone glycoside, which may have an anti-inflammatory activity and anti-atherosclerotic potential and promote hippocampal neurogenesis Yang [90]; Yu et al. [91]; Zhang [92]. Heat-reflux and ultrasound-assisted extraction method are superior to traditional heat-reflux extraction method regarding the extraction time, extraction temperature, solvent consumption and yields in the extraction of baicalin from *Scutellaria barbata* D Don Wei [49]. The optimal conditions for the extraction of baicalin from *Scutellaria barbata* D. Don includes an ultrasonic frequency of 40 kHz, power of 185 W, duty cycle of 75% (intermittent sonication), mean particle size of 0.355 mm, extraction temperature of 50°C, ratio of solvent to raw material of 12:1 (mL/g), ethanol concentration of 60% (v/v), and extraction time of 30 min and three cycles.

Extraction of breviscapine: Breviscapine is a flavonoid extracted from plants and has therapeutic benefits for patients with diabetic nephropathy, cardiovascular and cerebrovascular diseases Ji [93]; Liu [94]. Ultrasound-assisted extraction is a simple, inexpensive and effective method for the extraction of breviscapine from *Erigeron breviscapus* He ME [95]. The optimal conditions include extraction time of 24.5 min, ethanol concentration of 74.7% and a ratio of solvent volume to plant material mass of 19.8 (mL/g).

Extraction of isoflavonoids: Puerarin is an isoflavonoid extracted from the root of *Pueraria lobata* (Wild.) Ohwi Yeung [96]. It has been widely used in Chinese herbal medicine due to its numerous beneficial actions for cardiovascular diseases, acute dysentery, hypertension, alcoholism, deafness, cancer and diarrhea Jintao [97]. Ultrasound-assisted extraction could be used in the extraction of puerarin and total isoflavones from the root of *Pueraria lobata* (Wild.) Ohwi Fan [98]; Wu [99]. The optimal extraction conditions include ethanol concentration of 71.35%, extraction time of 49.08 min and a solvent-to-material ratio of 21.72 for puerarin extraction from the root of *Pueraria lobata*, whereas the optimal conditions for total isoflavone extraction include 80% ethanol, extraction time 55 min and a solvent-to-material ratio 12.81 Wu [99].

EXTRACTION OF GLYCOSIDES

It has been known that glycosides have numerous important biological functions Diederich [100]; Xue [101]. Thus, glycosides from plants are often used as pharmaceutical drugs Oerther [102]. Glycosides may also be extracted from plants by ultrasound-assisted extraction method Dong [36].

Extraction of geniposide

Geniposide is a glycoside, which is the important bioactive component extracted from the fruits of *Gardenia jasminoides* Ellis Cai [103]. Geniposide has been shown to possess anti-inflammatory, antioxidant, anti-carcinogenic and anti-angiogenic activities Miao [104]; Huang [105]. Ultrasound-assisted extraction could be successfully used in the extraction of geniposide from *Gardenia jasminoides* Ellis Wang [27].

Extraction of paeoniflorin

Paeoniflorin is a glycoside and has numerous biological functions including anti-cancer and neuroprotection activities Hao [106]; Liu [107]. Paeoniflorin could be isolated from the root of *Paeonia lactiflora* by ultrasound-assisted extraction Xie et al. [108]; Liu et al. [42].

Extraction of phillyrin

Phillyrin is a glycoside found in plants and fungi, which possesses anti-bacteria, anti-viruses, anti-inflammation and anti-oxidation properties Xia [109]; Wei [110]; Qi [111]. Phillyrin can be extracted from *Forsythia suspensa* (Thunb.) Vahl by ultrasound-assisted extraction and the optimal extraction conditions include 20% methanol, solvent-to-material ratio 10, ultrasound power 600W, ultrasound frequency 40 kHz, extraction temperature 60 °C and extraction time 60 min Xia [109].

Extraction of saponins

Saponins are a group of amphipathic glycosides found in plants. They have anti-cancer, anti-inflammatory, antioxidant, expectorant and vasoprotective activities Kang [112]; Koczurkiewicz [113]. Ultrasound-assisted extraction is a simple and effective method to extract saponins from different types of ginseng and other Chinese medical herbs Wu [114]; Liu [115].

EXTRACTION OF LIGNANS

Lignans are a group of polyphenolic compounds present in plants. It has been shown that lignans have anti-cancer, anti-inflammation, anti-oxidation and neuroprotection activities Adfa [116]; Hu [117]; Li [118]; Teponno [119]. Ultrasound-assisted extraction has been successfully used in the extraction of lignans such as honokiol and magnolol from *Magnolia officinalis* Zhang [120]. Ultrasound-assisted extract in combination with an aqueous two-phase system is much better in the extraction of lignans from *Schisandra chinensis* and *Zanthoxylum armatum* Guo [121]; Su [122]. For the extraction of lignans from the root and stem mixture of *Zanthoxylum armatum*, the optimal conditions include an aqueous two phase system of 20% n-propanol and 24% (NH₄)₂SO₄ in combination with ultrasonic-assisted extraction of a solvent to solid ratio 15:1, ultrasonic power 250W, extraction temperature 40°C and extraction time 55 min. To extract lignans from *Schisandra chinensis* seeds, 25% (w/w) (NH₄)₂SO₄ and 19% (w/w) ethanol are combined with the optimal ultrasound-assisted extraction conditions of a solid-liquid ratio 20:1, ultrasonic power 800W and extraction time 61.1 min Guo [121].

EXTRACTION OF OILS

Oils extracted from plants have several medicinal applications

Li [123]; Kasrati [124]; Wangchuk [125]; Uma [126]. Ultrasound-assisted extraction is the most effective method for the extraction of essential oils from *Ligusticum chuanxiong* as compared with supercritical fluid extraction, Soxhlet extraction and hydro-distillation extraction Yang [127]. Ultrasound-assisted extraction can be used in the extraction of oils from grape and papaya seeds Da Porto [128]; Samaram [129]. However, ultrasound-assisted extraction may not be a suitable method for extracting volatile oils from *Rhizoma Curcumae* Zhang [130].

EXTRACTION OF PHENOLIC COMPOUNDS

Phenolic compounds may be divided into two categories, simple phenols and polyphenols. Phenolic compounds from medicinal plants usually contain phenolic acids, flavonoids, tannins, stilbenes, curcuminoids, coumarins, lignans and quinones. Phenolic compounds are used in medicine due to their antioxidant, anticarcinogenic, antimutagenic and anti-inflammatory activities Huang [131]; Zhu [18]. Ultrasound-assisted extraction can be efficiently used in the extraction of total phenolic compounds from plants including *Amygdalus persica*, *Cucurbita moschata*, *Inula helenium*, *Myrcia amazonica* DC and *Vaccinium ashei* Wang et al. [132]; Altemimi [21]; de Moraes Rodrigues [133]; He [88].

EXTRACTION OF POLYSACCHARIDES

Polysaccharides are polymers of three or more monosaccharides. Polysaccharides have many biological functions such as anti-tumor, anti-virus, immune modulation and antioxidative activities Feng et al. [134]; Nie et al. [135]; Wang et al. [136]; Dan Liu et al. [137]. Studies have shown that ultrasound-assisted extraction may be effectively used in the extraction of polysaccharides from a variety of plants You [138]; Jia [139]. Zhang et al. [140]; Ren [141]. The optimal conditions for extraction of polysaccharides from different plants are not identical. For instance, the optimal conditions for ultrasound-assisted extraction of polysaccharides from mulberry fruits include a ratio of water to raw material 40.25, extraction temperature 69 °C, ultrasonic power 190W and extraction time 75 min, whereas those for the extraction of polysaccharides from *Artemisia sphaerocephala* Krasch seeds include a solid-liquid ratio 64:1, extraction temperature 64 °C, ultrasonic power 243W and extraction time 125 min You et al. [138].

As structural polysaccharides, pectin is present in the primary cell walls of plants. Pectin is usually used in food preparation and medicine Eliaz [142]; Delphi [143]; Ueberall [144]. Ultrasound-assisted extraction can be efficiently used in the extraction of pectin from mango, tomato and *Artocarpus heterophyllus* fruit peels Grassino [38]; Wang [145]; Moorthy [146]. In addition, ultrasound-assisted extraction is an effective method for extraction of β -D-glucan from hull-less barley Koocheki et al. [147].

EXTRACTION OF STEROIDS

Steroids are organic molecules containing a four-ring core. Steroids possess various biological functions and clinical benefits including cytotoxicity, antibacteria, antifungi, antiviruses and anti-inflammation Kuthubutheen [148]; McCabe [149]; Zubair [150]. Hundreds of steroids are present in plants, and thus steroids may be isolated from plants by ultrasound-assisted extraction (Schinor, Salvador et al. 2004). For instance, two steroids (β -sisterosterol and

stigmaterol) have been purified from *Annona glabra* leaves by ultrasound-assisted extraction Matsumoto [151].

EXTRACTION OF TAXOL

Taxol is a chemotherapy drug, which is extensively used in the treatment of cancer patients Lemstrova, [152]; Chen [153]. It is usually isolated from the bark, roots, stems and leaves of plants from the genus *Taxus* including *Taxus baccata*, *Taxus brevifolia*, *Taxus chinensis* var. *mairei*, *Taxus cuspidate* and *Taxus madia* Dong [154]. Yew plants in the genus *Taxus* usually grow slowly and contain very low amounts of taxol Mayol [155]; Gong et al. [156]. In addition, conventional extraction methods have a low efficiency in the isolation of taxol from yew plants Kim [157]. Ultrasound-assisted method with 50% ethanol is an efficient method to extract taxol from *Taxus cuspidate* Xiao, Lao et al. [158].

PROSPECTS OF ULTRASOUND-ASSISTED EXTRACTION

As compared with conventional extraction methods, ultrasound-assisted extraction has several advantages such as low energy consumption, less extraction time, less active compound damage and high extraction yields. Thus, ultrasound-assisted extraction has become one of most attractive methods used in Chinese herbal medicine. There are several limitations, however, which require further investigations for useful and effective applications in Chinese herbal medicine.

So far, majority of reports focused on the optimization of ultrasound-assisted extraction conditions used in the isolation of medicinal compounds from plants Bashi [22]; de Moraes Rodrigues [133]; Dranca [45]; Kazemi [29]; Meullemiestre, [159]; Nour [160]; Alves Monteath [161]. Thus, ultrasound-assisted extraction used in the isolation of medicinal compounds from plants was restricted to laboratory investigations. Further studies will be required for the application of ultrasound-assisted extraction for the large-scale isolation of medicinal compounds from plants.

Very few studies have evaluated the biological functions of medicinal compounds isolated from plants by ultrasound-assisted extraction method. The flavonoids isolated from *Stachys parviflora* L. using ultrasound-assisted extraction possess significant antioxidant activities Bashi [22]. Polysaccharides isolated from *Artemisia selengensis* Turcz by ultrasound-assisted extraction have anti-tumor activity Wang et al. [162]. With these limited studies, evaluation of the biological functions of medicinal compounds isolated from plants by ultrasound-assisted extraction method warrants further investigations.

The advantages of ultrasound-assisted extraction for isolating medicinal compounds from plants are well-documented Ghitescu [163]; Chemat [164]; Espada-Bellido [165]. However, the underlying mechanisms of these benefits are not clearly understood Saleh [166]. We believe that a dissection of the mechanisms is critical for ultrasound-assisted extraction to be applied, improved and expanded in relation to medicinal compound extraction, which is of enormous relevance to research and industry in Chinese herbal medicine. It is anticipated that ultrasound-assisted extraction method will be extensively used in Chinese herbal medicine industries [167-173].

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