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OPTIMISING ULTRASOUND-ASSISTED EXTRACTION OF PHENOLIC COMPOUNDS FROM GINGER: A REVIEW

Adilah Anuar[a,d]*, Mohammad Amil Zulhilmi Benjamin[b], Mohd Azrie Awang[c], Nor Munirah Rohaizad[a]

[a]Faculty of Chemical Engineering and Technology, Universiti Malaysia Perlis, Kampus UniCITI Alam, Sungai Chuchuh, 02100 Padang Besar, Perlis, Malaysia
[b]Borneo Research on Algesia, Inflammation and Neurodegeneration (BRAIN) Group, Faculty of Medicine and Health Sciences, Universiti Malaysia Sabah, Jalan UMS, 88400 Kota Kinabalu, Sabah, Malaysia
[c]Innovative Food Processing and Ingredients Research Group, Faculty of Food Science and Nutrition, Universiti Malaysia Sabah, Jalan UMS, 88400 Kota Kinabalu, Sabah, Malaysia
[d]Centre of Excellence for Frontier Material Research (CFMR), Universiti Malaysia Perlis,64-66, Blok B, Taman Pertiwi Indah, Jalan Kangar - Alor Setar, Kampung Seriab, 01000 Kangar, Perlis

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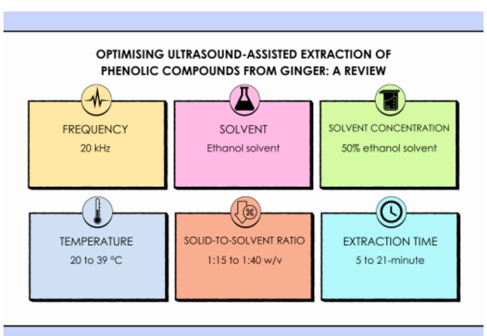
*Corresponding author
adilahanuar@unimap.edu.my

Graphical abstract



Abstract

Ginger (*Zingiber officinale* Roscoe) has a long-standing history as a therapeutic agent in traditional remedies due to its diverse pharmacological effects. This review explores the potential of phenolic compounds in ginger for disease treatment, highlighting the benefits of ultrasound-assisted extraction (UAE) as an eco-friendly alternative to conventional methods. UAE offers reduced solvent usage, shorter extraction times, and lower energy consumption. Optimal UAE parameters (ultrasonic frequency, solvent choice, solvent concentration, temperature, solid-to-solvent ratio, and extraction time) for extracting phenolic compounds from ginger are summarised, with examples from fruits and vegetables illustrating general trends and enhancing understanding. The review emphasises the importance of precise extraction techniques in maximising the health benefits of natural resources like ginger, with promising applications in both food and pharmaceutical industries.

Keywords: Ginger, ultrasound-assisted extraction, frequency, solvent, solvent concentration, temperature, solid-to-solvent ratio, extraction time

Abstrak

Halia (*Zingiber officinale* Roscoe) mempunyai sejarah yang panjang sebagai agen terapeutik dalam ubat tradisional kerana kesan farmakologinya yang pelbagai. Ulasan ini meneroka potensi sebatian fenolik dalam halia untuk rawatan penyakit, menyoroti manfaat pengekstrakan bantuan gelombang ultrabunyi (UAE) sebagai alternatif mesra alam kepada kaedah konvensional. UAE menawarkan penggunaan pelarut yang lebih rendah, masa pengekstrakan yang lebih singkat, dan penggunaan tenaga yang lebih rendah. Parameter UAE yang optimum (frekuensi ultrasonik, pilihan pelarut, kepekatan pelarut, suhu, nisbah pepejal-ke-pelarut, dan masa pengekstrakan) untuk mengekstrak sebatian fenolik dari halia diringkaskan, dengan contoh-contoh dari buah-buahan dan sayur-sayuran yang menggambarkan trend umum dan meningkatkan pemahaman. Ulasan ini menekankan kepentingan teknik pengekstrakan yang tepat dalam memaksimumkan manfaat kesihatan sumber semula jadi seperti halia, dengan aplikasi yang menjanjikan dalam industri makanan dan farmaseutikal.

Kata kunci: Halia, pengekstrakan bantuan gelombang ultrabunyi, frekuensi, pelarut, kepekatan pelarut, suhu, nisbah pepejal-ke-pelarut, masa pengekstrakan

1.0 INTRODUCTION

There is a growing trend towards utilising fruits and vegetables as therapeutic medicines. This shift is driven by several factors, including a heightened awareness of the health benefits associated with natural remedies and a desire to minimise reliance on synthetic drugs with potential side effects [1, 2]. Fruits and vegetables, abundant in bioactive compounds like antioxidants, vitamins, and phytochemicals, are increasingly acknowledged for their health-promoting and disease-preventing properties, alongside their accessibility and affordability, rendering them appealing options for those seeking alternative treatment modalities [3]. As a result, there has been a resurgence of interest in traditional herbal remedies and plant-based diets as complementary approaches to conventional medical treatments [4]. This trend reflects a broader movement towards holistic healthcare and preventive medicine, emphasising the importance of nutrition and lifestyle factors in maintaining overall well-being.

Zingiber officinale Roscoe, commonly known as ginger, is a renowned herbal spice believed to have originated in either India or Southeast Asia. This perennial herb is characterised by a robust tuberous rhizome and a leafy aerial stem that can grow to a height of about one meter, adorned with striking purple flowers. Notably, ginger follows a unique reproductive process, propagating through rhizomes rather than traditional seeds, which renders it a sterile plant. Its adaptability is evident in its widespread cultivation in tropical and partially tropical regions across the globe [5]. This versatile plant has garnered acclaim not only for its culinary applications but also for its numerous health benefits, making it a valuable asset in traditional medicine and modern wellness practices alike [6].

In recent years, several innovative extraction technologies, including ultrasound-assisted extraction (UAE), microwave-assisted extraction, accelerated solvent extraction, and supercritical fluid extraction, have gained prominence. These methods offer advantages such as reduced extraction time, lower energy consumption, cost-effectiveness, and higher yields. Figure 1 provides a visual summary of the strengths and weaknesses of these extraction technologies. Among these, UAE stands out as a sustainable and efficient choice. It requires a modest amount of solvents and energy, ensuring ease of operation, safety, and reproducibility [7]. Operating at atmospheric pressure and room temperature, UAE proves to be a favourable option for phytochemical extraction [8, 9].

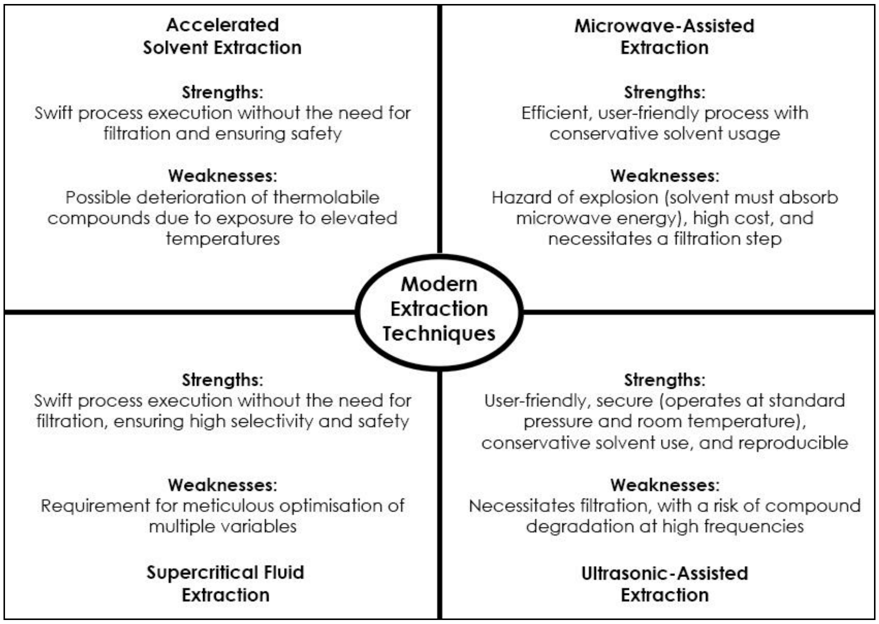


Figure 1 Pictorial representation of strengths and weaknesses of modern extraction techniques [9, 10]

This study delves into the factors influencing the extraction yield of phenolic compounds through UAE. While there has been extensive research on UAE for extracting phenolic compounds from fruit and vegetable sources, a comprehensive review encompassing all facets of this method is currently lacking. Thus, this review aims to explore the optimal conditions for UAE of phenolic compounds from ginger, with a particular focus on achieving high yields. By incorporating examples from fruits and vegetable, the study aims to illustrate general trends and enhance understanding of UAE techniques. The findings hold significant implications for industries, particularly in the food and pharmaceutical sectors, where ginger extracts have extensive applications.

2.0 PHENOLIC COMPOUNDS OF GINGER

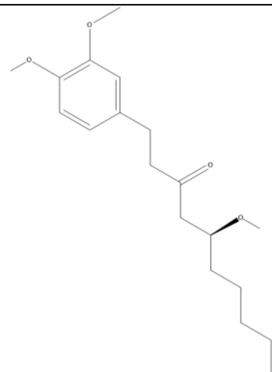
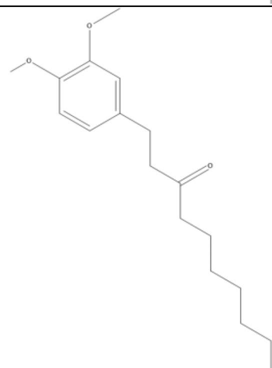
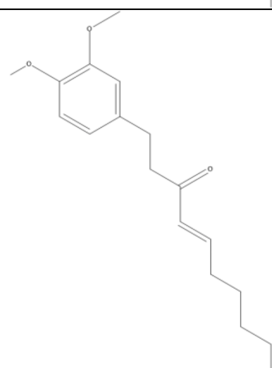
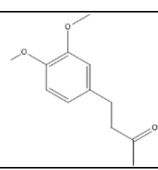
Researchers have identified a minimum of 115 constituents present in both fresh and dried ginger [11]. However, the primary active constituents abundant in ginger are phenolic compounds [12]. The ginger rhizome contains oleoresin with a variety of phenolic compounds, including gingerol, paradols, and shogaols [13]. These compounds contribute to the plant's pharmacological, biological, and pharmaceutical activities [14]. Moreover, fresh ginger is rich in gingerols, while heat treatment leads to increased levels of dehydrated derivatives such as shogaols and zingerone [15]. Additionally, ginger contains other phenolic compounds such as zingerone, quercetin, 6-dehydrogingerdione, and gingerenone-A [16, 17]. The biological activities of these main phenolic compounds, known to be gingerols, paradols, shogaols, and zingerone and their related compounds are outlined in Table 1. Thus, the phenolic compounds found in ginger contribute to its diverse health benefits, including antioxidant, anti-tumour, anti-inflammatory, anticancer, antimicrobial, antiulcer, antidiarrhoeal, antiemetic, immunostimulant, lipolytic, cardiovascular, and neuroprotective properties [18–22].

3.0 HISTORICAL OVERVIEW OF UAE

The utilisation of UAE technology has been extensively explored over the past two decades. This is because traditional extraction methods involving water often come with drawbacks such as associated risks, elevated production costs, and potential degradation of bioactive components. Sonication technology was introduced as an external intervention to overcome these limitations. UAE not only enhances the extraction efficiency significantly but also reduces the required solvent volume and extraction time. The growing adoption of sonication technology is evident from the exponential increase in research papers using this method [23].

The UAE technology has gained significant traction in the food and pharmaceutical sectors due to its scalability, cost reduction benefits, and enhanced safety measures during the process [24]. There are two primary methods to carry out UAE. The first involves introducing sonication through a sonication probe, while the second method utilises an ultrasonic water bath where ultrasound power is generated by a piezoelectric transducer. Figure 2 illustrates the UAE using an ultrasonic probe and ultrasonic water bath.

Table 1 Biological activities of ginger and its main phenolic compounds

Phenolic compounds	Chemical structures	Biological Activities	References
Gingerols and their related compounds		Antioxidant, anti-tumour, anti-inflammatory, and anticancer agents	[18, 19]
Paradols and their related compounds		Antioxidant, anti-tumour, anti-inflammatory, and anticancer agents	[18, 20]
Shogaols and their related compounds		Antioxidant, anti-tumour, anti-inflammatory, antimicrobials, antiulcer, cardiovascular, and neuroprotective agents	[18, 20, 21]
Zingerone		Antioxidant, anti-inflammatory, anticancer, antidiarrhoeal, antiemetic, immunostimulant, and lipolytic agents	[20, 22]

(a) (b)

Figure 2 UAE using (a) ultrasonic probe and (b) ultrasonic water bath

The ultrasonic bath operates by immersing a conical flask containing plant samples and solvents into the ultrasonic water bath. In comparison, the ultrasonic water bath is more user-friendly and cost-effective than the ultrasonic probe. However, the reproducibility with the ultrasonic water bath is lower than with the ultrasonic probe due to non-uniform energy distribution and a reduction in power over time, which decreases the efficiency of the bath system. In the ultrasonic probe system, the probe is directly immersed in the extraction vessel and delivers ultrasound into the medium with minimal energy loss and higher ultrasonic intensity at the tip of the probe, making it a powerful tool for the extraction of bioactive compounds. This system offers a higher intensity of ultrasonic power and a more efficient cavitation effect, as it is concentrated in a specific sample zone compared to the ultrasonic water bath [25].

4.0 UAE OF BIOACTIVE COMPOUNDS FROM FRUIT AND VEGETABLE SOURCES

The diverse fruit and vegetable sources offer a rich array of phenolic compounds, including pectin derived from fruit peels like grape pomace [26], grapefruit [27–30], sour orange [31], and banana [32]. Additionally, dietary fibre can be extracted from sources such as papaya peel [33], apple pomace [34], and soybean residues [35]. Polyphenols, encompassing phenolic and antioxidant compounds, can also be obtained from various fruit and vegetable sources. The optimised extraction conditions for fruit and vegetable sources are summarised in Table 2.

Based on the information provided in Table 2, it is evident that phenolic compounds stand out as the most extensively studied bioactive compounds across the 20 papers. These papers were selected through scientific databases such as Scopus and Web of Science from peer-reviewed articles in reputable journals, focusing on detailed experimental data and insights into optimal UAE parameters obtained from ginger specifically, and fruits and vegetables generally. This indicates a predominant focus on these particular parameters (ultrasonic frequency, solvent choice, solvent concentration, temperature, solid-to-solvent ratio, and extraction time) within the realm of UAE. This emphasis can be attributed to the well-established health benefits associated with phenolic compounds, particularly their potent antioxidant properties known to combat oxidative stress and mitigate various chronic diseases [9]. Moreover, this concentration of research effort underscores the potential applications of phenolic compounds in food and pharmaceutical aspects. Overall, the notable attention given to phenolic compounds and antioxidants underscores their pivotal role in the bioactive composition of fruit and vegetable extracts obtained through UAE techniques.

5.0 OPTIMISING FACTORS IN UAE

Researchers widely agree that there are no universally applicable parameters that consistently yield optimal results across different fruit and vegetable sources in UAE, particularly in the case of ginger. Since the optimal conditions of the parameters were referenced from other fruit and vegetable sources such as turmeric, beetroot, and grape, they served as baseline data to ensure the maximisation of yield in ginger extract. Therefore, it becomes imperative to systematically investigate the extraction conditions. This exploration is vital to pinpoint the most appropriate combination of factors, including ultrasonic frequency, solvent choice, solvent concentration, temperature, solid-to-solvent ratio, and extraction time, specifically tailored for the unique characteristics of fruit and vegetable sources when utilising UAE.

5.1 Selection of Ultrasonic Frequency

The main driving factor behind UAE is the phenomenon of acoustic cavitation, which triggers alternating rarefactions and compressions within the solvent molecules. This process leads to the formation of bubbles due to changes in temperature and pressure [56]. Figure 3 provides a summary of research studies that have examined the use of optimal ultrasonic frequency in UAE from fruit and vegetable sources, based on the information presented in Table 2.

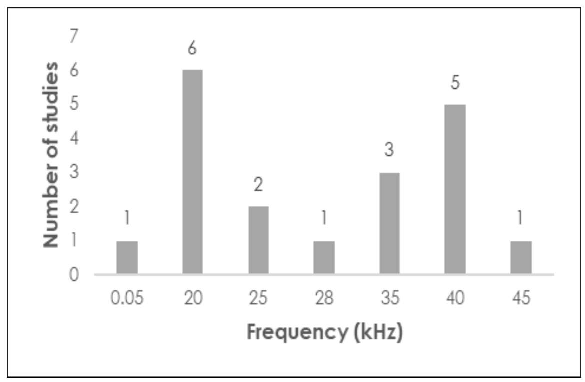


Figure 3 Optimal ultrasonic frequency applied in UAE on fruit and vegetable sources

Low-frequency sonication, typically ranging from 20 to 45 kHz, is commonly employed in UAE for fruit and vegetable sources. Cavitation is particularly strong at these frequencies, resulting in high-intensity ultrasound due to the formation, growth, and collapse of bubbles through acoustic cavitation. Based on the findings, 20 kHz is the most employed frequency in UAE for fruit and vegetable sources compared to other frequencies, with ultrasound probes and water baths being the most used within that condition. This preference for a consistently low frequency is likely because it leads to the creation of fewer but larger cavitation bubbles, which have a more pronounced effect. However, as ultrasound frequency increases, the cavitation effect diminishes [57]. The formation and expansion of cavitation bubbles require a specific minimum duration of the compression-rarefaction cycle; If this cycle is too brief, it will not induce the formation and growth of cavitation bubbles.

5.2 Selection of Solvent

The selection of a solvent considers factors such as solubility, selectivity, safety, and cost, aiming to match the polarity of the target product [58]. The extraction process typically involves four stages: solvent permeation into the solid matrix, solute dissolution, solute diffusion out of the matrix, and collection of the extracted solutes [58]. The choice of solvent significantly influences extraction outcomes due to its polarity, with extensive research exploring its impact on fruit and vegetable sources. Figure 4 provides an overview of optimal solvents used in UAE for these sources, as detailed in Table 2.

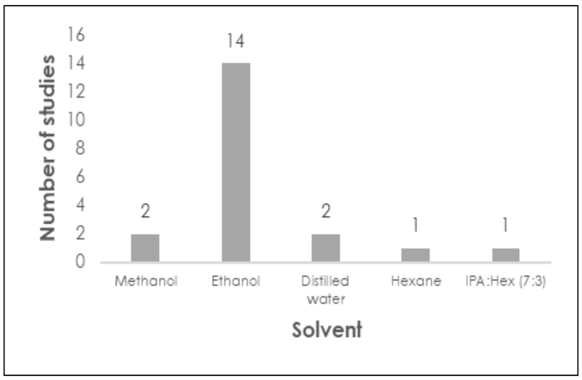


Figure 4 Optimal solvent used in UAE on fruit and vegetable sources

Commonly used solvents in UAE include methanol, ethanol, distilled water, hexane, isopropanol, and a mixture of isopropanol and hexane in a 7:3 ratio [IPA:Hex (7:3)]. Ethanol, in particular, is favoured for its high affinity in many systems, affordability, renewable source from sugar cane, and classification as generally recognised as safe [59]. However, the concentration of ethanol plays a crucial role in extraction yield, with ongoing research aiming to minimise its volume or eliminate its use altogether.

5.3 Selection of Solvent Concentration of Ethanol

The concentration of ethanol in hydroalcoholic mixtures is a crucial factor, particularly for extracting polyphenols efficiently. Pure organic solvents, while effective, can cause cell breakdown and dehydration in plants, aside from concerns about toxicity, cost, and availability [60]. Ethanol, known for its effectiveness in extracting phenolic compounds from various sources, is commonly chosen for phenolic extraction from ginger materials. Figure 5 illustrates the optimal ethanol concentration used in UAE for fruit and vegetable sources, as outlined in Table 2.

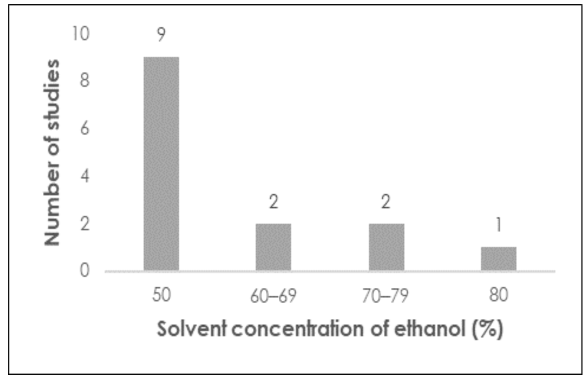


Figure 5 Optimal solvent concentration of ethanol used in UAE on fruit and vegetable sources

Based on the findings, a 50% ethanol concentration emerges as the predominant choice for UAE extraction from these sources. Increasing ethanol concentration initially enhances phenolic compound yield, but only up to an optimal concentration. Beyond this point, further increases result in diminishing returns. In simpler terms, there is a proportional relationship between ethanol concentration and phenolic compound yield up to a specific threshold. Beyond this threshold, higher ethanol concentrations lead to reduced phenolic compound yields. The use of pure alcohols can induce protein degradation and tissue dehydration. Prior to the threshold, higher ethanol concentrations enhances solubility and diffusion of phenolic compounds due to a reduced dielectric constant [25].

5.4 Selection of Temperature

The extraction temperature plays a critical role in UAE, significantly impacting the extraction on phenolic compounds due to their sensitivity to temperature variations [38]. Figure 6 summarises the optimal temperature ranges used in UAE for various fruit and vegetable sources, as indicated in Table 2.

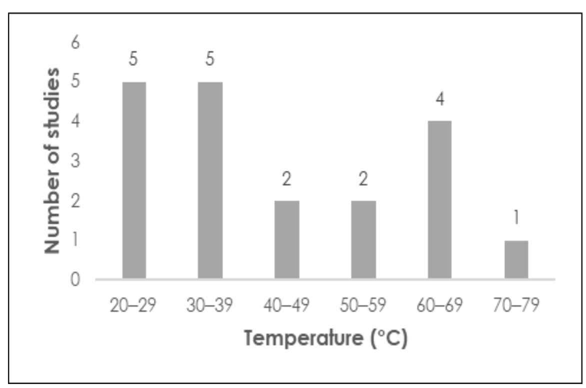


Figure 6 Optimal range of temperature used in UAE on fruit and vegetable sources

Temperatures ranges of 20–29 °C and 30–39 °C have been observed to yield notable results in extracting compounds from fruit and vegetable sources using UAE. Initially, there is a gradual increase in yield with rising temperature. This is attributed to higher temperatures facilitating matrix bond ruptures, increasing solvent diffusion rate, enhancing compound solubility, and improving mass transfer [61]. However, excessively high temperatures can lead to reduced cavitation efficiency, potential degradation of phenolic compounds, and subsequently lower yields [62].

Several hypotheses attempt to explain the increase in yield at higher temperatures in UAE. One suggests that the higher vapour pressure of the solvent at elevated temperatures plays a crucial role, resulting in less intense collapse of cavitation bubbles and reduced cell damage. Another hypothesis proposes that higher temperatures reduce shear stress on the solvent, lowering the rate of mass transfer of phenolic compounds. Conversely, the final hypothesis suggests that shear stress increases with rising temperatures, leading to the degradation of phenolic compounds due to a greater number of cavitation bubbles formed [25,28,63].

5.5 Selection of Solid-to-Solvent Ratio

The solid-to-solvent ratio refers to the quantity of sample (measured in mg) used for extraction relative to the volume of solvent (measured in mL), commonly expressed as mg/mL or w/v. Similar to the trend observed in solvent concentration conditions in UAE, the solid-to-solvent ratio conditions exhibit a comparable pattern. Figure 7 summarises the varied optimal solid-to-solvent ratios used in UAE for different fruit and vegetable sources, as indicated in Table 2.

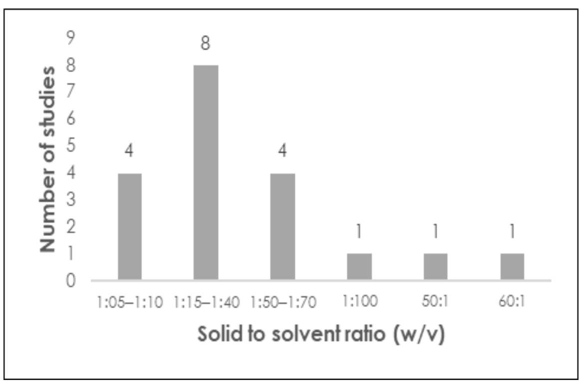


Figure 7 Optimal solid-to-solvent ratio used in UAE on fruit and vegetable sources

The solid-to-solvent ratio, typically ranging from 1:15 to 1:40 w/v, is frequently employed in UAE for fruit and vegetable sources. Initially, an increase in this ratio enhances the yield of phenolic compounds from the plant material, until a specific threshold is reached. Beyond this point, further increases in the ratio lead to diminishing yields. This threshold is determined through a screening process of extraction conditions. The decline in yield can be attributed to either the degradation of plant material or the saturation of the solid-to-solvent ratio, which reduces the efficacy of the cavitation effect in UAE [64]. In cases of low solid-to-solvent ratios, higher viscosity in the solvent implies a greater cohesive force to be overcome by the negative pressure during the rarefaction cycle of cavitation. For phenolic compound extraction, a higher solid-to-solvent ratio proves initially advantageous, as it augments the diffusivity and dissolution of the solid within the solvent. Moreover, it expands the contact surface area between the solid and solvent while intensifying the impact of ultrasound on the plant matrix. This amplifies the yield due to heightened fragmentation, erosion, and pore formation effects [25].

5.6 Selection of Extraction Time

The influence of UAE on the extraction time of phenolic compounds from fruit and vegetable sources has been thoroughly examined and well-documented. Researchers have sought to determine the most effective time frames for UAE, considering both yield and compound integrity. Figure 8 provides an overview of the optimal extraction times utilised in UAE for various fruit and vegetable sources, as detailed in Table 2.

Table 2 Optimised extraction condition for UAE of bioactive compounds from fruit and vegetable sources

Bioactive compounds	Source	Part	Ultrasound	Frequency (kHz)	Solvent	Temperature (°C)	Solid-to-solvent ratio (w/v)	Extraction time (min)	Optimum conditions	Reference
Gingerols	Ginger	Rhizome	Water bath	20	50% methanol	40	–	0–400	20 kHz 50% Methanol 40 °C – 200 min	[36]
Betaxanthin Betanin	Beetroot	Root	Probe	20	50% ethanol	45	1:50–4:25	0–180	20 kHz 50% Ethanol 45 °C 1:50 w/v 180 min	[37]
Antioxidant	Ginger	Rhizome	Probe	20	Distilled water	30–50	1:100	15	20 kHz Distilled water 26 °C 1:100 w/v 15 min	[38]
Curcuminoids	Turmeric	Root	Water bath	35	70–95% ethanol	25	1:10	5–15	35 kHz 70% Ethanol 25 °C 1:10 w/v 15 min	[39]
Phenolics Flavonoids Antioxidant	Ginger	Rhizome	Water bath	35	20–100% ethanol	30–70	20:1–60:1	10–30	35 kHz 86% Ethanol 65 °C 60:1 w/v 11 min	[40]
Gallic acid	Physic nut	Stem bark	Water bath	40	0–70 ethanol	35–55	1:15	10–50	40 kHz 50% Ethanol 35 °C 1:15 w/v 40 min	[41]
Salvianolic acid B	Red sage	Root	Water bath	28–100	0–90% ethanol	30–60	1:5–1:30	10–40	45 kHz 60% Ethanol 30 °C 1:20 w/v 25 min	[42]
–	Ginger Fingerroot Turmeric	Whole	Water bath	20	Hexane Isopropanol IPA:Hex (7:3)	–	1:10	5	20 kHz IPA:Hex (7:3) – 1:10 w/v 5 min	[43]
Phenolics	Wild thyme	Aerial	Probe	20	30–70% ethanol	25	1:10–1:30	5–30	20 kHz 50% Ethanol 25 °C 1:30 w/v	[44]

Bioactive compounds	Source	Part	Ultrasound	Frequency (kHz)	Solvent	Temperature (°C)	Solid-to-solvent ratio (w/v)	Extraction time (min)	Optimum conditions	Reference
									15 min	
Forsythiaside A Phillyrin Rutin	Weeping forsythia	Fruit	Water bath	40	40–80% ethanol	20–60	1:15–1:35	10–40	40 kHz 50% Ethanol 30 °C 1:32 w/v 37 min	[45]
Phenolics Antioxidant	Grape	Seed	Water bath	28	0–100% ethanol	20–60	1:4.5–1:38.5	0–40	28 kHz 61.76% Ethanol 50 °C 1:30 w/v 20 min	[46]
Phenolics	Pea	Pod	Water bath	–	50–80% ethanol	30–50	1:20–1.50	20–50	– 50% Ethanol 30 °C 1:40 w/v 20 min	[47]
Phenolics	Coconut	Shell	Water bath	25	50% ethanol	30–60	1:20–1:50	20–60	25 kHz 50% Ethanol 30 °C 1:50 w/v 20.5 min	[48]
Polysaccharide	Rambutan	Fruit	Water bath	20	Distilled water	40–60	1:20–1:40	30–50	20 kHz Distilled water 53 °C 1:32 w/v 41 min	[49]
Antioxidant	Papaya	Seed	Water bath	40	Hexane	25–50	1:6–1:10	5–30	40 kHz Hexane 62.5 °C 1:7 w/v 38.5 min	[50]
Phenolics Flavonoids Anthocyanins Proanthocyanidins	Black chokeberry	Dust	Water bath	40	50% ethanol	30–70	1:5	30–90	40 kHz 50% Ethanol 70 °C 1:5 w/v 45.6–89.7 min	[51]
Phenolics Antioxidant	Blackberry	Leaf	Water bath	40	20–80% methanol	30–70	1:60	20–120	40 kHz 61–64% Methanol 66–68 °C 1:60 w/v 105–117 min	[52]
Phenolics Antioxidant	Olive	Leaf	Water bath	0.05	0–100% ethanol	25	25:1–50:1	20–60	0.05 kHz 50% Ethanol 25 °C 50:1 w/v 60 min	[53]

Bioactive compounds	Source	Part	Ultrasound	Frequency (kHz)	Solvent	Temperature (°C)	Solid-to-solvent ratio (w/v)	Extraction time (min)	Optimum conditions	Reference
Phenolics	Sparganii rhizoma	Rhizome	Water bath	25	40–80% ethanol	20–25	1:10–1:30	20–40	25 kHz 75.3% Ethanol 20–25 °C 1:19.21 w/v 40 min	[54]
Phenolics Antioxidant	Jujube	Fruit	Water bath	35	0–100% ethanol	25–65	1:10–1:70	5–45	35 kHz 50% Ethanol 63 °C 1:67 w/v 25 min	[55]

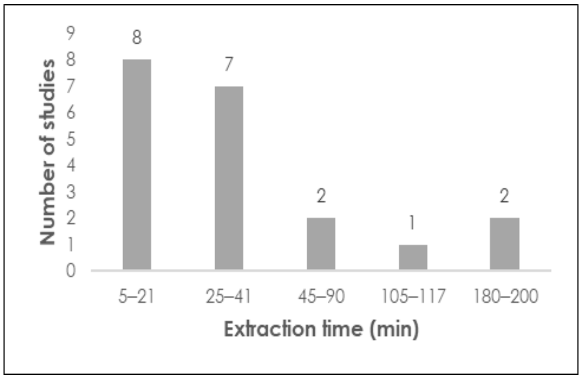


Figure 8 Optimal range of extraction time used in UAE on fruit and vegetable sources

The optimal extraction time for fruit and vegetable sources using UAE falls within the range of 5–21 min. Initially, prolonging the sonication time enhances the yield, but after a certain point, further increments lead to diminishing returns. This trend mirrors the effects observed with increased power and temperature. During the initial phase of extended sonication, ultrasound-induced cavitation intensifies swelling, hydration, fragmentation, and pore formation within the plant tissue matrix, facilitating solute extraction [10,25]. These processes collectively enhance the exposure of both the solute and the extraction medium, promoting their release into the solvent. However, prolonged exposure to ultrasound can result in structural damage to the solute, ultimately reducing the extraction yield [25].

4.0 EXPERIMENTAL DESIGN

The statistical design of experiments (DOEs) is a computer-assisted optimisation technique used to identify critical factors, uncover synergistic or antagonistic interactions, and determine the optimal process conditions for achieving desired outcomes. Response surface methodology (RSM) is applied to conduct experiments and explore the relationship between these parameters and the extraction process. Additionally, analysis of variance (ANOVA) is employed to assess if significant differences exist between the means of three or more groups.

This study specifically centres on determining the optimal extraction conditions for ginger extracts, considering the unique characteristics of various fruit and vegetable sources. To enhance the extraction of phenolic compounds and boost antioxidant activity in these sources, UAE conditions were optimised using RSM [65]. Phenolic compounds in the fruit and vegetable sources were quantified using a UV-vis spectrophotometer. The Design-Expert Software facilitated the execution of DOEs and subsequent statistical analysis. Both RSM and ANOVA were utilised to evaluate the significance of the model [66].

5.0 RESEARCH GAPS

UAE has proven to be an efficient method for extracting phenolic compounds from ginger, offering advantages in terms of time, energy, and reduced chemical solvent usage, while providing higher yields and ensuring safety. However, there are still areas that can be further refined. The variations in technology and extraction processes, including pretreatment and filtration, across different studies utilising UAE warrant exploration. Establishing standardised methods for filtering, extracting, and testing polyphenols could enhance the precision of results. Additionally, there is a need for continued efforts to elucidate and identify the mechanisms responsible for the phenolic group in ginger extracts for its pharmacological properties. This will lead to a clearer understanding of the targeted compounds for extraction. Similarly, other influential extraction parameters, such as amplitude, should also be investigated. Amplitude, which governs the intensity of sonification transmitted to the plant matrix, requires a study regarding its impact on polyphenol recovery. Its interaction with other variables, particularly its synergy with extraction temperature, should be analysed to gain a comprehensive understanding.

6.0 FUTURE PROSPECTS

Enhancing the efficiency of ginger extraction for its bioactive compounds involves optimising the extraction process and maximising yields. The effectiveness of these approaches is demonstrated in the optimised extraction of phenolic compounds from ginger, as well as fruit and vegetable sources, based on parameters extensively discussed in preceding findings. These parameters, including a 20 kHz ultrasonic frequency, 50% ethanol solvent, 20 to 39 °C temperature range, 1:15 to 1:40 w/v solid-to-solvent ratio, and 5 to 21-minute extraction time, are derived from the thorough examination of UAE techniques and their implications for phenolic compound extraction. Further research is needed to investigate the pharmacological properties and therapeutic applications of ginger extracts obtained through UAE, paving the way for their utilisation in pharmaceuticals, nutraceuticals, and functional foods.

Given the increasing prevalence of UAE across diverse sectors like food and pharmaceutical aspects, this method has captured the attention of researchers for conducting more comprehensive studies. The advantages of UAE, including improved yield, reduced costs and energy consumption, enhanced safety, scalability, shorter processing times, lower temperature requirements, and minimised chemical waste generation, all contribute to its appeal and address challenges commonly encountered with conventional extraction methods. This aligns with the sustainable energy paradigm, as it utilises renewable raw materials from fruit and vegetable sources, especially ginger, for phenolic compound extraction.

7.0 CONCLUSION

Overall, UAE presents a promising method for optimising the extraction of phenolic compounds from ginger and other natural sources such as fruits and vegetables. This study highlights the importance of precise UAE techniques in harnessing natural resources for health-enhancing compounds, potentially unlocking their full therapeutic benefits. The discussed parameters—ultrasonic frequency, solvent choice, solvent concentration, temperature, solid-to-solvent ratio, and extraction time—offer valuable insights into maximising yields and enhancing the health benefits of the extracted compounds. Future research is recommended to explore broader applications of UAE and to refine extraction processes for increased specificity and efficacy.

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Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper.

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