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FRUIT PEEL EXTRACTED POLYPHENOLS THROUGH ULTRASONIC ASSISTED EXTRACTION: A REVIEW

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ABSTRACT

Fruit are rich source of antioxidants and total phenolic compounds (TPC). They are helpful in improving human health. As the consumption of fruit is increasing day by day, its wastage is also increasing. Currently, there is an increasing interest worldwide in the extraction of valuable chemicals from underutilized agro-wastes to investigate their potential commercial applications in cosmetics, drugs, and food preservation. The peels of many fruits, which are a byproduct of underutilized fruit processing, are a great source of various bioactive substances, including tannins, flavonoids, phenolics, and particularly limonoids, which are uncommon in other plants. In this review, it is discussed how ultrasonic energy has great importance in extracting polyphenols. By applying ultrasonication with enzymolysis or solvent, the yeild of polyphenols extract increases. Polyphenols present in different fruit peels help in improving human health as a preventative treatment agent against several oxidative stress degenerative disorders. Ultrasonic assisted extraction (UAE) breaks the cell wall and intracelleluar material comes out. In this way, it increases the yield of different polyphenols in fruit peel.

Keywords: Total phenolic compounds, Fruit peels, Antioxidant, Ultrasound Assisted Extraction

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1. INTRODUCTION

Fruits are essential nutrients for physical health since they have a variety of flavours and are linked to a higher standard of living. In addition to having a great tan and flavor, horticultural crops are believed to reduce the risk of various chronic ailments. Fruits contain significant amounts of phytonutrients that have a negative correlation with mortality and morbidity from cardiovascular disease and cerebrovascular accidents (Vinatoru et al. 2017).

In accordance with Directive 2008/98/EC of the Commission of the European Union (EU), "waste" is defined as "any substance or object the holder discards, intends to discard, or is required to discard." As food moves from the point of harvest to the consumer, waste is defined as "edible material intended for human consumption that is degraded, lost, discarded, or consumed by pests" (Beddington 2011). Food waste is essential for sustainability of food systems on both an economic and environmental level. The stability of nutrients, the safety and quality of food, and environmental protection are all significantly impacted by food waste. Academics and business have been concentrating on ways to use and control food waste during the past few decades (Otles et al. 2015).

Food is lost or wasted worldwide on a yearly basis to the tune of 2.5 billion tonnes, according to a new analysis from Tesco and the WWF for Nature in 2021. The FAO UN estimates that between 17% and 14% of the food produced worldwide is either wasted or lost each year. From an earlier estimate of 1.3 billion tonnes, this implies an increase of about 1.2 billion tonnes. These new figures show that more food is wasted than previously believed (33%), with an estimated 40% of all food produced going uneaten. According to the FAO, if food waste were a country, it would produce more carbon dioxide than China and the US combined (Nirmal et al. 2023). A huge amount of fruit waste, including damaged or rotten fruit, seed, peel, core, rind, pulp, pomace, empty fruit bunch, and others, is produced during the processes of production, retailing, distribution, storage, and consumption due to the perishable nature of fruits, inedible portions of fruits, and various other factors. The typical fruit waste kinds and associated waste volumes have been given by Solangi and colleagues (Solangi et al. 2021). A sizeable portion is frequently squandered for a number of fruits. Mostly 30-50, 40-50, 20 and 30-50% amount of mango, pineapple, banana and orange is wasted, respectively (Leong and Chang 2022). Every year, between 25 and 57 million tonnes of waste are generated by common fruits such the banana, lemon, mango, orange, and watermelon. Fruit peel waste makes up 15–60% of the various forms of fruit trash that are produced and is typically thrown away (Rifna et al. 2023). Food waste contains several bioactive compounds (Herrero et al. 2015), pigments (Pereira et al. 2016; Loypimai et al. 2015), polyphenols (Paes et al. 2014), nutraceuticals (Galanakis 2013), bioactive compounds (Herrero et al. 2015), bioactive compounds, bioactive compounds, and dietary fibres (Pereira et al. 2016). However,

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food loss or wastage is expected to reach more than 2.5 billion tonnes annually worldwide, according to a new report by the WWF and Tesco, 2021. From the prior estimate of 1.3 billion tonnes, this indicates an increase of over 1.2 billion tonnes. According to these new figures, 40% of all food produced is thought to go uneaten, which is more uneaten food than was previously believed to be squandered (33%). According to the FAO, if food waste were a nation, it would be third in the world in terms of carbon dioxide emissions, behind the United States and China (Nirmal et al. 2023). Fruit wastes, particularly peels, include more phenolic chemicals, such as phenolic acids, flavonoids, anthocyanins, and carotenoids, relative to their content in fruit pulp (Safdar et al. 2017). This means that they have more antioxidant potential. Fruit wastes contains more polyphenols than fruit pulp, especially in the skin of the fruit. According to studies, fruit peels have greater antioxidant potential than fruit pulp. Fruit peels contain far more phenolic components than fruit pulp does, including carotenoids, phenolic acids, flavonoids, and anthocyanins (Jabbar et al. 2015).

It is known that many fruit peels have a phenol concentration that is almost twice as high as that of the seed and pulp. Despite the intra-varietal variations, it has been shown that mineral content, ascorbic acid content, and the antioxidant activity of papaya peel are higher than those of the seeds. Similarly, Sultana et al. (2012) found that the peels of most tropical fruits, including mango, dragon fruit, and mango seeds, have much greater levels of gallotannins and overall phenolic content than the pulp, stone, and kernel. Because jackfruit peels contain 17.74–18.63% pectin, they can be used to create biodegradable films and biosorbents (Lim et al. 2015). When Wolfe et al. (2003) evaluated the phytochemical content and antioxidant activity of stone fruits (apples), they found that the fruit peels had higher levels of phenolic and flavanoid compounds than the meat did. Using methanol and ethanol as solvents, Biradar et al. 2016 tried to extract bromelain, a-carotene, and lutein from citrus fruit peel waste. The results showed that discarded peels from pineapple and orange might be used as antimicrobial agents to protect against certain diseases, including *Pseudomonas aeruginosa*, *Klebsiella pneumoniae*, and *Bacillus subtilis*. The peels of avocado, banana, and custard apples, which principally contain gallocatechin, catechin, and epicatechin, also contain significant amounts of condensed flavonoids and tannins, including procyanidins. Gallocatechin, catechin, and epicatechin, however, are the main substances present in banana peels (Rudra et al. 2015).

1.1. Polyphenols

The four broad classes (Fig. 1) of phenolic substances are phenolic acids, tannins, stilbenes, and flavonoids. Phenolic acids can be divided into two subtypes, derivatives of hydroxycinnamic or hydroxybenzoic acid, depending on the skeltal structure made of carbons. The main structural components of phenolic acids are a phenolic ring and a carboxylic group. The most widespread phenolics are flavonoids. Their 15-C backbone, which is constituted by two aromatic rings connected by O-heretocycle pyrane, is their canonical structure. The compounds known as stilbenes are made up of two phenyl moieties connected by a 2-C methylene group and could isomerize between the Z (cis) and E (trans) forms. Piceatannol and resveratrol are two of them that are specifically listed in the document. The primary complex phenolic polymers found in plants are tannins, which can be found in both condensed and hydrolyzable forms. Secondary plant metabolites known as phenolic compounds have a significant role in determining the sensory and nutritive value of fruits, vegetables, and other plants (Lapornik et al. 2005). Numerous apple types include the five major classes of polyphenolic chemicals. These include procyanidins, catechin, dihydrochalcones, hydroxycinnamic acids, anthocyanins, flavan-3-ols, and dihydrochalcones (Wojdyło et al. 2008). These compounds have an aromatic ring with one or more hydroxyl groups, and their structures can range from those of a straightforward phenolic molecule to those of intricate high-molecular-mass polymers, according to Balasundram et al. (2006). These substances, which belong to one of the most prevalent classes of phytochemicals, have a significant physiological and morphological impact on plants. In addition to aiding in development and reproduction, these substances also offer defence against infections and predators (Bravo 1998). These also comprise phytochemicals and flavonoids. As they have a high redox potential, flavonoids are very important for their antioxidant capabilities (Ignat et al. 2011). Recent years have seen a marked increase in interest in food phenolics because of their capacity to function as antioxidant compounds (by the elimination free radicals and chelating metals) and because of their potential benefits for human wellness, including both the prevention and treatment of cardiovascular illness, cancer, and other pathologies (Bravo 1998).

1.2. Fruit Extraction

From a value-adding perspective, there is significant interest in the research of underutilised agro-wastes from fruit processing for the separation of volatile oils and high-value bioactive (Qadir 2018). Currently, there is an increasing interest worldwide in the extraction of valuable chemicals from underutilised agro-wastes in order to investigate their potential commercial applications in cosmetics, drugs, and food preservation. The peels of many fruits, which are a byproduct of underutilised fruit processing, are a great source of various bioactive substances, including tannins, flavonoids, phenolics, and particularly limonoids, which are uncommon in other plants.

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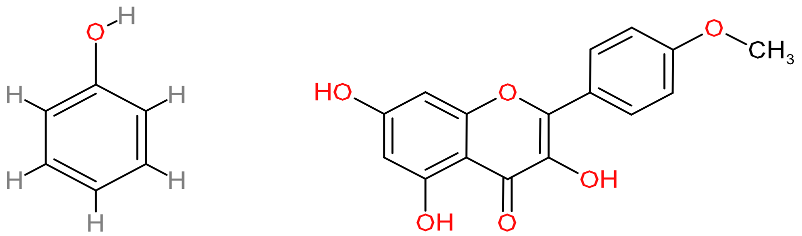
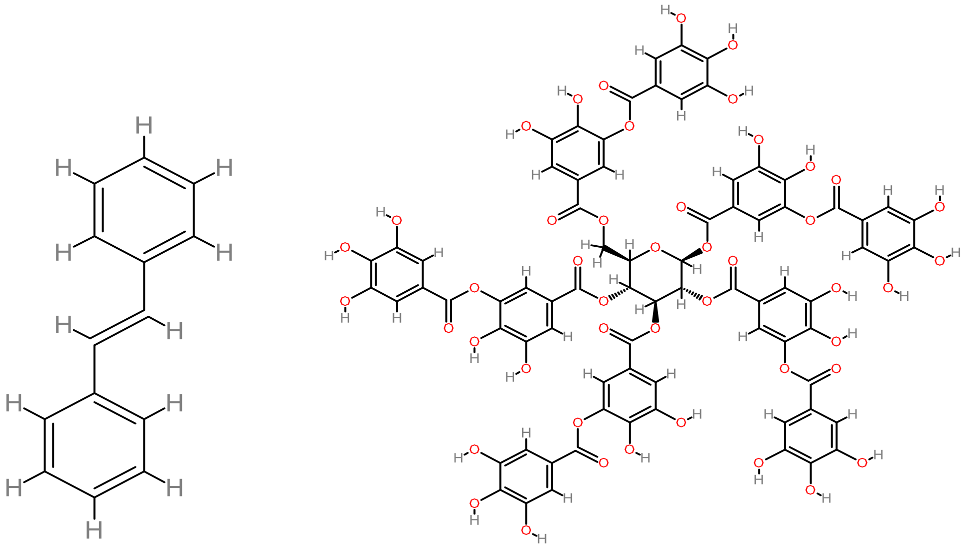


Phenols **Flavanols**



Stilbene **Tannin**

Fig. 1: Major Classes of Polyphenols

According to Bouarab Chibane et al. (2019), Cao et al. (2019) and Ali et al. (2022), these bioactive substances exhibit significant biological effects including antioxidant, anticancer, anti-inflammatory, and antibacterial properties. Different extraction techniques can be used to extract plant components. The primary limitations of classical extraction include longer extraction durations, demand for expensive, superior solvents, the evaporation of huge volumes of solvent, poor extraction effectiveness, and the thermal decomposition of thermo-labile compounds (Luque de Castro and Garca-Ayuso 1998). New and promising extraction strategies are proposed to address the disadvantages of traditional extraction procedures. These processes are known as non-traditional extraction methods. Due to decreased use of organic and synthetic chemicals, decreased operating durations, and increased yield and extract value, non-traditional methods have emerged over the past 50 years that are more ecologically friendly (Azmir et al. 2013). The production and specificity of bioactive components from material from plants should be increased by ultrasound (Ghafoor et al. 2009; Lee and Yoon 2023; Villamil-Galindo et al. 2023), pulsed electric field (Fincan et al. 2004; Toepfl et al. 2006), enzyme digestion (Gaur et al. 2007; Yan et al. 2018; Marathe et al. 2021), extrusion (Lusas and Watkins 1988), microwave heating (Kaufmann and Christen 2002; Barrios et al. 2022; Liang et al. 2023), ohmic heating (Torgbo et al. 2022; Sharifi et al. 2022; Goksu et al. 2022), supercritical fluids (Mira et al. 1999; Berna et al. 2000; Comim et al. 2010; Aniceto et al. 2021), and accelerated solvents (Smith 2002). These methods are believed to be non-conventional methods. These techniques are regarded as “green techniques”. These contain less dangerous chemical synthesis, safer chemical design, energy efficiency design, catalysis, safe solvent auxiliaries, fewer derivatives, renewable feedstock usage, prevent degradation design, atom economy, and time analysis for pollution prevention, as well as naturally safer chemistry for accident prevention (Azmir et al. 2013). Some of the phenolic compounds in mango peel with possible health advantages include antioxidative, anti-mutagenic, anti-atherosclerosis, and anti-carcinogenic actions include ellagic acid, rhamnetin, kaempferol, magniferin, and quercetin (Safdar et al. 2017).

1.3. Ultrasound Assisted Extraction (UAE)

UAE benefits include a decrease in energy use, extraction time, and use of solvents. Chemat et al. (2008) claimed that the use of ultrasound energy enables effective mixing, quick energy transfer, reduced heat gradients and fewer equipment, particular extraction, the temperature of extraction, quicker response to process extraction control, rapid start-up, greater yields, and the removal of process phases. Herrera and Luque De Castro, (2004) developed a semi-automatic ultrasonic extraction method for phenolic substances such quercetin, naringin, naringenin, rutin, ellagic acid, and kaempferol from strawberries using a 0.8 s duty cycle for thirty seconds streamlined manufacturing and cut down processes in the process. Zhong et al. (2022) extracted pitahaya peel polyphenols using ultrasound-assisted alkaline hydrolysis. In addition to being a successful approach for releasing phenolic compounds, ultrasound-assisted alkaline hydrolysis also provides the opportunity to further separate these active components, allowing for the creation of functional foods and novel medications. Rostagno et al. (2003) demonstrated the effectiveness of the mix-stirring extraction method for the extraction of four isoflavone metabolites from soybean, namely genistin, malonyl genistin, glycitin, and daidzin. Yang and Zhang (2008) used the best sonication conditions to extract the bioactive substances quercetin and rutin from Euonymus alatus (Thund.) Sieb and found that the ultrasonic approach had a higher extraction efficiency compared to traditional methods. from *Catharanthus roseus*, three alkaloids i-e catharanthine, vinblastine, and vindoline have been extracted using an ionic liquid-based UAE that has been deemed to be particularly successful (Yang et al. 2011). Grape peel was used as the source for the extraction of anthocyanins and phenolic compounds, and the extraction method was optimised for time, solvent, and temperature considerations (Ghafoor and Choi 2009). Using an Ionic liquid-based UAE methodology, rosmarinic acids, carnosic acids, and phenolcarboxylic acids were extracted from *Rosmarinus officinalis*. This method was shown to be more effective and efficient than traditional extraction procedures (Zu et al. 2012). Typically, phenolic chemicals are extracted using organic solvents such acetone, ethanol, ethyl acetate, and methanol. The phenolic acids are sequentially and methodically released from their various forms throughout the extraction process. Since soluble phenolic acids (soluble esters, soluble glycosides, and free acids) are easily extracted with organic solvents in aquaous form, the initial step of the procedure typically uses an aqueous organic solvent to extract these compounds. The sample is combined with an organic solvent in a beaker or flask and placed in an ultrasonic bath with a predetermined duration and temperature for the extraction of polyphenols using ultrasound technology. During the procedure, sound waves are created, breaking down the sample's cell walls and allowing phenolic chemicals to be extracted. According to Aadil et al. (2015), traditional extraction procedures often take 12 or more hours to complete, whereas ultrasound-assisted extraction times are typically shorter than 1 hour, yielding a higher amount of material.

Since all that is needed to initiate ultrasonic-assisted leaching is to put the crushed sample in contact via the solvent in an ultrasonic bath that typically runs at 40 kHz instead of a more energy-concentrating probe at 20 kHz, UAE is regarded as a straightforward and economically low-cost extraction method (Rodríguez De Luna et al. 2020). According to Ameer et al. (2017), the disruption and removal of inert material layers that occur during sonication increases surface area available for the mass transfer of solutes during extraction. To induce cavitation bubbles, which have mechanical and thermal impacts on plant cells, ultrasound-assisted extraction needs additional ultrasound energy. Bioactive substances are released into the solvent media via diffusion and/or dissolution when a cell wall is broken. As a result, bioactive substances are extracted from plant cells when a mass transfer gradient is present. One or more mechanisms may be used during the ultrasound-assisted extraction process (Yusoff et al. 2022). Ultrasonic efficiency may be increased by the joint mechanism of UAE by (i) causing cell disruption and (ii) encouraging mass transfer. To facilitate water evacuation, ultrasonic energy may form tiny channels and cavities (Zahari et al. 2020). According to Chen et al. (2020), the development of cavities and microchannels may enhance the contact area between solvent and bioactive chemicals, hence speeding the mass transfer phenomena. The sample-containing solvent was submerged completely with the ultrasonic probe. To aid in the extraction process, the ultrasonic device may provide cavitation with a bubble implosion effect (Zahari et al. 2020). When powerful ultrasonic waves interact with a matrix, bubbles develop in liquid medium. Once the bubbles have reached their full capacity for energy absorption, prolonged exposure to ultrasonic waves causes the bubbles to expand and eventually collapse; in sonochemistry, this collapse is known as cavitation. By disrupting solid particles and removing inert material layers during sonication, which may result in passivation, ultrasonic waves enhance the surface area available for the mass transfer of solutes during extraction. For the extraction of thermosensitive phenolic chemicals from a variety of plant matrices, the UAE is a favoured option.

Mango peel extraction using ultrasonic aided extraction and mechanical extraction were compared in a study Safdar et al. (2017). It was investigated to determine the antioxidant capacity and quantify phenolic components using high performance chromatography, as well as to extract the polyphenols from mango peels using maceration and UAE procedures. Rich sources of phenolic chemicals with potent antioxidant activity may be found in mango peels. High levels of polyphenol may be extracted with ultrasound assistance, making it a more effective method than maceration. In compared to aqueous solvents, absolute solvents did not guarantee a more equitable extraction of polyphenols, and they also had poorer antioxidant activity. Both methanol and ethanol are effective solvents for extracting polyphenols, however because it is used in the food chain, GRAS-designated ethanol is preferable. Total polyphenol concentrations and antioxidant activity were shown to be strongly correlated.

HPLC has been used to identify and quantify eleven phenolic components, including four phenolic acids and seven flavonoids. The phenolic acid that was most prevalent in mango peel extracts was coumaric acid. The other

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phenolic components found in high quantity in mango peel extracts were ferulic acid, gallic acid, and epicatechin, whereas myrecetin was the least detected flavonoid. The study concluded that since mango peels are a possible source of phenolic chemicals, they might be used as a component in the creation of functional meals.

In another study, polyphenols from pomegranate peels were recovered utilising an ultrasound-assisted enzymatic extraction procedure employing a viscozyme and ultrasonic bath. Pomegranate peel is a significant agricultural waste but is high in polyphenols, particularly hydrolyzable ellagitannin, which makes it a great natural source of antioxidants (Kushwaha et al. 2015). Utilising a central composite rotatable design and response surface technology, the process was optimised. A potential technique for extracting polyphenols from wastes is the ultrasound aided enzymatic approach for extraction of polyphenols from pomegranate peels. It may be used to extract significant biomolecules from agricultural and food wastes without requiring chemical solvents. Due to the increased extraction rate and significantly lower energy consumption of ultrasonic equipment when compared to conventional microwave treatmentor heat treatment, this approach of extracting polyphenols using ultrasound and enzymes may be more economically advantageous. It can be concluded that pomegranate peel, a waste product, is a possible source for extracting polyphenols, and that ultrasonic aided enzymatic extraction procedure may be used as a new technique for extracting diverse biomolecules from a range of biological sources (Nag and Sit 2018).

It was investigated if sonication and maceration, two common extraction methods, could extract polyphenols from apple and pomegranate peels. Pomegranate and apple peel powder were processed using the sonication method to extract polyphenols. In the investigation, methanol, ethanol, and acetone were employed at two distinct doses (50% and 75%). The highest TPC was found to be at acetone 75% for apple peel under sonication and at methanol 50% for pomegranate peel. The results also showed that pomegranate peel had stronger polyphenols and more radical scavenging action than apple peel. It was determined that date bars enriched with apple and pomegranate peel polyphenolic extracts might be used as a preventative treatment agent against several oxidative stress degenerative disorders (Ranjha et al. 2020).

An ultrasonicator with a functional frequency of twenty kHz was used in a study by Nishad et al. (2019) to perform UAE, which involves exposing a solvent and citrus peel powder combination to acoustic waves. While varying various processing variables, the extraction was carried out at room temperature. The influence of various solvent types on the TPC yield was shown by experimental findings for UAE, with 50% ethanol producing the most phenolics. This may be because ethanol is an excellent solvent in that study because to its comparable polarity range to phenolics and superior ability to absorb sonication energy by ethanolic extract during UAE, which promotes increased recovery of bioactive. The extract from the United Arab Emirates with the highest content of catechin and caffeic acid showed improved release of free and bound phenolics through UAE.

Using microwave-assisted extraction (MAE) and UAE, Rodsamran and Sothornvit (2019) examined the extraction of natural phenolic chemicals from lime peel wastes. The UAE was performed using 30 ml of different lime peel powder i-e 1.5/0.001g) and ethanol concentrations (X1) ranging from 50 to 100%. To work with small volumes at different time frames for extraction (X3, that range between 2 and 4min) and ultrasound amplitudes (X2, that range between 20 and 40% of the unknown full power), an additional 3mm diameter stepped micro tip was fitted to the regular tip of the ultrasound instrument. Lime peels' natural phenolic extract may be utilised to produce functional and active components for both culinary products and medicines. The TPC enhanced with an extended extraction duration because of improved phenolic component extraction. UAE waves encourage solvent absorption into the sample matrix, which speeds up the mass rate of transfer of the antioxidant compounds into the extraction solvent.

Another study sought to enhance the ultrasonic extraction procedures for phenolic metabolities from orange and pomegranate peels, which are considered agricultural wastes, in order to employ the improved extracts to enhance beverages. For the purpose of maximising the extraction of OPE and PPE, the impact of three variables i-e extraction time (X1) ranged between 10–40 min, temperature (X2) that range between 40–70°C, and solid-to-solvent ratio (X3) that vary between 1:20–1:40 g/mL, on two outcomes i-e antioxidant activity and TPC was examined. In the X1: 40 min, X2: 70°C, and X3: 1:40g/mL conditions, OPE and PPE showed the greatest antioxidant activity (54.27 and 72.11%) and TPC (1.86 and 2.70mg GAE/g). According to the findings, OPE and PPE have exceptional concentrations of bioactive chemicals with antioxidant activity and may be employed to improve functional qualities and the health benefits of food items, particularly beverages (Selahvarzi et al. 2022).

Sharayei et al. (2019) conducted a study in which the pomegranate (*Punica granatum* L.) peel (POP) was subjected to UAE technology in order to recover useful components. The effects of independent process variables ultrasonic exposure time (UET) ranged between 5, 10, and 15min and ultrasonic amplitude (UA) vary between 20, 60, and 100% on the antioxidant properties and yeild of TPC of peel extract were examined using the response surface method. According to both combinations and individual of all process factors, UET 6.2min and UA 60% were the ideal conditions. According to that study, the peel of pomegranates may contain active substances such polyphenols, which are well-known for their antioxidant capabilities. The efficient method for extracting these

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chemicals is ultrasound extraction. To create high-quality, high-performance POP extract, it may be important to optimize the UET and UA.

According to a study by Khan et al. (2010), orange (*Citrus sinensis* L.) peel polyphenols, notably flavanones, may be extracted from the peel. Ethanol is used as food grade solvent. A central composite design (CCD) and response surface methodology approach were used to investigate the influence of process variables on the UAE. The research showed that particles with a diameter of $2cm^2$ produced the highest yield of extraction. According to statistical study, 40°C, 150W of sonication power, and ethanol:water ratio of 4:1 (v/v) were ideal circumstances. When compared to the traditional approach, the optimised UAE's high total phenolic content demonstrated its effectiveness. In comparison to the usual method, the UAE of phenolic antioxidants from orange peels using ethanol-water combinations seemed to be highly successful. According to the CCD data, temperature, and the ethanol: water ratio are second and third in importance to sonication power in the UAE process. UAE is an example of "green" or "environmentally friendly" design. Overall, the production of extracts high in natural antioxidants intended to replace synthetic antioxidants could be made more effective and environmentally friendly by using food-grade solvents and ultrasound to assist in the polyphenol's extraction from plentiful food by-products i-e orange peels.

By using ultrasound-assisted extraction, functional compounds from Campbell Early grape peel were isolated. A five level, three variable central composite rotatable design was used to conduct trials. Using response surface approach, optimal extraction variable combinations were discovered for the greatest phenolic components and antioxidant activity of grape peel extracts. For the greatest total phenolic chemicals, the ideal circumstances are 46.03°C temperature, 53.14% ethanol and 24.03min. According to that study, the peel of the Campbell Early grape is an excellent supplier of phenolic compounds, and ultrasonication was a successful method for extracting total phenols (Fig. 2) and antioxidants because it significantly shortened the extraction time when compared to other extraction techniques (Ghafoor 2009).

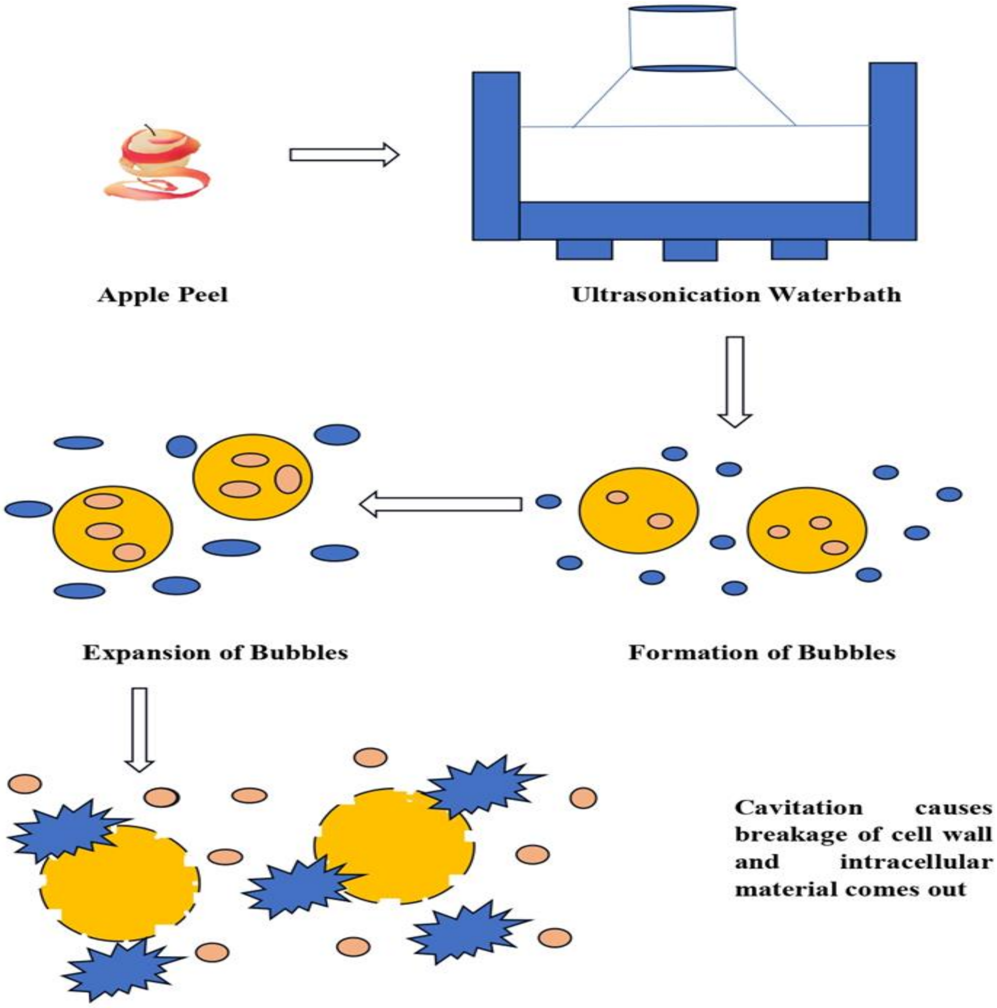

Fig. 2: Ultrasonication assisted extraction mechanism.

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Utilizing response surface approach and Box-Behnken design, the collection of phenolic compounds and evaluation of the antioxidant activity in watermelon seed (WMS) and peel (WMP) were improved by ultrasound-assisted extraction. Antiradical activity and TPC of WMs and WMP were significantly affected by UAE process factors (ethanol concentration, sonication duration, and temperature). The most TPC was produced at the ideal WMP extraction circumstances (ethanol concentration: 42.84%, sonication time: 31.63min, and sonication temperature: 47.82°C). The extraction rate of antiradical activity and TPC in extracts of watermelon by-products were shown to be strongly influenced by the ethanol content and sonication period, according to the results. The hypothesis states that the modification in UAE process parameters helped identify the best UAE factor combination that may provide the highest phenolic extraction from watermelon waste (Fadimu et al. 2020).

Another study on Kinnow mandarin peel was conducted to standardise the process parameters of the probe sonicator for the isolation of bioactives using response surface approach. Total phenolic content was determined for the obtained crude extract. Maximum TPC were seen after 15min of treatment at a temperature of 41°C, a liquid to solid ratio of 30:1, and an amplitude of 31%. In order to confirm the numerous functional groups found in the extract, the extract prepared under optimal circumstances was further subjected to Fourier Transform Infrared Spectroscopy (FTIR) analysis. The scale-up process, use of the kinnow peels' potential as nutraceuticals, and the creation of functional meals can all benefit from the findings of this study. Therefore, biorefining of kinnow mandarin peels can help the citrus sector control waste. According to the results of the study, ultrasound aided extraction is a quick and efficient method for obtaining bioactive phytochemicals from kinnow mandarin byproducts (Kaur et al. 2021).

The peel of the hass avocado (*Persea americana* Mill.) is a fantastic source of antioxidants. A study Hefzalrahman et al. (2022) looks at the effectiveness of ultrasonic and enzyme-assisted techniques for extracting avocado peel polyphenols with antioxidant characteristics. The peel of the hass avocado is a rich source of polyphenols. To improve the polyphenol yield extraction from avocado peel, viscozyme L. (E) and an ultrasound-assisted procedure were used. Benzoic acid, vanillic acid, resveratrol, and syringic acid were the main polyphenolic chemicals found in the extracts under investigation. Phenolic extraction yields comparable to enzyme-aided extraction were achieved with the use of ultrasonic technology. The phenolic compounds may oxidise during a lengthy extraction period as a result of exposure to oxygen and light. Regarding the antioxidant activity of the extractable phenolic compounds, ultrasound assisted extraction turned out to be more effective than enzyme assisted extraction.

Another study employed artificial neural networks (ANN) and RSM to model and optimize UAE conditions used to extract phenolic from avocado residues. With the use of ANN and RSM, the recovery of phenolic compounds from avocado seed and peel was modelled with the goal of maximising extraction temperature, solvent concentration, and extraction time. The findings of the study enable industry to develop extraction methods that are effective, affordable, and environmentally friendly for collecting bioactive metabolites from leftover avocados.It is suggested that the UAE technique be used and that additional factors such as size of particle, kinds of solvent, ultrasonic frequency and power, and solid/liquid ratio be investigated in order to maximise the benefits of these bioactive components found in avocados (Monzón et al. 2021).

The study was conducted to see how best to use ultrasounds to extract antioxidants from avocado peel (AP). Response surface methodology was used to assess how ethanol/water ratio and time affected the results. By using HPLC-ESI-MS and FTIR, the optimised extracts were chemically characterised. According to Rodríguez-Martínez et al. (2022) phenolic acids including hydroxybenzoic and hydroxycinnamic acids made up the majority of the phenolic components in the avocado peel extract.

Researchers used an ultrasonic bath and sonotrode to optimise the extraction of phenolic chemicals in a different investigation. The ideal conditions for obtaining high total phenolic compound extraction were determined using a Box-Behnken design to optimise the extraction variables. HPLC-ESI-TOF-MS was used to characterise the extracts produced under ideal circumstances. There were found to be 35 different phenolic compounds. Galloylglucose and methylgallate, which together made up more than 50% of the phenolic compounds in mango peel byproducts, made up most of the samples' phenolic acid derivatives. More than half of the phenolic compounds from byproducts of mango peel extractions were gallic acid-derived phenolic acid derivatives, which dominated both extractions. The major phenolic component in both extracts was galloylglucose, and both methods yielded quantities of the same order of magnitude. The sonotrode sample had a higher overall concentration of phenolic compounds (+33%) and required less time to get there. In addition, pilot and commercial scale scaling of sonotrode ultrasonic technology is possible. The production of enhanced phenolic compound extracts from mango peel byproducts using sonotrode is a promising green technology that may be used in food, cosmeceutical, and nutraceutical goods (Aznar-Ramos et al. 2022).

Junjian et al. (2013) conducted a study in which apple peel polyphenols were extracted using cellulase enzyme extraction with ultrasonic-assisted technology such as UAE, and polyphenol extraction parameters were optimised using response surface approach. By assessing the overall polyphenol content and the levels of three specific

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polyphenols, the efficacy of extraction was increased. Temperatur, enzyme concentration and extraction time were considered as three separate variables that were independent. The results of the statistical analysis showed that the yields were significantly influenced by the extraction time and its quadratic. Phlorizin, hyperoside, and chlorogenic acid were found in the greatest concentrations among the seven polyphenols that could be identified in apple peel when extracted with ethanol. Samples were detected using HPLC in conjunction with DAD. Only trace quantities of protocatechuic, catechin, caffeic acid, and epicatechin were found.

Another research was done to investigate the effects of frequency vary between 37 and 80kHz, ultrasonic operation mode like sweep, normal and pulse, and temperature ranged between 40–70°C. The interactions of these variables on the recovery of phenolic compounds and antioxidants present in pomegranate peel using ultrasound-assisted extraction also studied in that resaerch. Total phenolic compounds, total extract yield (X_0) and antioxidant capacity (AC) were analyzed. The conditions i.e., temperatures ranged 50–60°C with 37 kHz frequency and modes (normal and pulse) provided better yields of X_0 and TPC. In addition to the identified phenolic substances like ellagic acid, a-punicalagin and b-punicalagin, other polyphenols, presumably including high molecular weight polyphenols, should be present in large quantities in the ultrasonic extracts such as ellagitannins, proanthocyanidins, and flavonoids (Machado et al. 2019).

Table 1: TPC concentration extracted through UAE in different fruit peel

Fruit Peel	Condition	TPC Concentration (mg GAE/g)	References
Pomegranate	UA 60%, UT 6.2min, UF 20 kHz	42.2	Sharayei et al. (2019)
	UTP 60°C, UF 37kHz	43.20	Machado et al. (2019)
	UT 40min, UTP 70˚C, SS ration 1:40g/mL	2.70	Selahvarzi et al. (2022)
	UTP 45˚C, UT 60min, SS ratio 1:20, 50% methanol	72.21	Ranjha et al. (2020)
	UT 45min, UTP 44.85˚C, Enzyme concentration 1.32 ml/100ml	19.77	Nag and Sit (2018)
Avocado	UTP 50.9˚C, UA 49.5%, UT 61.8min, UF 42 kHz	124.050-125.187	Monzón et al. (2021)
	38.46% ethanol concentration, UT 44.06min	45.34	Rodríguez-Martínez et al. (2022)
	UI 20% and 10% for 30 and 45min, respectively, SS ratio 1:20	35.4	Hefzalrahman et al. (2022)
Orange	UTP 40˚C, UP 150W, SS ratio 4:1	275.8	Khan et al. (2010)
	UT 40min, UTP 70ºC, SS ration 1:40 g/ml	9.86	Selahvarzi et al. (2022)
Kinnow Mandarin	UF 20kHz, UA 31%, UTP 41˚C, UT 15min, SS ratio 30:1	36.17	Kaur et al. 2021
Lime	55% Ethanol concetration, UA 38%, UT 4 min	54.4	Rodsamran and Sothornvit (2019)
Citrus	UF 20 kHz, UA 70.89%, UT 35min, 50% Ethanol concentration	1590	Nishad et al. (2019)
Apple	UT 37min, UTP 37˚C, Enzyme concentration $2500Ug^{-1}$	766.96	Junjian et al. (2013)
	UTP 45˚C, UT 60min, SS ratio 1:20, 75% Acetone	44.71	Ranjha et al. (2020)
Mango	UTP 45˚C, UT 60min, UF 35kHz, 80% Ethanol	67.58	Safdar et al. (2017)
	UT 18min, UA 65%, 55% Ethanol concentration, Sonotrode method	3.9-9.4	Aznar-Ramos et al. (2022)
	UT 60min, SS ratio 1:450, 45% Ethanol concentration, US bath type	1.6-8.7	Aznar-Ramos et al. (2022)
Watermelon	UTP 47.82˚C, UT 31.63min, 42.84% Ethanol concentration	7.944	Fadimu et al. (2020)
Grape	UTP 46.03˚C, UT 24.03min, 54.14% ethanol concentration	6.70	Ghafoor and Choi (2009)

UTP=Ultrasonic Temperature, UT=Ultrasonic time, UF=Ultrasonic frequency, UA=Ultrasonic Amplitude, SS ratio=Solute Solvent ratio, UI=Ultrasonic Intensity

2. CONCLUSION

In conclusion, the escalating consumption of fruits, owing to their rich antioxidant and total phenolic compound content, underscores their pivotal role in enhancing human health. However, the concurrent increase in fruit wastage poses a challenge. There is a growing global interest in extracting valuable compounds from underutilized agro-wastes, with a focus on potential applications in cosmetics, drugs, and food preservation. Fruit peels, often discarded as byproducts in the fruit processing industry, emerge as a valuable reservoir of bioactive substances such as tannins, flavonoids, phenolics, and notably, limonoids—compounds uncommon in other plants. This review sheds light on the vital role of ultrasonic energy in the extraction of polyphenols from fruit peels. The

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strategic application of ultrasonication, in conjunction with enzymolysis or solvents, proves to be a key factor in augmenting the yield of polyphenol extracts. The polyphenols derived from various fruit peels exhibit significant potential in mitigating oxidative stress-induced degenerative disorders, thereby contributing to overall human health. The process of ultrasonic-assisted extraction (UAE) emerges as a transformative technique, effectively breaking down cell walls and facilitating the release of intracellular materials, ultimately leading to an increased yield of diverse polyphenols from fruit peels. This approach not only addresses the issue of fruit wastage but also unlocks the untapped potential of fruit peels as a sustainable source of valuable bioactive compounds with broad applications in various industries.

List of abbreviations

AC	Antioxidant capacity
ANN	Artificial neural network
AP	Avocado peel
CCD	Central composite design
FTIR	Fourier Transform Infrared Spectroscopy
HPLC	High performance liquid chromatography
RSM	Response surface methodology
SS ratio	Solute Solvent ratio
TPC	Total phenolic compounds
UA	Ultrasonic Amplitude
UAE	Ultrasound assisted extraction
UF	Ultrasonic frequency
UI	Ultrasonic Intensity
UT	Ultrasonic time
UTP	Ultrasonic Temperature
WMP	Watermelon peel
WMS	Watermelon seed

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