ORIGINAL ARTICLE

Green extraction techniques for obtaining bioactive compounds from mandarin and pomegranate peel: Phytochemical analysis and process optimization

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Abstract

This study used advanced green extraction techniques to examine the effective utilization and valorization of mandarin and pomegranate peels. Several extraction techniques have been collected in the literature for the extraction of bioactive components from mandarin and pomegranate peel in the first step of this investigation. Due to high applied temperatures and pressures or lengthy extraction times (the conventional solvent extraction), extraction procedures can degrade phenolic compounds. The polarity of phenolic compounds, however, sets limits on different recovery methods, including supercritical CO_2 separation. To speed up the extraction process, enhance extraction yield, and prevent phenolic compounds from degrading, new methods of extracting bioactive compounds have been developed. The various extraction techniques used to extract the phenolic components from mandarin and pomegranate peels are critically compared in this article. The review combines essential information that may be helpful in selecting the best extraction technique for bioactive chemicals from natural sources.

Key words: Bioactive chemicals, green extraction, natural sources, phenolic compounds, pomegranate peel

INTRODUCTION

A medicinal plant is one that resembles the qualities of common pharmaceuticals.[1] Citrus is one of the fruits that is grown and eaten the most everywhere. In 2016, Spain ranked fifth globally in terms of citrus fruit production, trailing only China, Brazil, India, and the United States. The second most extensively cultivated citrus crop is citrus reticulata mandarins, which make up about 22% of the orange produced worldwide[2] and are important Spanish citrus fruits, producing more than 2.408.753 tons of them annually in 2018–2019. Valencia province harvested 39.6% of Spain's total mandarin citrus yield during this season.[3] Citrus fruits vary in size and color but share a similar structural make-up. Most citrus fruits are utilized to make juice, and between 45 and 60% of their weight is lost to trash.[4] The main waste component is citrus peel (flavedo and albedo), which is also a rich source of natural antioxidants (including pectin, polyphenols, carotenoids, and other substances).[5] Citrus peels' usual orange-yellow color results from green chlorophyll degrading and forming the distinctive yellowish-red pigment. Due to the ripening process, flavedos undergo a color change (conversion of, -carotenoid to, -carotenoid).[6] Among the cultivated citrus, the mandarin is the second-most significant group of citrus plants in the world in terms of climatic tolerance. It occupies 80% of the land used for citrus farming.[7] Peels from citrus fruits are rich in Vitamin C, fiber, pectin, oily compounds, and flavonoids. Which can be used to create especially in the agricultural, biological sciences, and pharmaceutical

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sectors, goods with added value.[8] Fruit peel is the main type of waste material gathered in the mandarin juice industry.[9] The existence of bioactive substances in citrus leftovers, including mandarins, has been studied for more than 20 years. However, because they might be employed as a less expensive source to obtain this kind of chemicals, their use and exploitation have grown recently. Over get natural food colorants, for instance, as these are preferred to synthetic ones.[10] Extraction of bioactive chemicals, primarily polyphenols, carotenoids, and other antioxidant elements for the pharmacy and beauty care industries, is the principal use of citrus leftovers. Citrus residue extracts or their bioactive components are also extensively studied for usage in food products due to their nutraceutical effects and health advantages.[11] The antioxidant, anti-inflammatory, anticancer, antibacterial, cardioprotective, neuroprotective, nephroprotective, and antiallergic properties of the Vitamin C compound, fruit antioxidants, carotenoids, flavonoids, and other substances have been investigated, supporting this class of residues as functional material.[12] Pomegranate (*Punica granatum* L.), a Mediterranean native, has been widely employed in traditional medicine in the Indian subcontinent and many other nations.[13] The peel of a pomegranate fruit makes up approximately 50% of its weight. which is frequently thrown away as waste.[14] Although juice has been found to have better biological activity, it has been revealed that fruit peel contains the highest concentrations of bioactive chemicals.[15] The pomegranate peel is a possible source of antioxidants, contains a wide range of phytochemicals, and has antibacterial and antifungal properties.[14] Processing-generated food and agricultural waste has proven to be a suitable substrate for bioactive component extraction.[16] Pomegranate peels have the potential to serve as a feedstock for the effective recovery of phytochemicals and bioactive. According to studies, pomegranate juice does not have the same level of antioxidant power as pomegranate peel extract.[17] Pomegranate peel extracts have a variety of biological effects, including antibacterial, anticancer, anti-diarrheal, anti-inflammatory, and anti-diabetic properties.[1] The pomegranate peel contains phytochemicals such as punicalins, punicalagins, punicalins, ellagic acid, and gallic acid. *P. granatum* is a potent bioactive chemical source that contains a wide range of second-level metabolites.[18] Pomegranate peel, a part of the fruit that cannot be eaten, has been discovered to have greater medicinal benefits.[19]

Benefits of Mandarin Peel

Mandarin oranges provide many health benefits for the skin, including bright complexion, enhanced skin tone, less wrinkles, and faster wound healing.

It has a lot of Vitamin C, which is necessary for preserving the health of gums, skin, and blood vessels.

It helps to produce collagen, absorb inorganic iron, lower plasma cholesterol levels, stop the generation of nitrosamines, interact with singlet oxygen and other free radicals (antioxidant), and produce collagen.

Benefits of Pomegranate Peel

Because fruit peels contain phytochemicals that are employed in the beauty products, pharmaceutical, and food sectors.

Since they have demonstrated a range of health benefits, including acting as anti-inflammatory, antidiabetic, anti-allergic, and anti-platelet agents, flavonoids are contained in pomegranate peel. However, only a few of these flavonoids have drawn attention.

The Tables1 and 2 provides various extraction methods carried out and bioactive compounds isolated from Mandarin and pomegranate peels.

EXTRACTION

Extraction is a separation process consisting of the separation of a substance from a matrix.

Green extraction techniques take a lesser amount of time, effort, and solvents that are needed. In addition, the production of chemical-free compounds, which are considered safe and preferred by customers, is made possible using green solvents.

Collection and Extraction of Mandarin Peel

Mandarins were purchased at the local store and were peeled off.

Then, these peels were dried in three separate locations – in the sun for 3 days, in a microwave for 20 min at 100 PW, and in an electric oven for 48 h (about 2 days) at 50°C – until they took on a crispy form suitable for grinding.

Extraction of Peel

For 24 h at room temperature, two g of peel were extracted with 25 mL of acetone in a stoppered flask with intermittent shaking. Filtered extract was then evaporated in a China dish that had been pre-weighed. As needed, the dried material was dissolved in alcohol/dimethyl sulfoxide.[20] The same process was used for the methanol, ethanol, and aqueous extractions, which were each stored at 4°C in the refrigerator in ambered colored bottles. The preliminary phytochemical screening of these solutions will be used in subsequent research to quantify the numerous phyto-constituents contained in them.

ADVANCED EXTRACTION TECHNIQUES FOR MANDARIN PEEL

Ultrasound-assisted Extraction (UAE)

An ultrasonic microprocessor was employed for UAE, with its operating speed adjusted at 20 megahertz. The study specified 400 W, 80% (v/v) duty cycle, and a top temperature of 40°C for the extraction conditions. The container used for the reaction was a small piece of glass that contained 6 g of mandarin peel and sixty milliliters of water containing 50 percent (v/v) ethanol. The samples were extracted for 5, 15, and 30 min, respectively. Using a Whatman membrane filter, each extract was filtered after treatments before being gathered and covered from light in a flask with a volumetric measurement. Once they were required for evaluation, all the samples were kept at 20° Celsius.[21]

Method of Control Extraction

Mandarin peel was processed using parameters similar to those in the UAE for the control extraction technique, but without using ultrasonic power, to compare with UAE samples. Instead, a 40°C-operating device that mixed was electromagnetic. The extracts were collected in a volumetric container that was shaded from sunlight, filtered with a Whatman no. 1 membrane filter, and then kept at a temperature of 20 until needed.

Supercritical CO_2 (SC-CO_2) Extraction

As previously explained in detail, In the SFE system, SC-CO_2 extractions were performed to produce extracts full of aromatic and volatile chemical compounds.[22,23] Each experiment's 100.0 g of freezing peel was kept in an extractor jar with an aluminum bar with an outside diameter of 100 millimeters and a height of 500 millimeters (about 1.64 ft). This material was pulverized in a laboratory mill before being added. The extraction studies were carried out using at two different pressures (100 and 300 bar), a CO_2 bulk with a velocity of 2.0 kg/h, and a set room temperature of 40°C, a flowmeter was applied. The extractions took 90 min (about 1½ h) to complete.

Subcritical Water Extraction (SWE) Technique

After the aromatic and four of the 16 non-polar components were removed, the drained substance that remained after the SC-CO_2 process at a 300-bar working pressure was used as raw material for the SWE technique to obtain the phenolic compounds. In a modified SWE system that had previously been reported. SWE extraction tests were conducted. The extraction vessel, which was made of aluminum bar, was positioned underneath 1.0 g of pretreated plant material from orange peel. Because nitrogen was introduced to the extraction vessel through a combination of heat exposure and airborne oxygen, oxidation processes were inhibited. In the tests, duration (5–15 min), heat (130–220°C), and solvent–solid ratio (10–30 mL/g) were altered to see if they would have an impact on the SWE process.[24]

The filtered final product contained both a solid residue and a phase that is soluble in water (extract).

The aqueous extracts that resulted were then subjected to a phenolic component HPLC analysis.

Pressurized Fluid Extraction (PFE)

For the extraction of flavonoids, PFE has been frequently used.

For the PFE tests, we used a 10 mL metal extract cell. Each extraction employed 2 g of peels from oranges from Lot 1 or Lot 2 and was completed at 1000 rpm, the correct temperature, and fluid for using a flow velocity of 2.37% g/min for 40 min, producing a S/F ratio of 47 kilo fluid/kg material under extreme conditions. After the extraction process, the mixture of the solvents and the resulting solution was decompressed through a micrometer valve before it was gathered in opaque flasks with airtight sealing. To prepare the substances extracted for future study, they were sized, stored at −18°C, and insulated from light.[25]

Extraction with Organic Solvent

10 mL of ethanol was combined with about 1 g of dried and crushed peels (1 mm), mixed for 1 minute, and then left to sit for 24 h. After that, the collected specimens had been centrifuged for ten minutes at 6000 g. In a glass tube, the supernatant was collected. Four times, the extraction process was carried out. Using a Rotavapor Laborota 4000-Efficient device, the solvent was extracted under vacuum.

COLLECTION AND EXTRACTION OF POMEGRANATE

Sample collection and preparation: Pomegranate fruit was obtained at a nearby market in the Eros region. Remove the peel and use it as a sample from the fruits you have collected. After being rinsed under running water to remove any remaining solids from the surface, the peel was dried in the shade for 5 days before being ground into powder and placed in an airtight container.

Table 1: Extraction methods and its active constituents for mandarin peel

Method	Procedure	Active constituent
Ultrasound-assisted extraction	A small piece of glass that contained 6 g of mandarin peel and sixty milliliters of water containing 50% (v/v) ethanol. The samples were extracted for 5, 15, and 30 minutes, respectively. Using a Whatman membrane filter, each extract was filtered after treatments before being gathered and covered from light in a flask with a volumetric measurement. Once they were required for evaluation, all the samples were kept at 20° Celsius.	Total flavonoids like hesperidin, naringin, rutin, and neohespiridin.
Control Extraction Method	peel was processed using parameters like those in the UAE for the control extraction technique, but without using ultrasonic power, to compare with UAE samples. Instead, a 40°C-operating device that mixed was electromagnetic. The extracts were collected in a volumetric container that was shaded from sunlight, filtered with a Whatman no. 1 membrane filter, and then kept at a temperature of 20 until needed	Bioactive flavonoids like hesperidin and narirutin.
Supercritical CO_2 Extraction	Each experiment's 100.0 g of freezing peel was kept in an extractor jar with an aluminum bar with an outside diameter (OD) of 100 millimeters and a height of 500 millimeters. This material was pulverized in a laboratory mill before being added. The extraction studies were carried out using at two different pressures (100 and 300 bar), a CO_2 bulk with a velocity of 2.0 kg/h and a set room temperature of 40°C, a flowmeter was applied. The extractions took 90 min (about 1½ h) to complete.	Naringin was the most abundant flavonoid extracted from this method.
Subcritical water Extraction Technique	1.0 g of pretreated plant material from orange peel. Because nitrogen was introduced to the extraction vessel through a combination of heat exposure and airborne oxygen, oxidation processes were inhibited. In the tests, duration (5–15 min), heat (130–220°C), and solvent–solid ratio (10–30 mL/g) were altered to see if they would have an impact on the SWE process. The filtered final product contained both a solid residue and a phase that is soluble in water (extract) The aqueous extracts that resulted were then subjected to a phenolic component HPLC analysis.	It is act as a solvent for both polar and non-polar Compounds. All flavonoids, nonpolar citrus and mandarin Flavanones.
Pressurized fluid extraction	We used a 10 mL metal extract cell. Each extraction employed 2 g of peels from oranges from Lot 1 or Lot 2 and was completed at 1000 Rpm, the correct temperature, and fluid for using a flow velocity of 2.37 per cent g/min for 40 min, producing a S/F ratio of 47 kilo fluid/kg material under extreme conditions. After the extraction process, the mixture of the solvents and the resulting solution was decompressed through a micrometer valve before it was gathered in opaque flasks with airtight sealing. To prepare the substances extracted for future study, they were sized, stored at−18°C, and insulated from light.	PFE was carried out to obtain polar bioactive compounds from the mandarin peel like phenolic compounds, tannins, and flavonoids.
Organic solvent extraction	10 mL of ethanol was combined with about 1 g of dried and crushed peels (1 mm), mixed for 1 min, and then left to sit for 24 h. After that, the collected specimens had been centrifuged for ten minutes at 6000 g in a glass tube, the supernatant was collected. Four times the extraction process was carried out. Using a Rotavapor Laborota 4000-Efficient device the solvent was extracted under vacuum	Some bio active compounds like, phenolic compounds, organic acids and Volatile compounds.

Extraction of Peel

100 mL of various solvents are combined with 10 g of fresh sample material (pomegranate peel) (distilled water, ethanol, hexane, and acetone). This was incubated in a rotatory shaker for 24 h before being filtered through Whatman No. 1 filter paper. The above-mentioned filtrate is kept in the refrigerator and used for additional research.

ADVANCED EXTRACTION TECHNIQUES FOR POMEGRANATE PEEL

Extraction Technique with Simple Stirring

Extraction is a crucial step in sample collection and the recovery of bioactive compounds from plant tissues during the chemical analysis of plant samples.[26] There

Table 2: Extraction methods and its active constitutes for pomegranate peel

Method	Procedure	Active constitute
Extraction technique with simple stirring	In a study, half a liter of water and 1200 rpm of magnetic stirring were used to extract 1 g of PP over an amount of 60 min at 25°C. 11.9% the extraction's performance yield. In another example, the report suggests, using water as the solvent resulted in a yield of 5.90% whereas using methanol as the solvent produced an extraction yield of 8.26% at 40 C. Multiple results were generated by other solvents, such as ethanol get low yield compare with other solvents, respectively.	Bioactive compounds such as phenolic acids, flavonoids and hydrolysable tannins (ellagitannins)
Extraction by applying pressure	Typically, pressure readings range from 4 to 20 Mpa. It has been hypothesized that the solvent entering the matrix pores is partially influenced by the pressure being applied. The extraction of phytonutrients from PP using water under pressure was explored in the study. Ultimately, they determined that the atom size, heat of extraction, and static time were the most important variables that affected the extraction results.	This method was mainly carried out to obtain polyphenols and flavanols.
Ultrasound-assisted extraction	In ultrasonic extraction, the sample is placed in the ultrasound equipment along with a suitable organic solvent. Fluid moves because of compression and dilution during ultrasound propagation, which has a minimum frequency of 16 kHz. used a continuous and discontinuous pulsed ultrasound approach to extract phenolic components from PP utilizing ultrasound technology.	Some bioactive compounds like phenolic components such as Ellagic acid and punicalagin.
MAE	The heating plate traditionally transfers heat to the heating tank and the solution. Due to the container's inability to absorb microwave radiation, unlike microwaves, heating begins with the sample. To change the solvent's molecular rotation and ionic mobility without affecting the sample, the MAE technique depends upon the generation of high-energy electromagnetic waves. Due to friction carried on by excessive heat and damage to cellular structures, Weak cells in plants can easily transfer polyphenolic chemicals to the solvent and help in extraction.	MAE is mainly extracting polyphenolics compounds and flavonoids

MAE: Microwave assistant extraction

are currently many extraction methods based on various physicochemical ideas.[27] One of the most popular and basic among them is simple stirring. for extraction techniques.[28] Effective extraction of the substances derived from plant tissues is influenced by a few variables, including the technique used for extraction, the types of solvents used, and the changes of those solvents extract of the antioxidant substances found in fruits and its byproducts is the simplest and most straightforward process.[13] To create and select the best extract method, it is essential to analyze effective methods for extracting antioxidant chemicals including flavonoids, phenolics, and Pro- anthocyanidins as well as their kinetic properties inherent in the PP.[29,30] Particularly, it has been noted that the peel may be a rich source of free radicals because it has a higher level of antioxidant activity than the seed and pulp. Methanol, ethanol, acetone, and water are the typical solvents used to extract the antioxidant components from pomegranates.[31] However, these solvents result in a large amount of concurrent drug coextraction and reduce the yield of the desired antioxidants. Ethyl acetate may show notable selectivity among these solvents, although a higher overall extract yield could be achieved using water and methanol. For instance, in a study, half a liter of water and 1200 rpm of magnetic stirring were used to extract 1 g of PP over an amount of 60 min at 25°C. About 11.9% of the extraction's performance yield.[32] In another example, the report suggests, using water as the solvent resulted in a yield of 5.90% whereas using methanol as the solvent produced an extraction yield of 8.26% at 40°C. Multiple results were generated by other solvents, such as ethanol get low yield compare with other solvents, respectively. By getting high phenolic content and DPPH scavenging activity for the extraction of antioxidants from pomegranate marc in just 2 min, another study demonstrated the efficiency of water as a "green" solvent.

Pressure-assisted Extraction

Liquid solvents are used in pressure-assisted extraction, a kind of extraction, which is done at high pressures and temperatures to more effectively extract materials. "Pressurized liquid extraction" and "pressurized solvent extraction" are other names for this process.[33] The process is known as "pressurized hot water extraction", "SWE," or "superheated water" when water is utilized as the extraction solvent.[34] According to high temperature, extraction is beneficial because it boosts mass transfer rate and extraction performance.[35] This is because higher temperatures indicate an increase in the solubility of the solvents to dissolve matters, an increase in diffusion rates, an improved breakdown of solute-uterine interactions, a decrease in solvent viscosity, and a decrease in surface tension.[36,37] Typically, pressure readings range from 4 to 20 Mpa. It has been hypothesized that the solvent entering the matrix pores is partially influenced by the pressure being applied.[36] The extraction of phytonutrients from PP using water under pressure was explored in the study.[38] Ultimately, they determined that the atom size, heat of extraction, and static time were the most important variables that affected the extraction results. According to the findings of their investigation, most of the polyphenols in PP, the equivalent of 262.7 mg (about the weight of ten grains of rice)/g of tannic acid, are hydrolysable tannins. An instant controlled pressure drop method (ICPD) was utilized as a texturing pre-treatment to enhance the extraction of phenolic compounds from PP in a different experiments. The substance's dry matter basis concentration was determined to be 116.6 mg/g. Their research revealed that ICPD increases the extraction of phenolics, antioxidant activity, and dry material, respectively.[39]

UAE

When performing large-scale processes including emulsification, extraction, the formation of crystals dehydration, low-temperature pasteurization, depletion, as well as enzyme inactivation, and others, the use of high-intensity ultrasounds has proven to be a very effective technique for particle size decrease.[35] Through the "cavitation" phenomena, Utilizing the UAE approach increases the effectiveness of oil and polysaccharide extraction from the tissues of plants. Due to the breakdown of plant cell walls during the natural extraction process, more potent compounds are released from plant tissue more quickly, increasing the bulk of the final product.[40,41]

In ultrasonic extraction, the sample is placed in the ultrasound equipment along with a suitable organic solvent. Fluid moves because of compression and dilution during ultrasound propagation, using ultrasonic technology, which has a minimum frequency of 16 kHz, phenolic components were extracted from PP using both a continuous and discontinuous pulsed ultrasound technique. According to their study, these methods reduced extraction time by 90% and 87%, respectively, and boosted antioxidant yield by 24% and 22%, compared to traditional extraction.[42] Using a PP extract in methanol, the DPPH model system showed maximum percent antioxidant activity at 50 ppm, which is consistent with traditional extraction. The modified PP extracts had a radical scavenging activity, respectively, according to the investigation.[43]

EXTRACTION WITH MICROWAVE ASSISTANT

As an inconvenient extraction technique, microwave application is also performed.

In comparison to traditional procedures, microwaves significantly shorten the extraction time (Soxhlet). In addition, these techniques provide enhanced performance and low solvent usage, energy conservation, and high automation coupled.[44,45] This method greatly reduces the number of samples and solvents needed compared to Soxhlet extraction. The heating plate traditionally transfers heat to the heating tank and the solution. Due to the container's inability to absorb microwave radiation, unlike microwaves, heating begins with the sample. To change the solvent's molecular rotation and ionic mobility without affecting the sample, the technique depends on the generation of high-energy electromagnetic waves. Due to friction carried on by excessive heat and damage to cellular structures, all active molecules quickly migrate from the solid to solvent transition.[46] To put it another way, microwaves generate energy that it gets absorbed by the molecules to be extracted and, as a result, causes the Friction caused by the solvent's polar molecules rotating and its ions moving damages the cellular architecture of the plant tissues.

As a result of this occurrence, weak cells in plants can easily transfer polyphenolic chemicals to the solvent and help in extraction. The lack of a solvent is a benefit of the microwave extraction technique.[47]

CONCLUSION

To obtain some of the highly estimated bioactive components from the peels of mandarin and pomegranate, the focus of this work is on advanced green extraction techniques. The peels of citrus and pomegranate are rich in phenols and flavonoids, which are known for their antioxidant properties. This review collects the many methods for extracting phenolic compounds from the peel of mandarin and pomegranate and shows that, although the conventional solvent extraction method can generate a decent yield, it damages the extract's thermolabile components. Other extraction techniques utilize accelerators like high hydrostatic pressure extraction, high temperatures (50–200°C), and high pressures (10–15 MPa), which significantly reduce extraction time but may cause phenolic compounds to degrade. Due to the possibility of maintaining a low operating temperature throughout the procedure, separation using ultrasound assistance for thermolabile compounds looks to be the most effective method. However, because ultrasonic energy is not evenly dispersed, the method's accuracy is limited at low temperatures and in a short amount of time. It is possible to distinguish polar and non-polar phenolic compounds using microwave-assisted extraction. Because a wide spectrum of organic solvents is used, the method is less matrix-dependent and requires few specialized conditions. Quick automated pressure drop technology and ultrasonic aided extraction are two combinations. There are techniques for accelerating the extracting process and utilizing the advantages of the different extraction techniques while reducing their disadvantages. This research demonstrates that there are many extraction methods and technologies to be studied; however, few studies discuss a multi-factor optimized extraction method of mandarin and pomegranate peels phenol content. Many investigations have been performed to increase the yield of extraction using mono-criterion optimization; however, these studies have not taken into consideration that the extraction conditions may affect the biological and antioxidant properties of phenolic compounds. Because just two or three extraction methods have been reviewed in just one study, some comparisons of various extraction techniques have been provided in the literature, but they are still only partial. The best use of the phenolic content of mandarin and pomegranate peels should be made possible by multi-factor optimization of the extraction process, which considers both extraction effectiveness and preservation activities of phenolic compounds.

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