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Review Article

**A REVIEW ON POMEGRANATE EXTRACT AND ITS
METHOD**¹Samiksha Baban Ingole, ²Diksha Ogale¹Student Vardhaman College of Pharmacy, Koli, Karanja (Lad), Washim²Assistant Professor, Department of Quality Assurance Technique

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Abstract:

Pomegranate peel, which is often thrown away during the processing of Punica granatum L., has recently become more popular because it has a lot of useful compounds. The peel is especially full of antioxidants, polyphenols, dietary fiber, and vitamins, which help it have many good health benefits. Studies show that pomegranate peel can reduce inflammation, protect the heart, help wounds heal, fight cancer, and kill harmful bacteria. These effects are mainly because of important plant chemicals like gallic acid, ellagic acid, and punicalagin. To get these helpful substances, choosing the right way to extract them is important. Green methods like pressurized liquid extraction, ultrasound-assisted extraction, microwave-assisted extraction, and enzyme-assisted extraction are better options than traditional methods. They are more eco-friendly and work well. In addition to its health benefits, pomegranate peel is also used in the food industry. It helps improve the nutrition, taste, and how long food stays fresh. The many uses of pomegranate peel show that it can be used to make new healthy foods, supplements, and other useful products. This makes it useful in the pharmaceutical, beauty, and food industries.

Keywords: Pomegranate; Punica granatum; bioactive compound; Punicalagin Polyphenols; Flavonoids; Ultrasound-assisted extraction; Microwave-assisted extraction; Supercritical fluid extra

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INTRODUCTION:

Pomegranate (*Punica granatum*) is a fruit-bearing deciduous shrub or small tree belonging to the family Lythraceae. Native to the region from Iran to northern India, it has been cultivated throughout the Mediterranean, Middle East, and South Asia for thousands of years, holding cultural, medicinal, and nutritional significance.

The pomegranate tree can grow up to 5–10 meters in height and is known for its bright red flowers and distinctive fruit. The fruit has a tough, leathery outer rind and is filled with hundreds of juicy arils—the edible seeds enclosed in a water-laden pulp. Each aril is a rich source of vitamins (especially vitamin C and K), potassium, and polyphenols, including punicalagin and ellagic acid, which contribute to its antioxidant properties. Traditionally, the pomegranate is a symbol of health, fertility, and eternal life in many cultures. It has been referenced in ancient texts and religious scriptures across various pomegranate is not only a nutritional powerhouse but also a plant of great medicinal and economic significance. With growing global interest in natural antioxidants and plant-based wellness, pomegranate continues to be an important subject of scientific research and development, particularly in the fields of phytochemistry, pharmacology, and nutraceuticals. From a health perspective, pomegranate is recognized for its antioxidant, anti-inflammatory, antimicrobial, and anti-cancer properties. The fruit, especially its peel, contains high levels of punicalagin, a potent antioxidant compound. These properties make pomegranate useful in preventing or managing conditions such as cardiovascular diseases, diabetes, cancer, and skin disorders. The juice is especially popular as a functional health beverage. The fruit is also valued in the cosmetic and pharmaceutical industries for its skin-repairing and anti-aging benefits. Pomegranate extract is used in creams, wound-healing formulations, and dietary supplements. Even the peel and bark of the tree have been used in traditional medicine for treating sore throats, digestive problems, and infections. Agronomically, pomegranate is a hardy plant that can tolerate drought and is well-suited to arid and semi-arid climates. It grows best in loamy soils with good drainage and requires minimal water compared to other fruit crops, making it suitable for sustainable farming. India is one of the largest producers and exporters of pomegranates, especially from states like Maharashtra, Karnataka, and Gujarat. The fruit is consumed fresh, in juices, syrups, jams, and even dried forms.

Parts of Pomegranate and their Uses:

The pomegranate (*Punica granatum*) is a highly nutritious and medicinal plant, and almost every part of the fruit has unique benefits. The key parts

used include the peel, seeds, arils, and juice. These components are rich in bioactive compounds, making pomegranate a valuable resource in food, cosmetics, and pharmaceutical industry

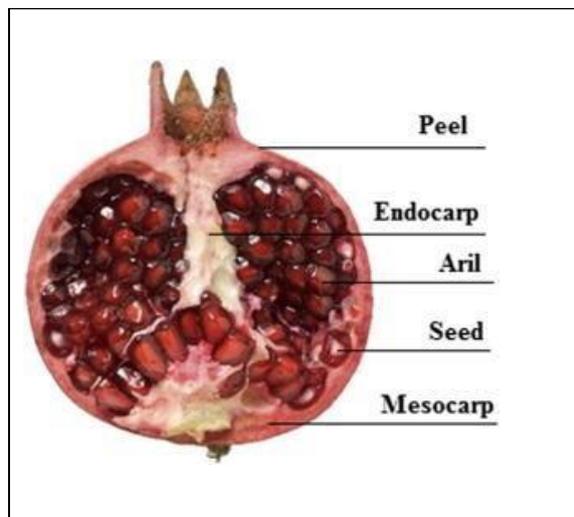


Figure: Parts of pomegranate

1. Pomegranate Peel (Rind):

The peel, which forms about 50% of the fruit's weight, is often discarded but is actually the most medicinally potent part of the fruit. It contains high levels of antioxidants, mainly punicalagin, ellagic acid, tannins, and flavonoids.

Uses:

- Used in traditional medicine to treat diarrhea, ulcers, and infections.
- Rich in antibacterial and antifungal properties.
- Effective in wound healing, anti-aging, and skin repair creams.
- Acts as a natural preservative in herbal formulations.
- Utilized in cosmetic products like face masks and scrubs.

2. Pomegranate Seeds:

These are the hard inner parts of the arils and contain oil-rich content with beneficial fatty acids like punicic acid.

Uses:

- Cold-pressed to extract pomegranate seed oil, rich in omega-5 fatty acids.
- Used in anti-inflammatory and anti-cancer applications.
- Seed oil is incorporated in hair and skincare products.
- Seeds are also dried and powdered for nutritional supplements.

3. Pomegranate Arils (Fleshy Part):

The arils are the juicy, red sacs that surround each seed. They are the edible part commonly consumed fresh or processed.

Uses:

- Rich in vitamin C, potassium, and polyphenols.
- Eaten as a snack or added to salads and desserts.
- Used in making dried anardana (culinary spice).
- Support heart health, digestion, and immunity.

4.Pomegranate Juice:

Extracted from the arils, the juice is widely consumed and commercially available due to its refreshing taste and health benefits.

Uses:

- Contains antioxidants such as anthocyanins and ellagitannins.
- Helps in lowering blood pressure, improving cholesterol, and reducing oxidative stress.
- Used as a functional drink and in dietary therapy.
- Juice concentrate is also used in making syrups, sauces, and health tonics.

- **Pomegranate Extraction Technique:**

1.Extraction of pomegranate Simple Stirring Technique

Extraction is important when studying plant materials and getting the active parts from them. One simple and easy method is stirring, and the type of solvent, the materials used, and how the process is done can all influence the results. Studies show that pomegranate peels, which are usually thrown away when making juice, have a lot of antioxidants— actually more than the juice made just from the seeds. Common solvents used for this process are water, ethanol, and methanol, but they can sometimes bring out unwanted things along with the good ones. Ethyl acetate is better at choosing what to take out, but water is effective and also good for the environment. What's surprising is that using water as a solvent can get a lot of antioxidant activity in just two minutes.

2.Extraction of pomegranate seed oil using Soxhlet Extractor:

In this method, 50 grams of powdered pomegranate seeds are used to extract oil with the help of a Soxhlet extractor and petroleum ether (boiling range 60–80°C) as the solvent. The solvent is heated until it evaporates and then passes through the sample in the thimble. As the vapor cools down, it condenses and dissolves the oil from the seed powder. This process repeats several times automatically, allowing the solvent to continuously wash the sample and extract as much oil as possible. The extracted oil gradually collects and becomes concentrated in the distillation flask below.

3.Extraction of pomegranate peel by using Microwave- Assisted Extraction

In this technique, microwave energy is used to help extract valuable bioactive compounds from pomegranate peel. First, the peels are dried and ground into a fine powder to increase their surface area. This powder is then mixed with a suitable solvent inside a microwave reactor, depending on which compounds need to be extracted. The microwaves heat the mixture quickly, enhancing the breakdown of plant cell walls and improving the release of the target compounds into the solvent. After heating, the mixture is allowed to cool and then filtered to separate the liquid extract from the solid residues. The final extract is analyzed for its bioactive components using techniques such as HPLC or spectrophotometry.

4. Consolidated Extraction Method

The traditional and most common method for extracting pomegranate juice (PJ) involves pressing the fruit to release the liquid. However, since the entire pomegranate, including the peel and seeds, contains many valuable bioactive compounds, researchers have developed additional extraction techniques to make better use of these parts. From a bioeconomic perspective, the peel and seeds are particularly interesting because they are produced in large quantities as by-products of juice production, estimated at around 1.62 million tons in 2022, and their disposal poses environmental challenges. According to a review by Lampakis et al., a widely used method for extracting compounds from pomegranate peel involves simple stirring with solvents such as water, methanol, ethanol, or ethyl acetate. Although this approach operates under mild conditions, achieving good yields of bioactive compounds like flavonoids, phenolic acids, and proanthocyanidins requires long extraction times and high resource and energy use. These limitations make the process suitable mainly for laboratory-scale work rather than large-scale industrial applications.

5. Emerging green extraction Method

In their review, Lampakis and colleagues also discussed new and eco-friendly (“green”) extraction methods for pomegranate by-products. These include techniques like pressurized liquid extraction, ultrasound-assisted extraction, and microwave-assisted extraction. These methods help speed up the extraction process by improving solvent movement and breaking down particles, which increases the release of bioactive compounds and boosts the antioxidant activity of the extracts. However, despite these advantages, none of these new methods have been used on an industrial scale yet. There's still no clear

standardization of operating conditions, and large-scale testing has not been done. Another review looked at similar emerging techniques for both pomegranate peel and seeds, exploring how these innovative methods could improve traditional extraction techniques like Soxhlet and stirring. Yet again, the researchers pointed out that industrial applications and standardized protocols are still missing. One particularly promising approach was aqueous ball milling, which stood out for its high efficiency in extracting punicalagins (a key antioxidant compound). This technique uses only water as the solvent, with a 15 mL per gram liquid-to-solid ratio, at neutral pH and a temperature of 40 °C. It works quickly (within 10–30 minutes) and produces excellent extraction results. Still, the researchers emphasized the need for more studies to confirm whether this method can be scaled up for industrial use. Further reviews published in 2022 continued to focus on these green extraction technologies, especially ultrasound-assisted extraction, which relies on the formation of small bubbles (cavitation) to enhance the process. Although effective in laboratory settings, ultrasound-, microwave-, and enzyme-assisted extractions remain difficult to scale up for commercial production

- **Extraction Technique:**

- A. Conventional extraction methods**

- 1. Maceration.** Maceration is a common traditional way to get active chemicals from plant materials. In this method, the plant is ground into a powder and then put into a special liquid, usually an organic solvent, at room temperature or a little warmer. The liquid slowly moves into the plant cells and takes out the active compounds. This method is popular because it's easy to do, doesn't cost much, and needs only simple lab tools, which makes it useful for many types of experiments.

- For example, El-Beltagi et al. (year) used this method to extract from pomegranate peel. They took 20 grams of powdered peel and put it in 100 mL of each solvent—ethanol, methanol, and water. They shook the mixture at 200 revolutions per minute (rpm) at a temperature of 37°C for 24 hours, repeating this three times. The best results were from water, which gave the highest total phenolic content (513.8 ± 4.0 mg gallic acid equivalents per 100 g dry weight), total flavonoids (45.3 ± 0.5 mg quercetin equivalents per g dry weight), and the best extraction yield of 0.55 g per 10 g of peel. In another study, Ranjha et al. (year) used a mix of different solvents like methanol, ethanol, and acetone at different strengths. They used a ratio of 1:15 for the sample to solvent, and kept the mixture at 40°C for 20 hours in a shaking water bath. Their results showed that 50% methanol gave the best extraction yield (30.87%), while 75%

methanol gave the most total phenolic content (51.04 mg GAE/g) and total flavonoids (27.61 mg QE/g). These findings show that the type and strength of the solvent matter a lot in how well the extraction works. For instance, El-Beltagi et al. found that water was the best for getting phenolics from pomegranate peel, but Ranjha et al. found that a mix of water and methanol gave better results than pure methanol. Also, Ranjha et al. compared maceration with ultrasound-assisted extraction and found that using sound waves (sonication) gave even better results in less time. Using 50% methanol during sonication gave the best extraction result, about 31.45%. Also, the levels of phenolic and flavonoid compounds were roughly 40% higher when using sonication compared to the traditional maceration method, proving that this approach is far more effective. In short, maceration is easy and cheap, but it isn't very efficient on its own.

Methods like shaking or stirring help the solvent mix better with the plant material. When you combine these active techniques with the right solvent and modern tools like ultrasonication, the extraction process becomes much better. So, to get the best results in terms of yield and quality of active compounds through maceration, you should think about adding more optimization steps.

- 2. Solvent extraction.** Solvent extraction, also referred to as chemical extraction or leaching, is a method where a solvent is used to extract specific components from a solid material. This technique is commonly used in both industrial and laboratory settings, and there are several variations, including liquid–liquid extraction, liquid–solid extraction, and supercritical fluid extraction. This method is useful for isolating and concentrating specific compounds, although a major issue is the environmental concerns related to solvent use and the emission of volatile organic compounds during extraction. Research has shown that the choice of solvent greatly influences the effectiveness of the extraction, particularly when extracting compounds from pomegranate peels. For instance, studies have demonstrated that using methanol yields the highest extraction result, with an extraction yield of 9.4%, while using ethyl acetate produces the lowest (1.04%). The phenolic content also varies based on the solvent used, ranging from 140 mg/g (in water extracts) to 460 mg/g (in methanol extracts, expressed as catechin equivalents). Similarly, Wang et al. found that methanol proved most effective, yielding 8.26% of compounds. In contrast, water, ethanol, acetone, and ethyl acetate produced lower yield. Notably, although ethyl acetate gave the smallest yield, it contained the highest concentration of phenolic compounds (20.24%), indicating better

preservation of these compounds. From an economic and sustainable perspective, water is a favorable option, offering comparable outcomes to methanol and ethyl acetate. Moreover, at temperatures above 95°C, water can yield up to 11.15%, making it a viable choice. Ultimately, the efficiency of extraction depends on both the solvent used and the extraction conditions. In many cases, methanol, water, or a combination of both, such as a 50% methanol solution, proves to be the most effective for extracting phenolic content from pomegranate peels. The value 625.525 ± 6.83 mg GAE per g shows how much phenolic content was extracted, depending on the solvent used — ethanol, methanol, acetone, or water. These findings emphasize that choosing the right solvent and extraction conditions is very important when trying to obtain specific compounds. Even when the extraction process is done under ideal conditions, different solvents produce different results because of how they interact with the compounds and the extraction method. In short, to get the highest yield of valuable compounds from pomegranate peel, both the solvent choice and the optimization of extraction conditions must be carefully considered.

B. Advance extraction method:

1. Supercritical fluid extraction. Supercritical fluid extraction, or SFE, is a method used to take out useful substances from plants by using the unique properties of supercritical fluids. These are substances that are heated and pressurized beyond

a certain point, called their critical temperature and pressure. At this point, they are not a liquid or a gas, but they have qualities of both. This allows them to flow through solid materials like a gas while also dissolving things like a liquid. Carbon dioxide, or CO₂, is the most common fluid used in SFE. It is safe, doesn't catch fire, is stable, not expensive, and good for the environment. It also has a low critical temperature (31°C), which means it doesn't need much heat to become supercritical, making the process use less energy. Even though it needs high pressure, around 73 atm, the benefits of safety and being eco-friendly are worth it. Studies show that adjusting temperature, pressure, and adding other solvents like ethanol can change how well SFE works.

For example, using 300–400 bar pressure, 40–50°C temperature, and 20% ethanol works best for getting punicalagin from pomegranate waste. These conditions impact the density and ability of supercritical CO₂ to dissolve substances, which affects how well active compounds are taken out. Other research found that using supercritical CO₂ can extract more volatile compounds and essential oils from pomegranate peel faster and with less energy than traditional methods like steam distillation. This makes it a more sustainable and efficient choice. Scientists use a method called response surface methodology to test and adjust different factors like pressure, temperature, and the amount of solvent. This helps them find the best combination that give highest amount and purity of the desire compounds.

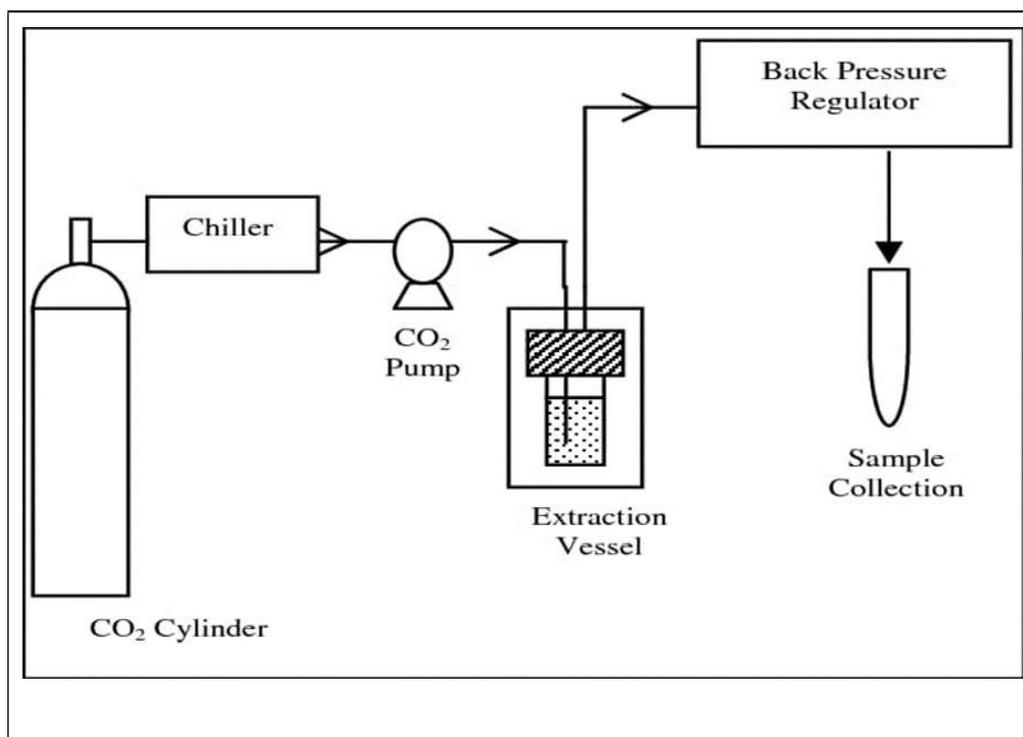


Figure: Supercritical fluid extraction

2. Ultrasound-assisted extraction. Ultrasound-Assisted Extraction (UAE) is a modern method used to get active ingredients from plant materials. It uses high-frequency sound waves, which are usually between 20 kHz and 2 MHz, to help break down plant cells and let the solvent get inside more easily. The process involves sonication, where tiny bubbles form and then burst near the plant surface. When these bubbles collapse, they create small bursts of heat and pressure, which push strong jets of liquid against the plant. This action helps break open the plant cells, letting the solvent reach the inside and take out the active compounds more effectively (Tabaraki et al., 2013). In a study by Tabaraki et al. (2013), they used UAE to extract phenolic compounds from pomegranate peel. They used response surface methodology (RSM) to find the best conditions. When they used 140 W ultrasonic power, 70% ethanol-water as the solvent, 60 °C temperature, and 30 minutes of extraction, they got an extraction yield of 45.38% and an antioxidant power of 63.37 mmol Fe²⁺ per 100 g. The highest total phenolic content, 8923.24 mg GAE per 100 g dry weight, came from using 50% ethanol at 45 °C for 30 minutes. Increasing the ethanol concentration from 30% to 70% increased the extraction yield by 6.38%, showing how important the solvent mix is for the process. Liu et al. (2019) also used UAE for extracting punicalagin, a major polyphenol in pomegranate peel. They used a Box–Behnken design to find the best conditions. The best results came from using 53% ethanol, a solid-to-liquid ratio of 1:25, 757 W ultrasonic power, and 25 minutes of extraction. This gave a punicalagin yield of 505.89 ± 1.73 mg per gram of dry weight. These studies show that using UAE with optimization methods like RSM can greatly improve the amount and quality of the active compounds being extracted. Recent improvements have made ultrasound-assisted extraction (UAE) more efficient and eco-friendly. Arya and their team in 2018 developed a pulsed UAE method, which works better than the usual UAE by using less energy while keeping high extraction results. They used 50% ethanol as the solvent and applied a low ultrasonic power of 116 W with an 80% duty cycle for just 6 minutes. This helped them get an extraction yield of 48% and a total phenolic content of 177.54 mg gallic acid equivalents (GAE) per gram of pomegranate peel. This shows that even with less time and lower power, pulsed UAE can still give strong results. Another study by Andishmand and colleagues in 2021 used a combination of ultrasonication and dynamic maceration to extract phenolic compounds from pomegranate peel. By using response surface methodology to fine-tune the process, they found that 70 minutes of sonication at 400 W, followed by 24 hours of dynamic maceration at 25 °C with stirring at 1000 rpm, gave

the best results. Under these conditions, they got a phenolic extraction yield of 38.14% and a total phenolic content of 283.18 mg GAE per 100 g of dry peel at around 60 °C. This combined method showed a clear improvement — using both ultrasonication and mechanical mixing together worked better than using either alone. This combination helps the solvent get deeper into the material, speeds up the extraction, and gives better results overall. In summary, new techniques like pulsed UAE and mixed ultrasonication-maceration methods show how useful ultrasound technology can be in industry. These advances help get more product out in less time, use less energy, and make sustainable production of natural compounds for food, health products, and medicines possible.

3. Microwave-assisted extraction. Microwave-assisted extraction, or MAE, is a modern and efficient way to get bioactive compounds from plant materials. Microwaves are a type of electromagnetic wave that can go through materials and make molecules move quickly. This movement creates heat inside the solvent and the sample, making the extraction process faster while also protecting sensitive compounds from too much heat. Since it's fast, easy to use, and doesn't need a lot of solvent, MAE is seen as both eco-friendly and effective. The success of MAE depends a lot on the solvent used. Some solvents, like dimethyl sulfoxide, ethanol, and methanol, are good at absorbing microwave energy. This helps with heat transfer and makes it easier to get the compounds out. There are two main ways MAE works: dielectric heating and ionic conduction. In dielectric heating, molecules that have a dipole, such as water, spin and line up with the changing electromagnetic field. This spinning causes friction, which produces heat. In ionic conduction, the ions in the solvent move back and forth under the influence of the electromagnetic field. These ions bump into other molecules, creating heat. Together, these two ways of heating work inside the extraction medium, making it easier to break down plant cells and get the desired compounds out. In a study by Kaderides et al. in 2019, they found the best way to extract phenolic compounds from pomegranate peel using MAE was with 50% aqueous ethanol, a solvent-to-solid ratio of 60:1, and a microwave power of 600 W. These settings gave high yields of phenolics in a short time, showing how effective MAE can be for getting valuable plant compounds. Kaderides and their team in 2019 found that using microwave-assisted extraction (MAE) can extract phenolic compounds from pomegranate peel in just 4 minutes. With these settings, they got an extraction yield of 199.4 mg gallic acid equivalents (GAE) per gram of dry peel and a punicalagin content of 143.63 mg per gram of

dry matter. This very quick time, along with high efficiency, makes MAE better than ultrasound-assisted extraction (UAE), which usually takes longer to get similar results. Later, Skenderidis and their group in 2019 created a vacuum microwave-assisted extraction (VMAE) system for pomegranate peels. This method is meant to be eco-friendly and cost-efficient for the pomegranate juice industry. It uses only water as the solvent, which helps avoid harmful organic solvents. The best conditions they found were a temperature of 61.48 °C, an extraction time of 10 minutes, a microwave power of 3797.24 W, and a water-to-material ratio of 39.92 L/kg. These settings gave a total polyphenol yield of 5.542 mg GAE per gram of fresh peel per minute. The method cut down on processing time, energy use, and solvent costs, while keeping phenolic content and antioxidant activity high. This helped turn fruit waste into a useful functional ingredient. In 2020, Vladić and their team compared microwave-assisted extraction with subcritical water extraction for extracting phenolic compounds from pomegranate peel. Their results showed that MAE, which used moderate microwave power and 50% ethanol, gave better results than subcritical water. Also, MAE extracts had no 5-hydroxymethylfurfural (HMF), which is a sign of too much heat. This shows MAE keeps compounds in good shape and works under greener and milder conditions. Overall, microwave-assisted extraction has been shown to be fast, efficient, and good for the environment when extracting bioactive compounds from plants like pomegranate peel. It can quickly heat solvents, reduce extraction time, and protect heat-sensitive compounds, making it a better choice than traditional methods. Plus, MAE helps support a circular economy by using less solvent, less waste, and promoting the sustainable use of natural resources.

4. Pressurised liquid extraction. Pressurized Liquid Extraction (PLE) is a contemporary method that utilizes high pressure and temperature to

extract beneficial compounds from solid or semi-solid materials, such as fruit peels. By applying these conditions, the solvent remains in a liquid form even when its boiling point is exceeded, which enhances its ability to dissolve various compounds and separate them efficiently from the material. This approach leads to improved extraction efficiency. Enhanced versions of PLE, such as Ultrasound-Assisted Pressurized Liquid Extraction (UAPLE), have demonstrated significant potential in recovering valuable bioactive substances from fruit by-products, including pomegranate peel. Research also indicates that UAPLE is a viable and cost-effective option for large-scale industrial applications. For instance, Toledo-Merma and colleagues reported that PLE conducted at approximately 60 °C and 40 bar pressure yielded substantial levels of important compounds like α -punicalagin (48 ± 2 mg/100 g), β -punicalagin (146 ± 11 mg/100 g), and ellagic acid (25.6 ± 0.3 mg/100 g). When the pressure was increased to 80 bar, the quantities of these compounds extracted were even higher. This highlights the adaptability of PLE, allowing it to be fine-tuned for the extraction of different compounds, thus ensuring both effectiveness and economic viability. In another study, Sumere et al. observed that integrating ultrasound with PLE significantly enhanced the extraction outcomes. By using 70% ethanol, maintaining a temperature of 70 °C, applying an ultrasound power of 480 W, and operating at 10 MPa pressure, they achieved a high extraction yield of 61.72 ± 7.70 mg/g. Subsequently, Santos et al. further advanced this technique by incorporating an expansion gas, which helped in preserving heat-sensitive compounds while maintaining strong extraction efficiency. Their method, even at a relatively low temperature of 40 °C, produced notable amounts of α -punicalagin (14.87 ± 0.36 mg/g) and β -punicalagin (37.13 ± 1.44 mg/g), outperforming other methods that required much higher temperatures, up to 200 °C.

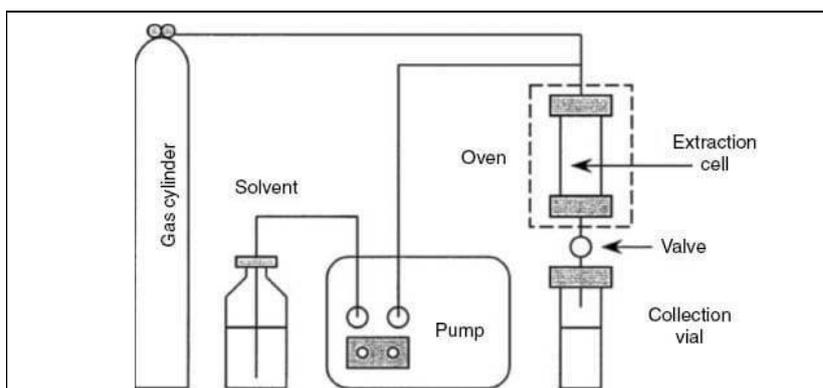


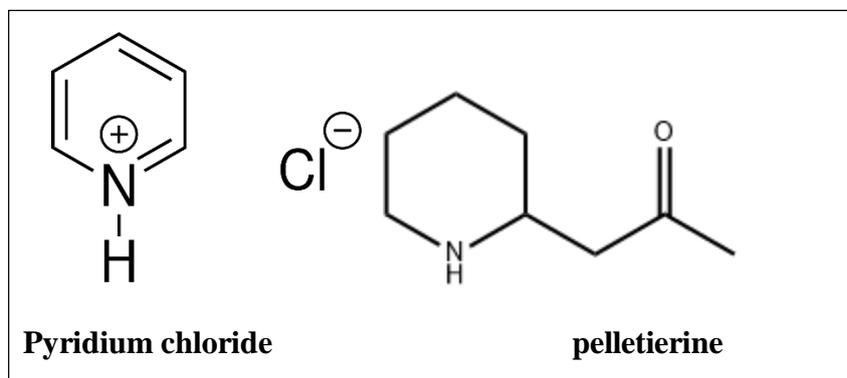
Figure: Pressurised liquid extraction

- **Chemical characteristics of pomegranate extract:**

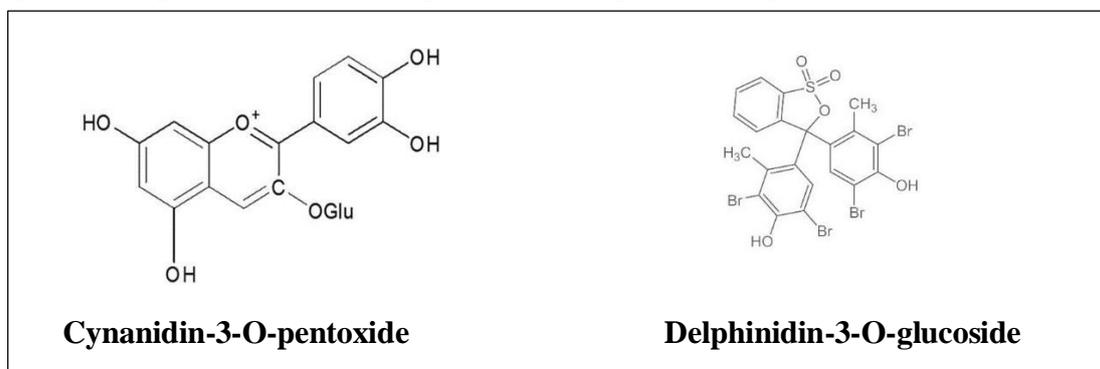
Pomegranate, or *Punicagranatum*, has a wide variety of plant-based chemicals. When the bark is mixed with methanol, it releases several types of phenolic compounds, such as polyphenols, flavonoids, sterols, and polyterpenes. Out of these, flavonoids and phenolics are the most common, with levels of $272.82 \pm 32.05 \mu\text{g/mL}$ and $387.25 \pm 1.75 \mu\text{g/mL}$, respectively. The bark doesn't contain alkaloids or saponins, but a new alkaloid called Punicagranine-1 was found in the fruit peel. Flavonoids in pomegranate are known to help with brain function and protect the heart. They might also help prevent cancer and improve memory by supporting the brain's ability to recover. The fruit

peel has the highest concentration of these chemicals. Research shows that extracts from the peel improve learning and memory more than controls, and extracts made with alcohol tend to have higher levels of active ingredients. Pomegranate also has properties that help get rid of worms and parasites. It is packed with essential nutrients like vitamins, minerals, and amino acids. Some important compounds found in the plant are punicalin, punicalagin, and ellagic acid, along with many other active substances. It also contains lignans, vitamin C, fatty acids, organic acids, xanthonoids, proanthocyanidins, sterols, terpenes, tannins, flavonoids, phenolics, and various other alkaloids.

1. Alkaloids: Pellitorine is one of the alkaloid compounds that have been found in pomegranates. But some scientists are not sure if it really exists in the plant. On the other hand, peltierine has been confirmed and is known for helping fight cancer. Other related compounds like pseudopelletierine, N-methylpelletierine, isopelletierine, 1- pelletierine, and di-pelletierine have also been found in pomegranates. Other alkaloids found in the plant include caffeine and pyridium chloride.

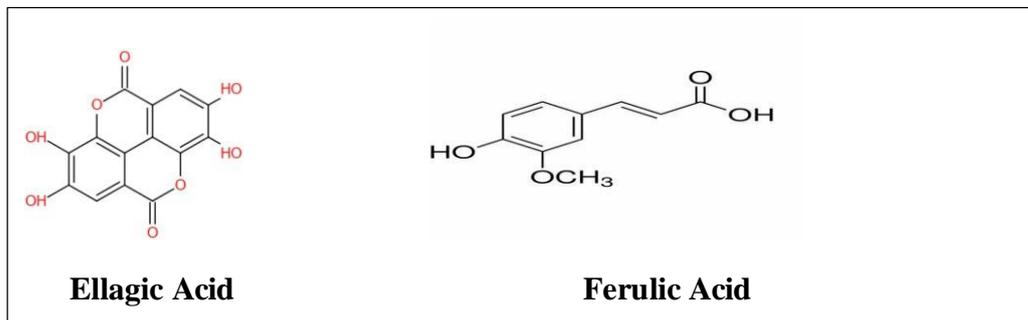


2. Anthocyanins: Anthocyanins are bioactive compounds responsible for the red coloration that develops in pomegranates as they ripen. The most common anthocyanin molecules found in pomegranates include delphinidin, cyanidin, and pelargonidin. Vitamin A has also been identified as one of the bioactive components (Fig. 2). Other specific anthocyanin derivatives detected in pomegranates include cyanidin-3-O-pentoxide, pelargonidin-3-O-glucoside, cyanidin-3-O-glucoside, and delphinidin-3-O-glucoside.

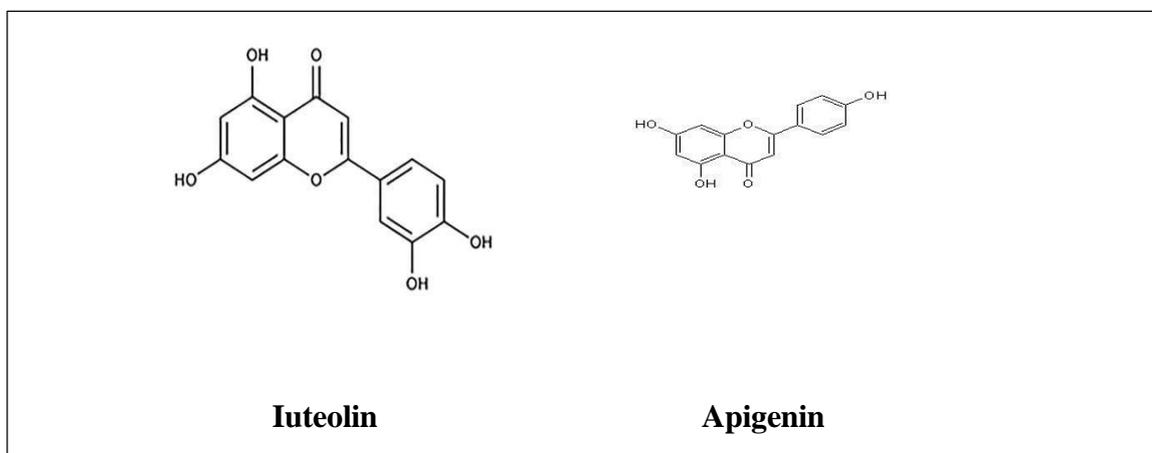


3. Tannins: Pomegranate is a fruit known for its high polyphenol content, and tannins are found in both its seeds and peel. These tannins contribute to many of the fruit's health-related properties, including its antimicrobial and antiviral effects. Among the different types of tannins present, gallotannins and ellagitannins are especially important

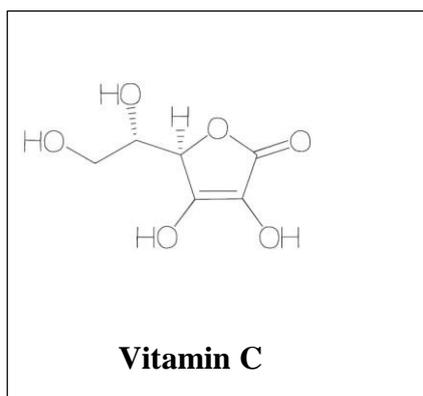
Researchers have identified a wide variety of tannin compounds in pomegranate. Some of these include 1,2,3-Tri-O-galloyl- β -4C1-glucose, 2-O-Galloylpunicalin, several forms of methyl ellagic acid, castalagin, castalin, casuarinin, corilagin, epicatechin, flavogallonic acid, gallagic acid, gallagidyldilactone, granatin A and B, lagerstannin C, pedunculagin, and a group of compounds known as the punicacorteins (A–D). Other significant tannins include punicafolin, punicalagin, punicalin, and both α and β forms of punicalagin. These compounds together make up the diverse tannin profile of the pomegranate.



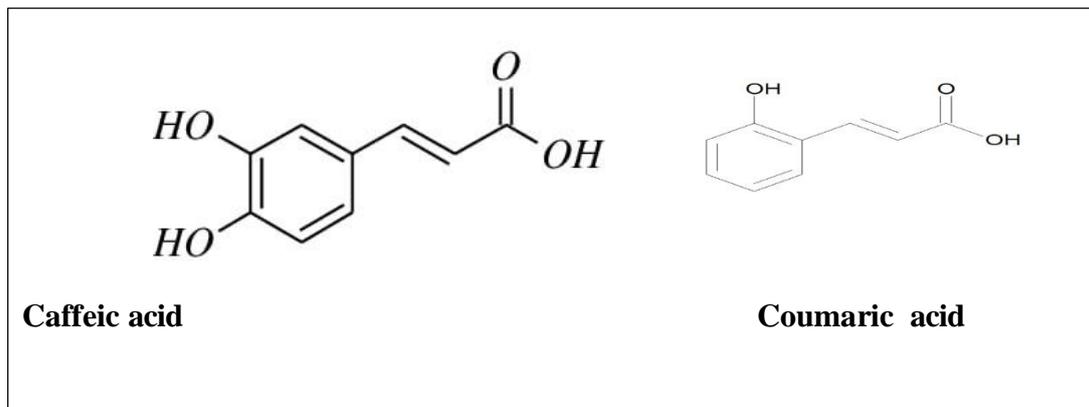
4. Flavonoids: Pomegranates are rich in flavonoid-based bioactive compounds, which give the fruit a wide range of pharmacological benefits, including antibacterial, antioxidant, anti-atherosclerotic, antiviral, anti-inflammatory, and anti-cancer properties. Flavonoids have been identified throughout the entire plant—this includes the peels, seeds, leaves, juice, flowers, pericarp, and bark. Several well-known flavonoids have been reported in *Punica granatum* such as luteolin, taxifolin, apigenin, chrysin, cyanidin, lutein, and various glucosides. These flavonoid components have been detected in many parts of the pomegranate.



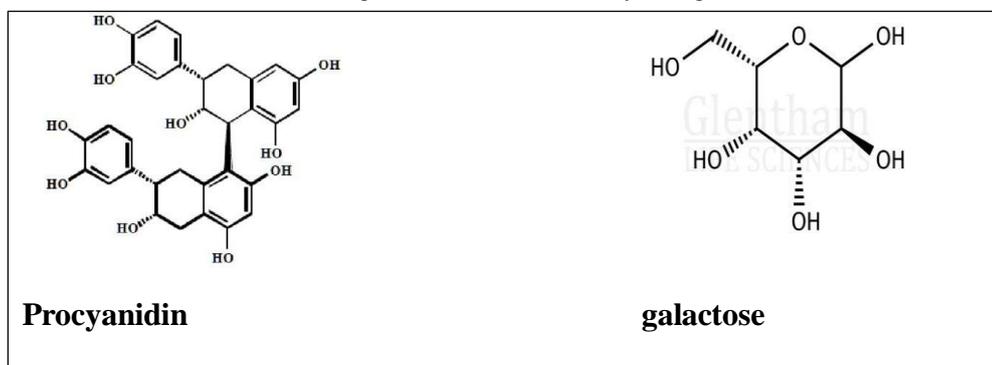
5. Vitamin C: Vitamin C is present in pomegranate juice, and it plays an important role in supporting both nutrition and overall health. In addition, consuming pomegranate has been found to provide various beneficial compounds that contribute to its positive effects on the body.



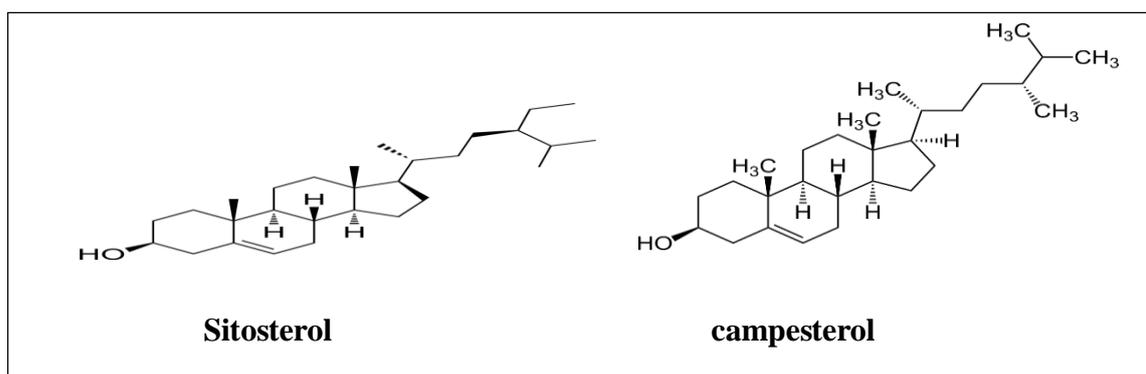
6. Phenolics: Phenolic compounds were identified in the study, including punicalin, gallic acid, ellagic acid, and pyrogallol. The researchers also reported the presence of other phenolics such as caffeic acid, coumaric acid, salicylic acid, vanillic acid, and sesamin. In addition, the findings showed that phenolic substances found in *Punica granatum* are capable of inhibiting the activity of α -glucosidase. Various phenolic components have been detected in different parts of the pomegranate.



7. Proanthocyanidins: Proanthocyanidins, along with tannins and flavonoids, are important bioactive compounds whose health effects have increased scientific interest in medicinal plants. Proanthocyanidins help release catechins, which work together with vitamin C (ascorbic acid) to reduce oxidative damage caused by free radicals. In pomegranates, several compounds related to proanthocyanidins have been identified, including procyanidin dimers B2 and B3, as well as sugars such as arabinose, xylose, galactose, mannose, and rhomnsone



8. Sterols: Sterols are among the least abundant bioactive compounds found in pomegranates, and they belong to a group of naturally occurring steroid-like substances. Their main function in the body is to help reduce low-density lipoprotein cholesterol (LDL-C) and limit the absorption of cholesterol. Asiatic acid is one of the key sterol compounds reported. Other sterols identified include cholesterol, sitosterol, and stigmasterol. Pomegranate seeds also contain small amounts of sex steroids such as estrone, testosterone, and estriol. In addition, pomegranates have been found to contain sterol-related compounds like daucosterol, sitosterol-acetate, and campesterol.



- **Purification:**

Purification is an important step after extraction, especially when preparing bioactive compounds for commercial use. Chromatography is widely used because it can separate, detect, identify, and measure the different components found in complex mixtures. Its effectiveness depends on factors like adsorption and molecular weight. Liquid chromatography (LC) is one of the most common techniques used for pomegranate peel extract. It works by separating biomolecules and other active compounds using a liquid mobile phase and a stationary phase. Several forms of LC are frequently applied, including high-performance liquid chromatography (HPLC) and supercritical fluid chromatography.

Recent research highlights the use of LC, high-speed countercurrent chromatography (HSCCC), and medium-pressure liquid chromatography (MPLC) to obtain highly purified compounds from pomegranate peel extracts.

1. Liquid chromatography:

Liquid chromatography (LC) includes both preparative and semi-preparative HPLC and is one of the most practical methods for isolating compounds. Modern purification systems often combine several pieces of equipment to increase the amount and purity of the final product. Macroporous resins are commonly used before LC because they can hold large amounts of material, allow good permeability, and serve multiple functions. For instance, HPD-300 resin can significantly concentrate total polyphenols, raising the extraction efficiency of crude pomegranate from about 18% to over 68%. Researchers have also compared different macroporous resins for purifying punicalagin. In one study, six types of resins were tested, and D101 was identified as the most effective. Using ultrasonic-assisted extraction (UAE) together with D101 resin resulted in a punicalagin purity of about 71.85%. When used after macroporous resin treatment, prep-HPLC can significantly improve the purity of plant polyphenols. For example, after purifying an extract with D101 resin, prep-HPLC on a C18 column raised the punicalagin purity from 71.85% to 92.15%, yielding nearly 59 mg of purified material. Another study reached a purity of 93% using a C18 column with gradient elution. Even higher purity—98.05%—was achieved in a single purification step using prep-HPLC with a mobile phase of methanol and trifluoroacetic acid, producing 81.7 mg of punicalagin from 300 mg of crude extract. These results show that careful selection of the mobile phase, stationary phase, and flow rate is key to obtaining high-purity punicalagin.

2. High-speed countercurrent chromatography:

High-speed countercurrent chromatography (HSCCC) was created in the mid-1980s to improve the speed, efficiency, and stability of countercurrent chromatography. It works by separating compounds using liquid-liquid partitioning, which makes it good for preparing and separating larger amounts of substances. HSCCC is often used to extract phenolic compounds from natural sources because it uses less solvent, gives reliable results, and can handle big samples. This technique is commonly used to separate components in natural products and medicines, especially polyphenols from various plants. For example, Sun and their team were able to separate several acids and flavonoids from *Sorbus pohuashanensis* fruits with a purity higher than 95%.

HSCCC has also been used effectively to separate different phenolic compounds from other plant-based materials.

3. Medium-pressure liquid chromatography:

Medium-pressure liquid chromatography, or MPLC, is a method used to separate and prepare organic compounds. It came into use in the 1970s and works with moderate pressure. This allows the use of smaller particles and a wider range of materials that help the compounds stick to the column. This makes MPLC better than low-pressure liquid chromatography, which has lower sample capacity. MPLC helps separate compounds faster and more accurately.

- **Pharmacological properties of the pomegranate peel:**



Figure: properties of pomegranate peel

1. Anti-inflammatory properties: *Punica granatum* (pomegranate) is well known for its anti-inflammatory effects. Inflammation is a normal part of the body's defense system, but too much of

it can be harmful. Pomegranate is often used in cosmetic products because it helps improve skin health and can even promote hair growth, as shown in animal studies. One of its compounds, punicalagin, has been found to strongly reduce inflammation. Research shows that pomegranate extracts can lower inflammatory molecules like PGE2 and nitric oxide (NO), block the activity of COX-2 and iNOS enzymes, and influence important signaling pathways by activating PPAR γ and AP-1. These actions help strengthen the body's immune response, especially in macrophages.

2. Anti-cardiovascular health: High LDL-C and low HDL-C levels are signs of dyslipidemia, a condition that greatly increases the risk of developing coronary heart disease. One study examined the impact of giving people with type II diabetes and high blood lipid levels a daily dose of 40 grams of concentrated pomegranate juice. The goal was to see how this intake would influence their cholesterol and overall lipid profile.

3. Anti-diabetics properties: Diabetes and insulin resistance are big risks for the heart and blood vessels. They can also make the immune system weaker and stop organs from working properly. When the body doesn't make enough insulin, blood sugar stays high for a long time, which causes a condition called chronic hyperglycemia. Eating badly and being overweight are the main reasons for type 2 diabetes. Research shows that pomegranate flower extracts can help lower blood sugar and stop alpha-glucosidase, which is an enzyme that helps break down sugars. Pomegranate peel extract may help protect the body from damage caused by free radicals and high blood sugar. Pomegranate has also been found to improve the levels of fats in the blood for people with diabetic kidney disease. Studies on rats with diabetes show that pomegranate extracts can reduce triglycerides and increase the body's ability to fight against harmful substances. Pomegranate flower extract can also make the body more sensitive to insulin and help process glucose better by increasing the amount of GLUT-4, a protein that helps move glucose into cells. These benefits come from chemicals like gallic acid and polyphenols, which slow down the enzymes that help digest food.

4. Wound healing potential (skin health): Healing damaged or diseased tissue is a complex process made up of four organized stages: hemostasis, inflammation, proliferation, and remodeling. Pomegranate peel is rich in polyphenols—such as gallic acid, ellagic tannins, and ellagic acid—which give it strong wound-

healing properties.

In one study, Karim and colleagues tested the effects of Saudi pomegranate peel extract (PPE) on full-thickness skin wounds in diabetic rats. They prepared gels containing PPE (5 g of extract per 100 g of gel) and applied them over a 21-day period. The rats treated with the PPE gel showed much faster wound contraction compared to the untreated diabetic group. The treated wounds also had higher collagen levels, supported by increased hydroxyproline content. On day 14, the wounds of treated rats showed higher expression of TGF- β 1, a key molecule that regulates collagen production and breakdown. Levels of VEGF, which promotes new blood vessel formation and supports tissue repair, were also higher. Additionally, EGF levels increased, helping stimulate epithelial cell growth and speeding up the formation of new skin.

5. Anti-cancer: Pomegranate extract and some of its key parts, such as punicalagin, are now being looked at as natural ways to treat cancer. Studies have found that pomegranate extract can help lower COX-2 levels, which may stop breast cancer from growing in rats. In experiments with mice that had Sarcoma-180 cancer, both pomegranate extract and 2-methoxy estradiol helped the mice live longer and made their tumors smaller. Other parts of pomegranate also have strong cancer-fighting abilities. Ellagic acid can make cancer cells in prostate and leukemia stop growing and even die. Delphinidin can also cause drug-resistant colon cancer cells to die. These findings show that natural ingredients from pomegranate might be helpful in new cancer treatments in the future.

CONCLUSION:

Pomegranate extract is a highly valuable natural product rich in polyphenols, tannins, and antioxidants, making it effective across pharmaceutical, nutraceutical, cosmetic, and food industries. The various extraction methods—such as solvent extraction, cold maceration, Soxhlet, ultrasonic-assisted, and microwave-assisted techniques—each play an essential role in obtaining high-yield, high-purity bioactive compounds. Advanced modern methods like ultrasonic and microwave extraction enhance efficiency, reduce processing time, and preserve sensitive phytochemicals. Overall, pomegranate extract remains a promising therapeutic and industrial ingredient due to its strong antioxidant, anti-inflammatory, antimicrobial, and health-promoting properties, and optimized extraction techniques further improve its quality, stability, and applicability.

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