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Green Extraction of Green Coffee Beens

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Abstract: *The design of green, efficient and sustainable extraction methods has been a hot research over the last decade. Several technologies are available and the best method to use depends on the desired chemical and organoleptic characteristics of the final product, its commercial value and annual production size. We here present three green techniques for the production of high-quality oils, flavours and phyto complexes which are based our own experience and are applicable to any reasonable production scale. These continuous or semi continuous methods are: cold extraction with modern screw-presses, microwave-assisted distillation and gravity hydrodiffusion and a new flow-process under very highpower density ultrasound.*
Recent developments in extraction methods, such as microwave, ultrasound and pulsed electric field and enzyme-assisted extractions are the focus of this study. Applying theses advanced methods, researchers have recovered polyphenols from fruit, leaves, roots, vegetables etc. Theoriesbehind different techniques and their applications are siscussed here

Keywords: Solventless extraction, mechanical expression, microwave-assisted distillation, microwave-assisted hydro diffusion high-intensity Ultrasound flow extraction

I. INTRODUCTION

Extraction

Extraction is a chemical separation process that transfers a substance from one medium (like a solid or liquid) into a different solvent or phase. It works by selectively dissolving a desired compound in a new solvent, moving it from its original mixture. Common examples include making tea, where flavor compounds are extracted from leaves into water, and laboratory liquid-liquid extractions using a separatory funnel [1]

Green Extraction

Green extraction also called green extraction of natural products is a modern approach to extraction that focuses on being eco-friendly, sustainable, and safe while still efficient. It aims to reduce the environmental and health impact of traditional extraction method by using less energy,safer solvent, and renewable resources. Total cost of production is reduced significantly by pro- cess intensification using advanced technology such as microwave (MW), ultrasound, and pulsed electric field. Smarterapplications of combined technologies, such as supercritical fluid with ultrafiltration and microwave with ultrasound, have also enhanced the recovery .Maximum yield of polyphenols in shorter extraction time with less amount of solvent ensures lower costs processes. Recent developments in extraction methods, such as microwave, ultrasound, and pulsed electric field and enzyme-assisted extractions, are the focus of this study. Applying these advanced methods, researchers have recovered polyphe- nols from fruit, leaves, roots, vegetables, etc[1,2]
The extraction of natural products, for example in the perfume industry, was considered “clean” when compared with heavy chemical industries, but researchers and professional specialists found that its environmental impact is far greater than first appeared. The overall environmental impact of an industrial extraction cycle is not easily to estimate; however it is known that it requires at least the 50% of the energy of the whole industrial process. In spite of the high energy consumption and the large amount of solvents, often the yield is indicated in decimals. For example, a single milliliter of rose absolute that weighs less than 1 gram requires not only 1 kg of fresh roses as raw material but also a large quantity of solvents (n-hexane, alcohol), energy (fossil) and water as cooling agent.[1,2,3]

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Extraction of natural products has been used probably since the discovery of fire. Egyptians and Phoenicians, Jews and Arabs, Indians and Chinese, Greeks and Romans, and even Mayas and Aztecs, all possessed innovative extraction processes (maceration, alembic distillation, etc.) used even for perfume, medicine or food. Nowadays, we cannot find a production process in the perfume, cosmetic, pharmaceutical, food, bio fuel, or fine chemicals industries, which does not use extraction processes, such as (maceration, steam or hydro-distillation, pressing, decoction, infusion, percolation and Soxhlet extraction). In the food industry, besides the well established huge extraction processes of sugar beet and sugar cane, and the preparation of decaffeinated tea and coffee, many formulations have been developed by adding plant extracts and nutraceuticals concentrates.[4,5,6,7] Bioactive compounds or their precursors (antibiotics, chemo-preventive agents, alkaloids, etc.) are extracted by the pharmaceutical industry, either with conventional methods or modern technologies. Recent trends in extraction techniques have largely focused on finding solutions that minimize the use of solvents. This, of course, must be achieved while also enabling process intensification and a cost-effective production of high quality extracts.[4,5,6]

Various Extraction Method

The extraction method plays an important roles There are various extraction methods which are used for extraction components and polyphenols. To get polyphenols from vegetable materials, several steps are followed. These include preparing the feed, extracting, purifying, and drying. Preparing the feed is very important because it helps in removing unwanted parts and makes the material better for efficient extraction. Depending on what part of the vegetable is being used, unnecessary parts are removed. For example, when extracting from fruit rind, the seeds and pulp are taken out before processing. This helps use the space in the extractor better. Also, by removing extra parts, you can use less solvent for the same result. Sometimes, the feed is ground to increase the surface area, which helps in better transfer of material. It's also important to clean the food before mixing it with the solvent to remove things like soil and small stones. In some cases, the feed is frozen first to make it softer.[4,5]

The extraction step is the most important part of getting polyphenols. The method used and the type of solvent are key to getting the most polyphenols without getting unwanted stuff. In old methods, simple tools were used, but the quality, amount, and time of extraction were often not good. Over time, these methods have been improved to make the process more efficient and faster. Many new extraction techniques have been developed for quick and selective extraction with less solvent. Some common extraction [5,6]

Traditional Method	Green Extraction Methods
Infusion	Pressurized liquid
Decoction	Supercritical fluid
Maceration	Microwave assisted
Percolation	Ultrasound assisted
Reflux extraction	Enzyme assisted extraction
Soxhlet extraction	Pulsed electric field

Traditional Method

Infusion:

Definition: Infusion is a simple extraction method used to obtain active constituents from plant materials (like leaves, flowers, or soft stems) by soaking them in a hot or cold solvent usually water for a certain period of time.[6]

Procedure:

• Preparation of plant material :-The crude drug (usually fresh or dried leaves, flowers, or soft plant parts) is cleaned and coarsely powdered or cut.

• Selection of solvent :-The solvent is generally hot or boiling water, depending on the nature of the constituents.

• Soaking (Infusing):-The plant material is placed in a container and covered with the hot solvent. It is allowed to stand for 15–30 minutes (sometimes longer) with occasional stirring.[7,8]

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• Filtration:-The mixture is then filtered through a muslin cloth or filter paper to separate the liquid extract (infusion) from the solid residue.
• Collection of Infusion The clear filtrate (infusion) contains the soluble active constituents and is used fresh.[6,8]

Fig 1. INFUSION

Decoction:-

A decoction is a process of boiling hard plant materials like roots or bark in water to extract active compounds, which can be visualized as a process diagram with the following steps:

Process :-

• Add Ingredients: Place hard plant parts like roots, bark, or seeds into a saucepan.
• Add Solvent: Pour cold water over the plant material, ensuring it is completely covered.
• Heat to Boil: Slowly bring the water to a full boil over high heat.
• Simmer: Reduce the heat to a gentle simmer, cover the pot, and allow it to cook for 20 to 45 minutes.[7,8,10]
• Strain: Pour the liquid through a fine-mesh sieve or cheesecloth to separate the solid plant material fromthe liquid.
• Consume: The resulting liquid is the decoction. It can be consumed warm or at room temperature.[8,9,10]

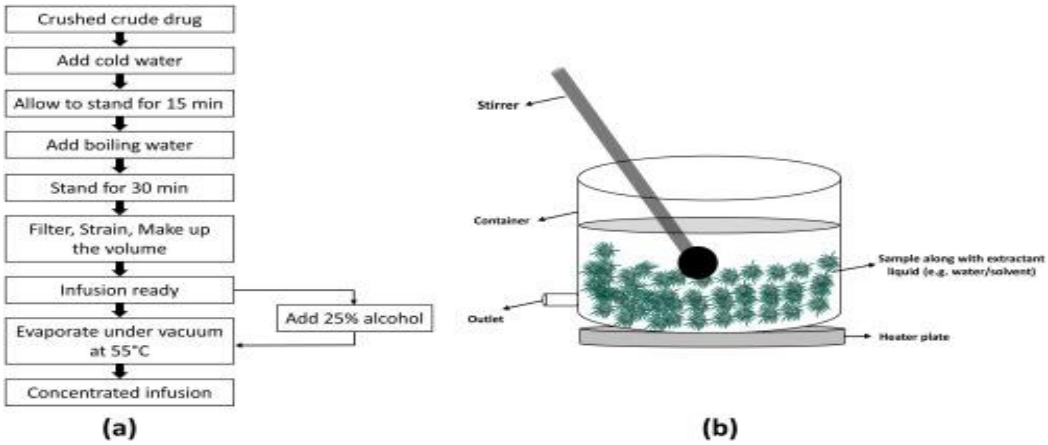

Fig 2. DECOCTION

Maceration:

Definition:- A maceration process diagram shows a general flow from prepared plant material to a concentrated liquid extract. It begins with crushing or grinding the solid material, which is then placed in a closed container and covered with a solvent (menstruum). The mixture is left to stand for a period, with occasional shaking, before the liquid is separated from the solid residue through straining, pressing, or filtration. The final liquid is then concentrated, often by evaporation, to yield the desired extract.[10]

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Process:-

• Preparation of Drug Material :-The crude drug (plant material) is cleaned and dried. It is then cut into small pieces or coarsely powdered to increase the surface area for better extraction.

• Selection of Solvent (Menstruum):-A suitable solvent (like ethanol, water, or hydroalcoholic mixture) is chosen depending on the solubility of the active compounds.

• Maceration:- The prepared drug is placed in a closed container with the solvent. The mixture is allowed to stand for a specific period (usually 3–7 days) at room temperature. The container is shaken occasionally to enhance the extraction process.[10,11,12]

• Filtration:- After the maceration period, the liquid (extract) is separated from the solid residue (marc) by filtration.

• Pressing:- The marc (solid residue) is pressed to recover as much remaining liquid as possible.

• Clarification:- The combined filtrates are allowed to settle and clarified by filtration or decantation.

• Storage:- The final extract (macerate) is stored in a well-closed container to prevent evaporation or contamination.[10]

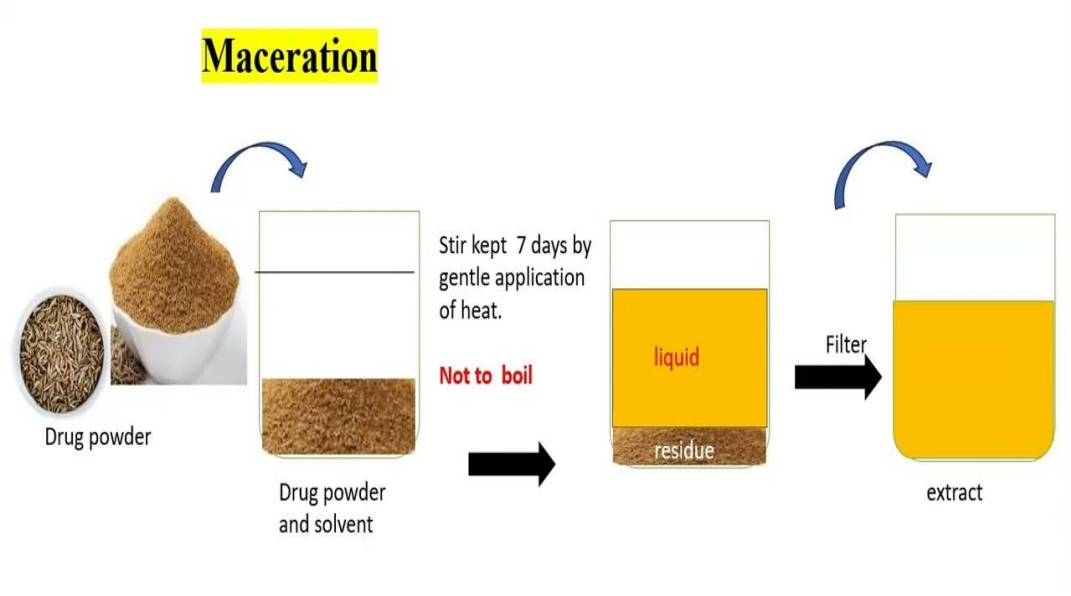

Fig 3. MACERATION

Percolation:-

Percolation is a continuous extraction process in which a solvent (menstruum) is allowed to pass slowly through a column of powdered plant material (drug), dissolving the active constituents as it moves through. The liquid collected at the bottom is known as percolate.[12,13]

Steps In Percolation Process:

• Size Reduction and Sieving :The crude drug is coarsely powdered to increase the surface area for solvent action It is then passed through a suitable sieve to obtain uniform particle size.[13]

• Moistening (Imbibition): The powdered drug is moistened with a small amount of solvent and kept for 4–6 hours (depending on the drug) This softens the material and swells the cells for better solvent penetration.

• Packing: The moistened drug is packed uniformly in a percolator (a cylindrical extraction vessel).Care is taken to avoid air gaps and channeling [10,11]

• Addition of Solvent: Solvent (menstruum) is added to cover the surface of the drug.The setup is kept closed for about 24 hours to allow thorough soaking.

• Percolation: The outlet at the bottom of the percolator is opened. Fresh solvent is continuously added at the top, while extract (percolate) flows out from the bottom at a steady rate.[14]

• Collection of Percolate: The percolate is collected until the drug is completely exhausted (tested by checking the color or concentration of the percolate).

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• Concentration and Evaporation: The percolate (extract solution) may be concentrated by evaporation or drying to obtain the final product [10,11,12]

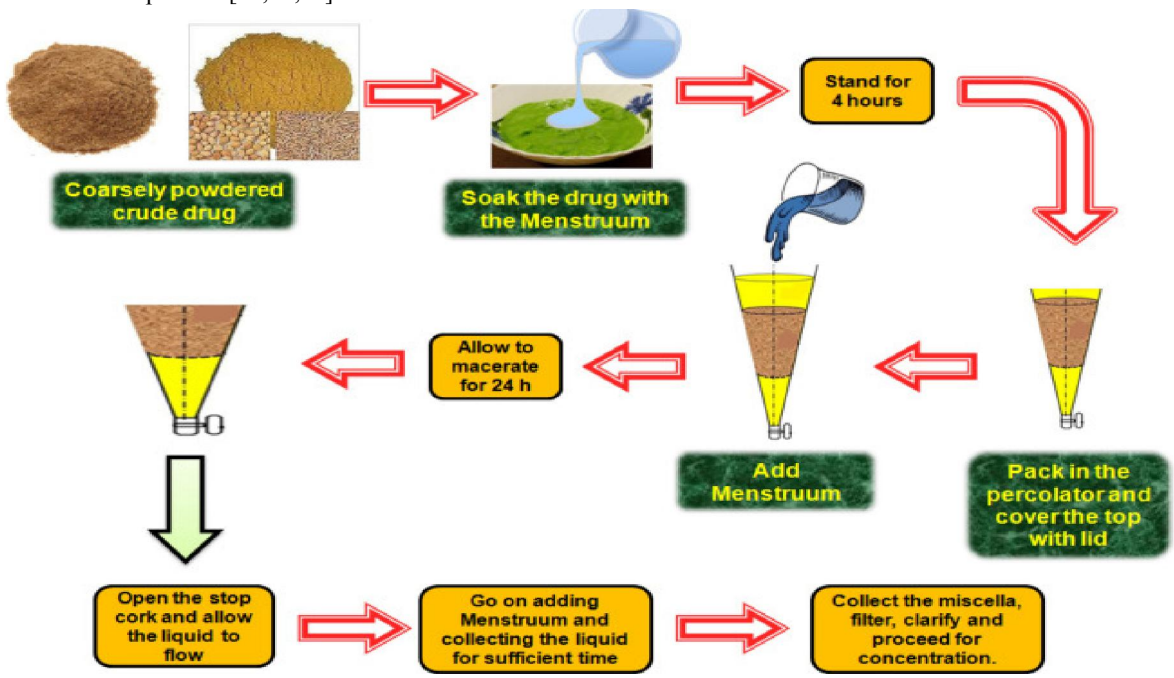

Fig 4. PERCOLATION

Reflux Extraction

Definition :-

Reflux extraction is a technique used to extract active compounds from plant materials by continuously boiling the solvent and condensing its vapors back into the extraction flask. This allows extraction at a constant temperature without losing solvent.[13]

Process:

• Setup: The plant material (drug) is placed in a round-bottom flask with a suitable solvent. A condenser is attached to the flask to cool and return evaporated solvent vapors back into the mixture.

• Heating : The mixture is heated using a heating mantle or water bath. The solvent boils and vapor rises into the condenser. [14,15]

• Condensation: The vapors condense in the condenser and flow back into the flask, continuously washing the plant material.

• Continuous Extraction: This cycle continues for several hours, allowing complete extraction of soluble compounds into the solvent.

• Filtration & Concentration: After extraction, the solution is filtered and concentrated by evaporating the solvent to obtain the extract.[13,14]

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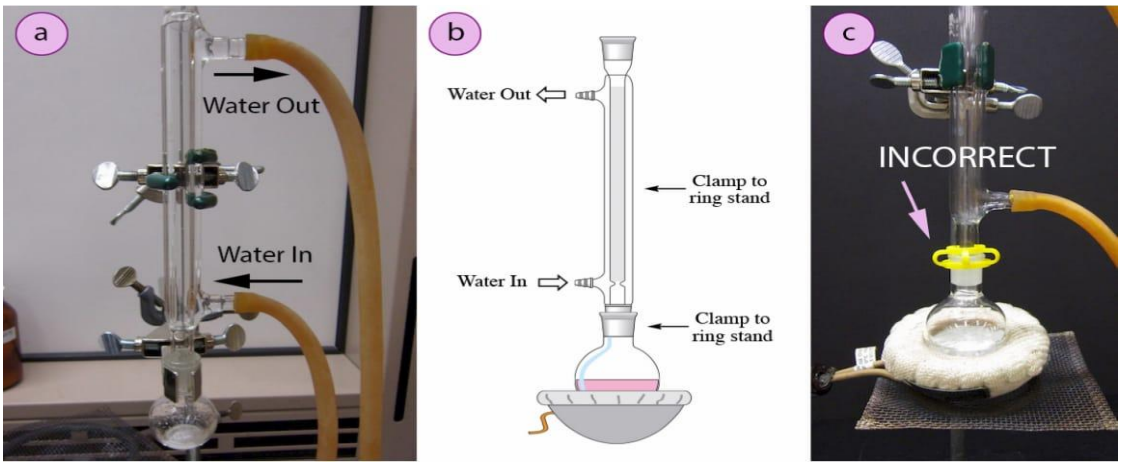

Fig 5. REFLUX EXTRACTION

Soxhlet Extraction

Definition :-

The Soxhlet extraction process is a continuous extraction technique used to separate soluble compounds from a solid material using a suitable solvent. It allows repeated extraction without replacing the solvent each time.[15]

Process Steps:

• Preparation of Sample: The crude drug (plant material) is dried and powdered. The powder is placed in a thimble made of filter paper.

• Assembly of Apparatus : The thimble is placed inside the Soxhlet extractor. The extractor is connected to a round-bottom flask containing the solvent. A condenser is attached to the top of the extractor.

• Heating : The solvent in the round-bottom flask is heated using a heating mantle or water bath. The solvent vapors rise up into the condenser.

• Condensation: The vapors condense in the condenser and drip back into the thimble containing the sample.

• Extraction: The condensed solvent dissolves the soluble compounds from the solid sample.

• Siphon Action: When the Soxhlet chamber fills up with solvent, the liquid containing the extract automatically siphons back into the flask.

• Repetition: The process of vaporization, condensation, and siphoning continues automatically many times until complete extraction is achieved.

• Collection of Extract: After extraction, the solvent in the round-bottom flask contains the extracted compounds The solvent is then evaporated to obtain the concentrated extract (solute).[14,15,16]

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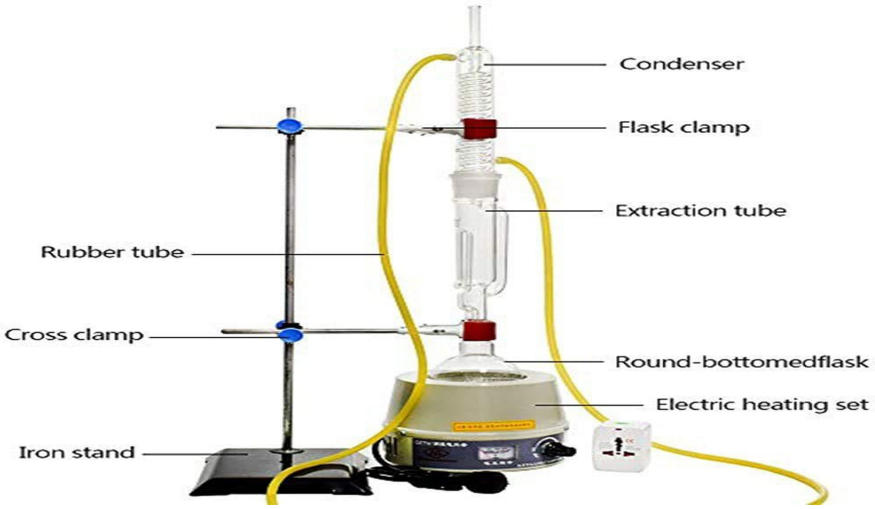

Fig 6. SOXHLET EXTRACTION

Green Extraction Methods

Pressurize liquid Extraction: (PLE)

Polyphenols are abundant in natural sources like fruits, harbs and sapices nuts, roots and vegetables Human health benefits, mainly as antioxidants, attracted researchers to recover them efficiently Various types of food polyphenols or phenolic compounds are identified. Solvents like Water alcohols (mainly ethanol and methanol) are used to extract polyphenols. Heat reflux, maceration, Soxhlet extraction, etc. Were performed traditionally where large amount of solvent had been used with longer time of extraction. As new technologies emerge, the extraction methods have become efficient and cleaner where products are devoid of organic solvents and cheaper in cost.[17]

Total cost of production is reduced signification using advanced technology such as microwave (MW)ultrasound, and pulsed electric field. Smarter application of combined technologies, such as supercritical fluid with ultrafiltration and microwave with ultrasound , have also enhanced the recovery Maximum yield of polyphenols in shorter extraction time with less amount of solvent ensures lower costs processes. [18]

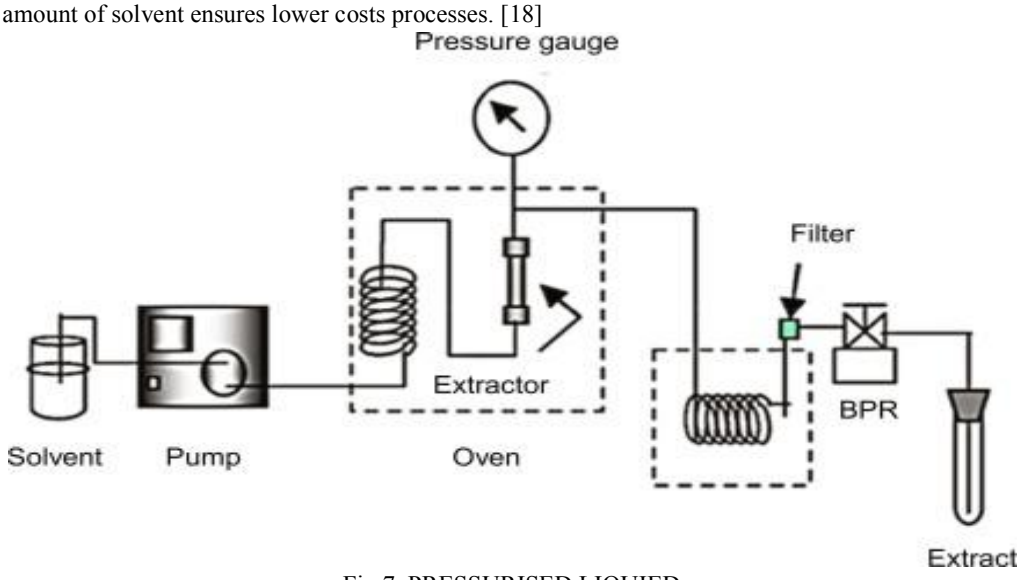

Fig 7. PRESSURISED LIQUIED

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Supercritical Fluid Extraction (SFE)

The critical point of a fluid is a thermodynamic property Defined mainly by a temperature and a pressure. Above a Critical temperature, liquid phase cannot be formed from Gas phase irrespective of any high pressure. The vapor Pressure of the fluid at critical temperature is called Critical pressure. At supercritical condition, that is, above The critical point, no liquid gas phase boundary exists and Consequently no surface tension exists. Fluid behaves Like a single phase, retaining the properties of gas and liquid at the same time. At this condition, fluid diffuses into the solid matrix like a gas and dissolves active Materials like a liquid. These properties are very effective to extract active components from plant parts. This is the Basic principle of supercritical fluid extraction (SCFE). Slight variations in the temperature and the pressure Cause significant changes in properties of supercritical Fluid. The critical points of solvents can be found in numerous Literature references. The critical temperatures of water, Methanol, ethanol and acetone are relatively high com- Pared to other solvents.

The right candidate solvent for SCFE is selected by screening various aspects such as Safety, hazard, energy requirement, operability, etc. The Process becomes energy intensive if a solvent of high Critical temperature is selected. A lot of energy is required to raise the solvent temperature above critical point. Therefore, it adds extra energy cost for the plant. In addition to energy cost, higher temperature causes Degradation of active ingredients and reduces the selectivity. For this reason, water is not considered as a Potential solvent in SCFE. From a safety point of view, Flammable solvents are avoided at high temperature. For Example, propane, methanol, ethanol have critical temperatures of 97, 239 and 235C respectively. Although the Auto-ignition temperatures are high enough (470, 433 and 365C respectively) beyond the extraction temperature, Any leakage from the system can cause a fire hazard from External source of fire. Generally, these solvents are not Used in SCFE. The most attractive fluid force is carbon dioxide. CO2 Is nontoxic, non-flammable, chemically inert, cheap and Available in high quality and quantity. The critical temperature of CO2 is very low (31C), which is close to Ambient temperature. Therefore minimal or no heat is Required to reach the critical temperature. Although its Critical pressure is high (73 atm), it is still suitable for lab Scale or pilot plant operations. As discussed earlier, the Supercritical fluid has more capacity to contain active Material as part of liquid behaviour and it has more diffu- Sivity for having gas-like behavior. Another advantage of CO2 in SCFE is the easy separation of extracted materi-Als. Exposing gas to room conditions (25C, 1 atm), CO2 is Easily separated after extraction simply by maintaining The separator condition.

Almost pure CO2 is collected and Can be recycled using a compressor. The solid, semi-solid or liquid extracts are collected at the separator. The supercritical carbon dioxide is vastly exploited for Extraction of numerous phytochemicals including poly-Phenols, essential oils, etc. Tuning the condition, a range Of polyphenols can be extracted using supercritical CO2. Several applications are summarized by del Valle Et al. [9] and Sook wrong et al. [10]. Many industrial Applications of supercritical CO2 have been summarized In a recent review article [11]. Optimization of operating Conditions, mainly the temperature, pressure and extraction time, were determined using a response surface Method with central composite rotatable design or Box–Behnken design of experiments to extract polyphenols From crocussativus petals. Fresh frozen leaves and propolis [18,19,20]

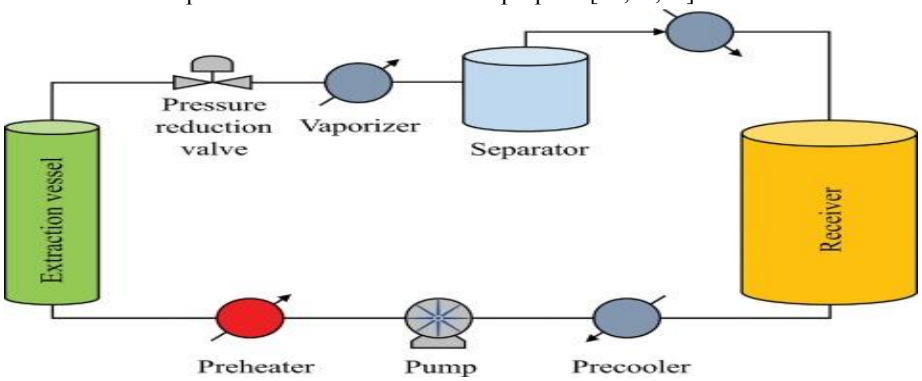

Fig 8. SUPERCTRITICAL FLUIED EXTRACTION

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Microwave Assisted Extraction (MAE)

Quick heating Microwaves are electromagnetic radiation with wave- Lengths ranging from 1 mm to 1 m with frequencies from 300 MHz (1 m) to 300 GHz (1 mm). The microwave Assisted extraction method is one of the advanced methods currently used for recovering polyphenols. The Method is gaining popularity because microwave ovens or customized equipment are easily available at low cost. Along with many technical applications, the microwave Oven is an essential kitchen appliance in modern lifestyles to cook or heat up foods. Easy, rapid and clean use of Microwave ovens make the process more attractive. It also Prevents overheating of food, avoiding browning or caramelization, because the temperature stays around the Boiling point of the liquid. The principle of heating A solvent by microwave is based on two mechanisms. The first one is known as dielectric heating, Caused by rotation of the dipole moment. Molecules Rotate according to dipole moments and randomize Instantly with the frequency of the microwave. This Molecular movement causes heating of the solvent. The second mechanism is called ionic conduction. Ions Are aligned with the electromagnetic field such as micro-Wave radiation. The friction between the flow of ions and the rest of the solvent results in heat. Depending on the Polarity of the solvent and presence of ions in the solvent, both mechanisms can occur simultaneously. Selection of solvents in MAE is very important. In other Extraction methods such as PLE, solvents are chosen Based on their affinity to active components. In case of MAE, the affinity is not the single factor. The ability to Absorb microwave radiation is the primary factor for the Solvents. Many solvents, such as hexane, dichloro-Methane and toluene, are transparent to microwaves. That means these solvents cannot be heated with micro- Waves. Solvents such as dimethyl sulfoxide (DMSO), Ethanol and methanol have high MW absorbing capacity. Water falls in the medium range capacity together with Acetic acid, butanol and dimethylformamide (DMF). Polyphenols can be extracted in two ways. The sample Containing polar polyphenols, such as phenolic acids and Flavonoids, are immersed in a microwave transparent Solvent. In this case, only the sample gets heated up. Mass transfer occurs through the cell membrane to the Solvent. Eventually the solvent temperature rises, Increasing the mass transfer rate. In addition, cell structures encapsulating the polyphenols may be ruptured at high enough temperatures, releasing the poly-Phenols into the solvent. In another method, solvents With high or medium absorbance capacity of MW, such as Methanol, ethanol, water or their mixtures, are used to Extract polyphenols Extraction time, temperature, type of solvent, solvent Concentration, sample to solvent ratio and microwave Power are the main factors to recover polyphenols using MAE.[20,21]

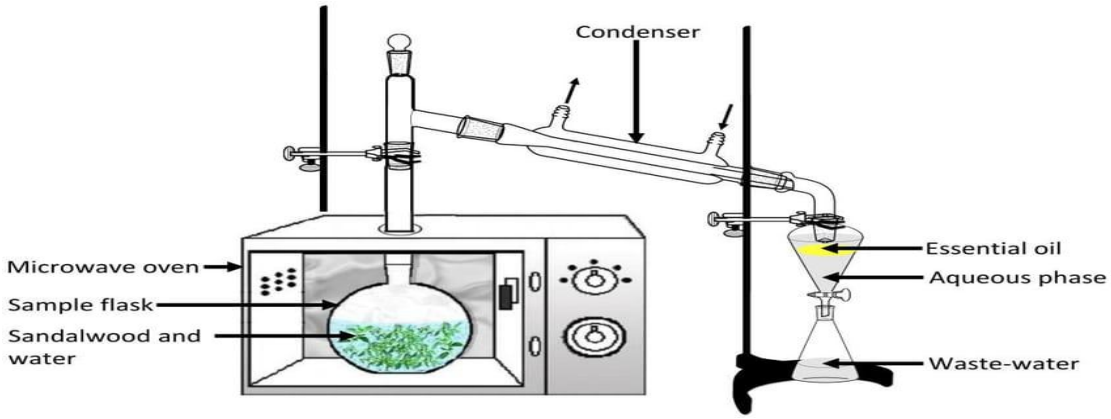

Fig 9. MICROWAVE ASSSISTED EXTRACTION

Ultrasound Assisted Extraction (UAE)

Unlike microwave (electromagnetic wave), ultrasound waves are sound waves with high frequency beyond human hearing capability. Considering healthy young adults, the upper limit of sound frequency for humans is 20 kHz. Hence, ultrasound devices for extraction work in the range of 20 kHz to 2 MHz (less than the frequency of MW). Sound waves have significant impact on an elastic medium such as liquid solvents, soft tissue of plant parts, etc. The medium changes in shape when sound waves travel through and returns to its original shape in the absence of sound waves.

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Therefore, high frequency ultrasound waves act as a piston on the medium. In the process, cavitation bubbles are generated inside the medium; upon collapsing, millions of these microscopic bubbles release energy, creating localized high pressure and temperature zones.

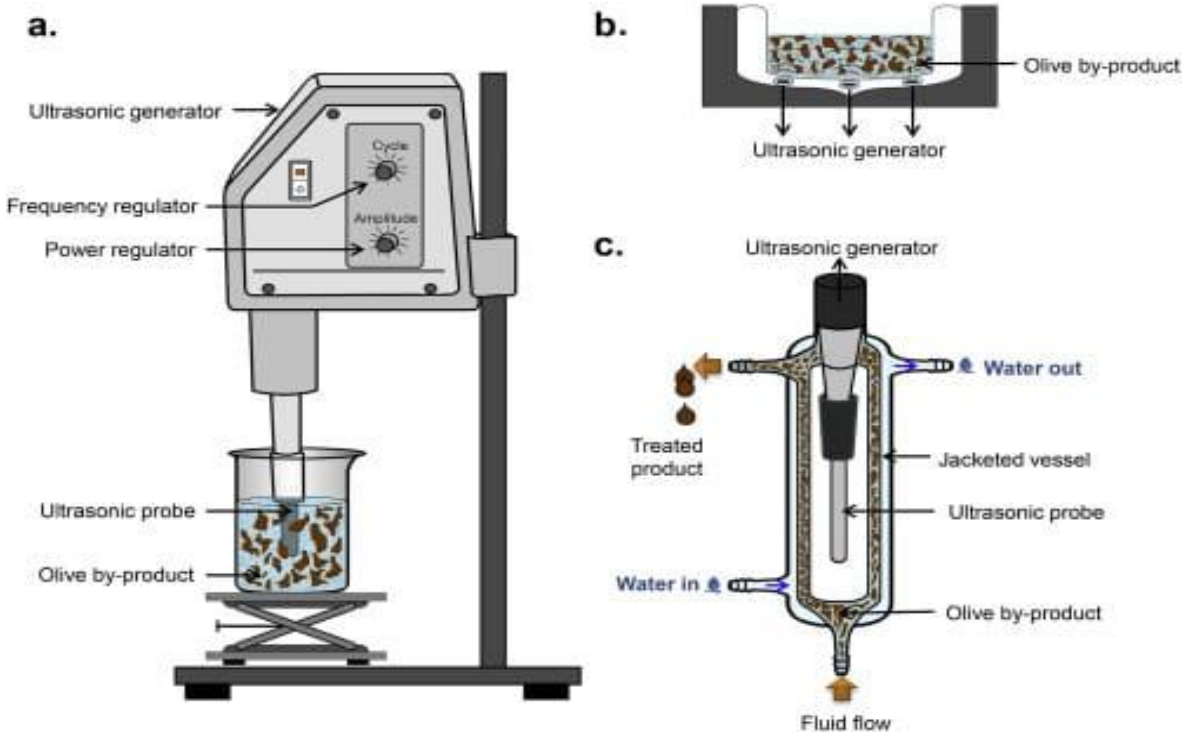

Fig 10. ULTRASOUND ASSISTED EXTRACTION

The mechanism is known as the cavitation effect. This is applied in extraction of phytochemicals as depicted. The mechanism can be described in 4 steps. In the first step, cavitation bubbles are generated near the surface of the plant matrix in the application of ultrasound waves. In the second step, bubbles are collapsed, releasing a microjet with pressure and temperature toward the surface. In the third step, the matrix surface is ruptured and a direct contact is established between active ingredients inside the cell and the outside solvent. Finally, active components are released and transported to the solvent. In this way, ultrasound waves enhance the mass transfer. Because this mechanism works on any liquid medium, use of UAE is not restricted by the selection of solvents, unlike MAE. It is a novel and unique way to agitate a solid/solvent mixture where mechanical agitation is not possible or not safe due to corrosion. Generally, an ultrasound generator probe is immersed in the solid/solvent mixture. UAE presents multiple advantages; it is a green efficient way to increase mass transfer, it requires less solvent, and it is compatible with any solvent (however, the solvents' affinity for the active components should be considered). All these factors reduce the cost of extraction using ultrasound.

The applications of UAE are varied, including extractions of essential oils to polyphenols. Influences of extraction time, temperature, solvent concentration, solid to liquid ratio, particle size, ultrasound power and frequency were investigated in several studies that extracted polyphenols from kinnow peel , mango peel, Clin canthus nutans, hasemi rice bran , Doum Hyphaene the baical. Mart. (Arecaceae) fruit, etc. A combined method of ultrasound assisted and micro-wave assisted extractions was adopted for polyphenol Extraction in distilled water with optimum conditions of Solvent to material ratio of 55 ml/g, microwave power of 90 W and 75 seconds of extraction cycle . Another Combined method included UAE followed by supercriti-Cal CO2 To extract polyphenols from grape marc. Researchers showed that UAE took much less time (just 1 hour) than the traditional maceration technique (72 hour) to extract polyphenols from Punica granatum Fruits at 30C with 50% ethanol and 1:20 (g/mL) solid to Liquid ratio . Similar results were found with citrus Peel, extracting several phenolic compounds simultaneously . The influence of the type of solvent and Extraction

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method on polyphenols from Orthosiphon stamineus leaves were investigated. In this study, UAE With 90 minutes extraction and maceration with 240 min-Utes extraction were compared using various solvents Such as methanol, isopropyl alcohol, water, 50% methanol, 70% methanol, 50% isopropyl alcohol, and 70% Isopropyl alcohol.

It was proven that aqueous alcohol (>40%) was more effective than pure solvent. The yield Of polyphenols was reduced for extraction times longer Than 90 minutes due to thermal degradation. The response surface method is one of the common Techniques to optimize the extraction process. Various Optimum conditions were reported for extracting poly- Phenols or phenolic compounds from olive pomace (80%Methanol, solvent to material ratio of 40 and 30 minutes of Extraction time). thymus serphyllum (30% ethanol, Solvent to material ratio of 30 and particle size of 0.3 mm and 3 minutes of extraction time). To develop the response surface, various designs of Experiments such as factorial , central composite , and face centered cube were utilized for optimization of polyphenol extraction from spruce wood bark (70% ethanol and 60 minutes of extraction time at 54C) maize filaments (61.08% ethanol, solvent to material Ratio of 26.83 ml/gm and ultrasonic power of 520.01 W), and Aronia melanocarpus by-products from a filter-tea Factory (50% ethanol, ultrasonic power of 206.64 W and 80.1 minutes of extraction time at 70C) [21,22]

Enzyme Assisted Extraction (EAE)

Enzyme assisted extraction (EAE) is another new green Technique where the addition of enzymes in the extraction medium enhances the recovery. The main purpose of The enzyme in extraction from plant materials is to break or soften the cell walls. This can give the active ingredients access to the solvent. Bound or dispersed Phytochemicals inside cells or on cell walls are difficult to Extract using normal solvent extraction. Enzymes help to release those components in a unique way by digesting are surrounding materials. Therefore, EAE is very effective for the extraction of Polyphenols that are bound with proteins or carbohydrates inside the cells or on the cell walls. Enzymes such As cellulose, pectinase, protease, etc. Are commonly used. The particle size and the ratio of enzyme and sample are the key controlling factors to maximize the polyphenol Yield. The main step of the extraction method is enzymatic hydrolysis, where a mixture of sample, enzyme and Solvent (water in most cases) is incubated at low temperature, around 35–50C, with adjusted PH. The Enzyme works best in an acidic medium. The hydrolysis Is stopped by deactivating enzymes at an elevated temperature of 80–90C.The main advantage of EAE is that is an environmentally Friendly process. Water is widely used instead of organic Solvents or chemicals. The low temperature extraction Also prevents any degradation and the process requires Less energy.

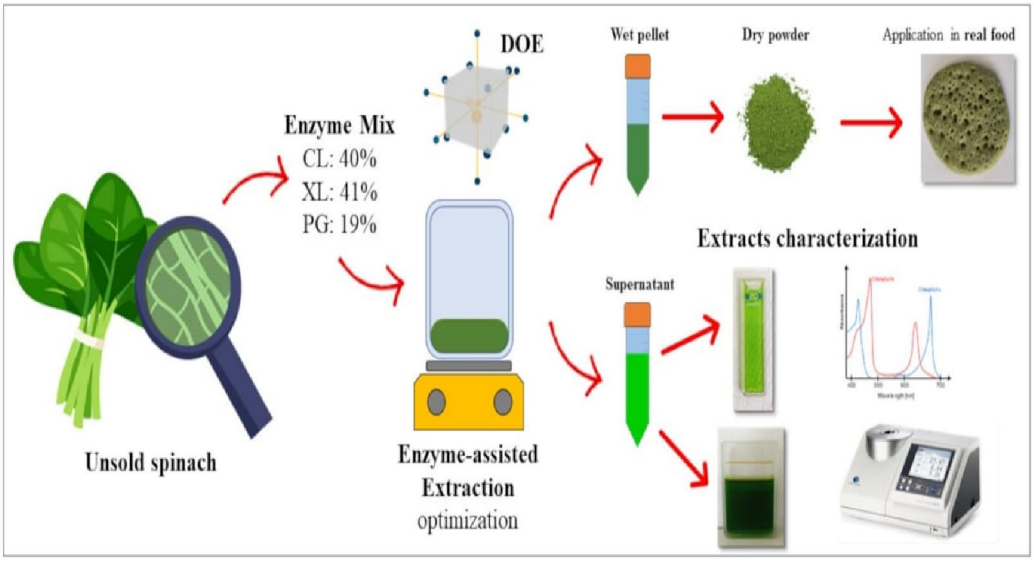

Fig11. ENZYME ASSISTED EXTRACTION

The main drawback of EAE is its prolonged Extraction time, which varies from 1 hour to 48 hours. Extractant is separated using filtration or centrifugation. The significant parameters for the extraction of antioxidant phenolics from

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black currant pomace were studied; These include: enzyme type (Grindamyl pectinase and Macer8 FJ), time of hydrolysis (0–8 hour), hydrolysis Temperature (20–50 C), particle size (250–500 mm or 500–1000 mm), substrate condition (with or without Seeds), and type of solvent (methanol or water). In Another study, antioxidant phenolics were recovered at 40C in an acetate buffer (pH 3.5) for 48 hour using Commercial enzymes such as Celluclast 1.5 L, Pectinex Ultra and Novoferm from grape wastes. The maxi-Mum amount was obtained at a temperature of 50C using the enzyme

Celluzyme MX, with an enzyme to peel ratio Of 1.5% (w/w). Likewise, 35% more phenolics were Recovered from raspberry solid wastes using enzymes Grindamyl and Maxoliva with 25% (V/V) aqueous ethanol In 18 hour of extraction at 50 C . Enzyme-assisted Extraction with a ternary mixture of pectin lytic, cellulose- Lytic and hemicellulolytic enzymes enhanced the recov-Ery of polyphenols from rose petals by 9–25% from . Other applications of enzymeassisted extraction include Recovery of polyphenols from old tealeaves and pomegranate peel.[22]

Pulsed Electric Field Extraction (PEF)

Pulse electric field assisted extraction (PEF) is an emerging non-thermal green technology for extraction of phy- to chemicals from plant's parts such as fruits, roots, leaves, etc. The temperature change of the solvent is very low during the extraction. In this method, electric pulses of moderate to high intensity are passed through samples placed between two electrodes. The method works based on the principle of rupturing cell membranes subjected to adequate external electric field. This technique is primarily used in microbiology to increase the permeability of cell membranes to deliver chemicals, drugs or DNA inside the cell. The method to enhance permeability of cell membranes by applying external electrical force is known as electro permeabilization or electroporation. Electric field strength (E = V/d), pulse duration and number of pulses are the important factors for efficient electroporation. According to Bazhal et al. [49], electric field intensities in extraction from food materials are divided as follows: low intensity (E 100–200 V/cm), moderate intensity (E = 300–1500 V/cm) and high intensity (E > 1500 V/cm). In general, short pulses (micro or milli-seconds) of high electric intensity are the most effective way to extract phytochemicals in PEF. Unlike applications of electroporation in microbiology where drugs are delivered from outside to the inside of cells, active ingredients inside cells are released to external solvent in PEF extraction. Depending on the intensity of the electric field, the damage to the membrane is either reversible, or it is permanent and hence irreversible. In the case of temporary damage, a live cell heals itself after a short duration after withdrawing the electric field.

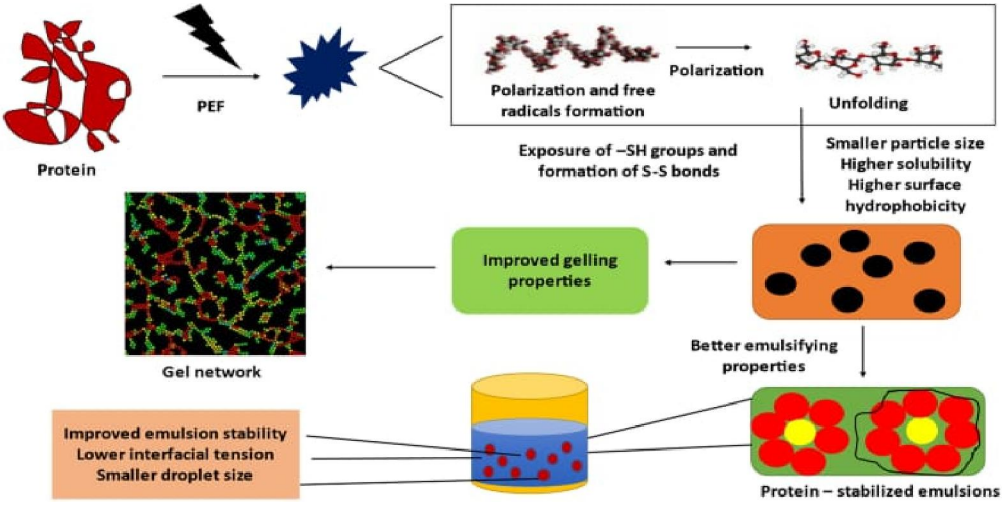

Fig 12 PULSED ELECTRIC FLUIED EXTRACTION

The working principle of electroporation is shown in Figure 2. Each type of cell has an electric endurance limit to protect the membrane, that is, cell membranes can withstand certain amount of electric field without any significant damage. The minimum threshold value is the critical electric field (Ec) for the particular type of cells. Damage to the

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cell membrane can occur when the electric field is higher than the critical level . The severity of the damage depends on the intensity of the electric field. Damage is reversible (temporary) under low to moderate intensity (not much higher than the

On the other hand, the application of a high intensity electric field causes irreversible (permanent) damage to the membrane. Consequently, active ingredients inside the cell are exposed and extracted directly by the solvent. Advantages of PEF include its non-thermal nature, selective extraction, shorter extraction time, and clean process. Non-thermal methods are particularly useful for thermally sensitive materials. Controlling the operating parameters of PEF is simple. Operating parameters (i.e. electric field strength, pulse duration and number of Pulses, the size of pores on the membrane) can be Manipulated in such a way that only the desired components can be released, keeping other components inside the cell. Under optimum conditions, the recovery factor is Significantly increased with the minimum extraction time [51]. Yields of polyphenols from apple mash were increased by Applying an electric field strength of 450 V/cm for 10 milliseconds of specific energy less than 3 kJ/kg[49]. The amount of polyphenols recovered from grape Skin were increased by PEF of 5 pulses per second with 30 (at 24C) to 60 kV (35C) [52]. Researchers proved that PEF was necessary to extract some polyphenols from Grape pomace and peel, which were not possible to extract by other treatments [53]. Various factors such as pulse Duration (0.05 seconds), number of pulses , pause Between pulses (PBP, 0.5–3 seconds) and pulse strength (0.4–0.9 kV/cm) were examined to maximize recovery of Polyphenols from fresh tealeaves [54,55]. It was established, based on this study, that the longer pulses were More effective and maximum recovery was obtained with 0.9 kV/cm for 0.5 seconds of PBP and 1.1 kV/cm for 3 seconds of PBP. PEF was applied to extract phenolics. [22,23]

Advantages of Green Extraction:-

1.Environmentally friendly:Uses non-toxic, biodegradable, and renewable solvents (like water, ethanol, or supercritical CO_2).

2. Energy-efficient:Techniques like microwave, ultrasound, or pressurized liquid extraction use less energy and time.

3. Better safety:Reduced use of hazardous chemicals makes the process safer for workers and the environment.

4. High extraction efficiency:Modern green techniques can give higher yields and better quality extracts.

5. Preservation of bioactive compounds:Gentle extraction conditions help retain sensitive nutrients, flavors, and aromas.

6. Reduced waste generation:Produces less chemical and solvent waste compared to traditional extraction.

7. Cost-effective in the long run:Though initial setup may be costly, the operational cost is lower due to less solvent and energy use.[23,24]

Disadvantages of Green Extraction

1. High initial equipment cost: Advanced technologies (like supercritical fluid or microwave extractors) are expensive to install.

2. Technical expertise required: Skilled operators and specific training are needed to handle modern extraction systems.

3. Limited solvent choices: Only a few green solvents are suitable for all kinds of plant materials or compounds.

4. Not always suitable for all compounds: Some sensitive or non-polar compounds may not extract well with eco-friendly solvents.

5. Scaling-up challenges: Industrial-scale green extraction may face technical and cost-related limitations.[23,24]

II. LITERATURE SURVEY

Safdar MN et 2016: Authors investigated extractions of polyphenols from the peel of kinnow by traditional methods, namely maceration and advanced techniques such as ultrasound-assisted extraction (UAE) method. UAE with the ethanol at 80% concentration yielded the highest recovery. UAE was proved to be a more efficient technique than maceration.

Lohani UC 2016: The total phenolic content in sorghum flour and apple pomace was enhanced by pulsed electric field to successfully release the bound phenolics after fermenting. Authors proved that the mild intensity pulsed

Jovanovic A 2017 : Ultrasound-assisted extraction of polyphenols from Thymus serpyllum was optimized using 30% ethanol as an extraction medium; amplitude was set to 65% and influential factors were considered, such as extraction

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time, solid to solvent ratio and particle size. The combination of extraction time of 3 minutes, solid to solvent ratio of 1:30 and particle size of 0.3mn

Mushtaq M 2017: Second order polynomial equations with rotatable central composite design of experiments were developed to predict and optimize the yield of polyphenols from pomegranate peel using enzyme. The effect of enzyme concentration, temperature, incubation time and pH were investigated. Increase in enzyme concentration enhanced extract yield and total phenols content

Vergara-Salinas 2016: In this book chapter, authors discussed a wide range of applications of
pressurized hot water extractions, a green technology. Polar to slightly non-polar phytochemicals can be dissolved in water by controlling the extraction temperature.

Taylor & Francis Group 2016: Authors discussed the applications of supercritical fluid extraction, mainly supercritical carbon dioxide for extraction of polyphenols from different available sources, such as herbs, flora, vegetables, fruits, and flora industrial wastes.

Sookwang p 2017:Authors reviewed studies regarding the extraction of rice bran oil (RBO) using various techniques such as solvent extraction using hexane and supercritical carbon dioxide. The health benefits of rice bran oil are also discussed. Advantages of such supercritical carbon dioxide oil soluble, non-toxic, cost-effective and easy separation are explained.

Aim : It aims to reduce the environmental and health impact of traditional extraction method by using less energy, safer solvent, and renewable resources.

Objective

• To study the extraction, composition, and pharmacological benefits of green coffee beans and evaluate their potential use as a natural antioxidant and weight management agent.[25]
• To evaluate the phytochemical components, especially chlorogenic acids, present in green coffee beans
• To assess the impact of processing and extraction methods on the quality and yield of bioactive compounds
• To explore the potential therapeutic applications of green coffee bean extract in human health.
• To analyze the stability and bioavailability of chlorogenic acid and related compounds.

Drug Profile: Green Coffee Bean

Fig.10 GREEN COFFEE BEANS

Drug Name:
Green Coffee Beans.
Synonyms :
• Raw Coffee Beans
• Unroasted Coffee Beans
• Coffee Seed
• Coffea arabica seeds (for Arabica variety)
• Coffea canephora seeds / Robusta seeds (for Robusta variety)

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Biological Source:
The biological source of coffee is its dried ripe seed.
The botanical name of coffee is Coffea Arabica Linn.
It belongs to the Rubiaceae family.
It is deprived of most of the seed coat.
Family : Rubiaceae
Taste :- They taste like a mix between herbal tea and coffee. Green coffee beans can also be referred to as raw coffee beans or unroasted coffee beans.
Colour :- Green coffee beans are obtained found in red colour, yellow and green colour

Extraction:

Green coffee beans are extracted using solvents such as water, ethanol, or methanol. Sometimes advanced green extraction methods (like ultrasound or pressurized liquid extraction) are used to obtain chlorogenic acid-rich extract.[25]

Medical Uses :

Weight Management, Antioxidant Activity, Blood Sugar Control, Blood Pressure Regulation , Liver Protection, Cardiovascular Health, Anit-inflammatory properties, Energy and Mental Alertness, Anti-aging Benefits. [25]

Dosage Form:

Capsules, tablets, and powder form (dietary supplements).

Side Effects:

• When taken by mouth: Green coffee is possibly safe when used appropriately. Green coffee extracts taken in doses up to 1000 mg daily have been used safely for up to 12 weeks. A specific green coffee extract has been used safely in doses up to 200 mg five times daily for up to 12 weeks.Green coffee contains caffeine, but in lower amounts than in regular coffee. One cup of green coffee contains about 25-50% of the amount of caffeine found in a one cup of regular coffee. Consuming large amounts of green coffee might cause caffeine-related side effects, including headache, anxiety, agitation, and irregular heartbeat.[43,44,45]
• sincreased heart rate: Green coffee contains caffeine, which can increase heart rate and cause palpitations, especially in people sensitive to caffeine.
• Digestive issues: Excessive consumption of green coffee may lead to stomach upset, nausea, or diarrhoea due to its high acidity.
• Insomnia: The caffeine content in green coffee can interfere with sleep patterns if consumed in large amounts or late in the day.
• Allergic reactions: Some individuals may experience allergic reactions like skin rashes, itching, or swelling after consuming green coffee.
• Bone health concerns: Excessive intake of green coffee may lead to calcium depletion in the body, potentially affecting bone health over time.
• Iron absorption: The inclusion of green coffee along with iron-rich foods might hinder the absorption of iron into the body's system. People suffering from iron deficiency anaemia are recommended to not choose green coffee.
• Increased anxiety: People prone to anxiety disorders may experience heightened symptoms due to the stimulant effect of caffeine in green coffee.[41,42]

Benefits of Green Coffee

• Helps in losing weight Green coffee has been recognised for its ability to help people lose weight. This is mostly due to the presence of chlorogenic acid, a substance that may aid in the reduction of body fat and improved metabolism. Chlorogenic acid is thought to function by decreasing glucose absorption while raising the rate at which the body burns calories.[36,37]
• Boosts metabolism Green coffee beans contain chlorogenic acid (CGA), a substance that may enhance metabolism. CGA is believed to work by restricting glucose absorption while raising the rate at which the body burns calories. "This

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can make people feel more energised and may aid in weight loss. Also, CGA may help manage blood sugar levels, promoting a healthy metabolism and overall well-being," explains the expert.[33,34]

• Regulates blood sugar Green coffee beans contain chlorogenic acid (CGA), which may help manage blood sugar levels. CGA is thought to operate by limiting the absorption of glucose from the intestines, resulting in a delayed rise in blood sugar levels after eating. This can be especially advantageous for people who already have diabetes or are at risk of getting it. CGA may help boost insulin sensitivity, as per a study published in the Nutrition Journal, allowing the body to use insulin more effectively to lower blood sugar levels.[31,32]

• Improves heart health Green coffee beans contain antioxidants, such as chlorogenic acid, which may benefit heart health. These antioxidants can help protect cells from free radical damage, lowering the risk of cardiovascular disease, as found in a study published in the Advances in Experimental Medicine and Biology. Chlorogenic acid may help lower blood pressure and cholesterol levels, both of which are crucial for heart health. Green coffee may help to protect the cardiovascular system by lowering oxidative stress and enhancing lipid profiles.[40,41]

• Rich in antioxidants Green coffee beans are rich in antioxidants, primarily chlorogenic acid. "Antioxidants are compounds that help protect cells from damage caused by harmful molecules known as free radicals. Free radicals can contribute to various health problems, including heart disease, cancer, and premature ageing," says the expert. By neutralising free radicals, antioxidants can help maintain overall health and well-being. Green coffee's high antioxidant content makes it a valuable addition to a healthy diet.[35,36]

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Molecular Weight :

Constituents	Molecular formula	Molecular weight (g/mol)
Triacylglycerol	$C_{57}H_{110}O6$	859.4
Sterol	$C_{17}H_{28}O$	248.4
Diterpene	$C_{20}H_{24}O_6$	350.45
α – Tocopherol	$C_{29}H_{50}O_2$	430.7
Chlorogenic	$C_{16}H_{18}O_9$	354.31

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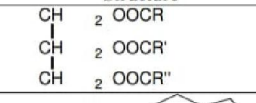
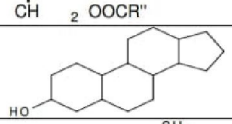
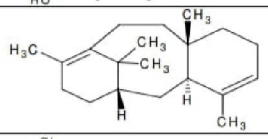
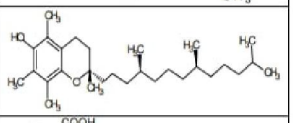
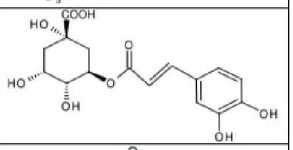
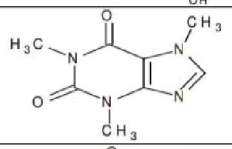
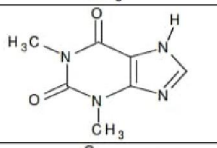
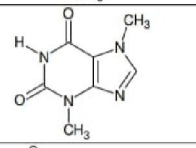
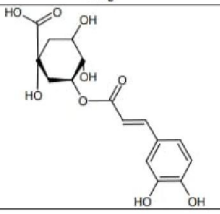
Caffeine	$C_8H_{10}N_4O_2$	194.19
Theophylline	$C_7H_8N_4O_2$	180.16
Theobromine	$C_7H_8N_4O_2$	180.16
3 – CQA (Caffeoylquinic Acid)	$C_{16}H_{18}O_9$	354.31

Chemical Constituents:

Constituent	Use	Structure
Triacylglycerol	These are the major dietary fat in the body. They are basically stored in the adipose tissues. These acts as the main energy source of the body.	
Sterol	These agents help in decreasing the cholesterol levels and prevent heart diseases.	
Diterpene	These are bitter tasting terpenoids that have shown activities to treat hypertension and respiratory tract disorders. Some analogues have also promising effect on tumour inhibition.	
α – Tocopherol	Also known as Vitamin E (which dissolves fats), this constituent has shown efficacy towards treatment of various nervous disorders like Alzheimer's Disorder, Parkinson's Disorder, Huntington's Chorea etc. It can also be used in the treatment of Vitamin E deficiency syndrome.	
Chlorogenic Acid	One of the new constituent that has been extracted has the action towards treating hypertension, inflammation and possibly can treat few respiratory allergies.	
Caffeine	This is one of the major constituent of green coffee. It is mostly used to improve the mental alertness. But the use of caffeine is not limited till here. Caffeine has promising effects in treating pain and headache (migraine) when used with other agents. Other than this caffeine helps in treatment of disorders like asthma, diabetes etc.	
Theophylline	This agent helps in the treatment of various respiratory disorders like asthma & COPD (Bronchitis, Emphysema).	
Theobromine	Theobromine has proven its efficacy in reducing blood pressure & strengthening the tooth enamel. As it belongs to the same class of caffeine, it also has a mild stimulant activity.	
3 – CQA (Caffeoylquinic Acid)	Same as Chlorogenic Acid	

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Pharmacological Actions:

Antioxidant Property :

the antioxidant property of green coffee bean extract by measuring radical scavenging capacity (RSC) by DPPH method. This method revealed the elimination of free radicals. The antioxidant property found in green coffee extract due to chlorogenic acids and caffeine identified through HPLC (Patriche et al., 2015). In other study Nosari et al. revealed the antioxidant property of green coffee oil which is prepared through cold pressing method of unroasted coffee beans.[26]

Anti-Obesity Activity :

Choi et al. studied that mice fed with green coffee bean extract decreased the body fat mass and suppressed the high dietary fat induced obesity. The mice fed with green coffee beans extract at 50, 100, and 200 mg/kg with high fat diet which showed decrease in weight gain, liver weight and also supress the genes of adipogenesis. Tanakal et al. also studied anti-obesity activity of green coffee beans on male Sprague-Dawley rats fed with normal diet which showed that green coffee bean extract decreased the fatty acid synthetic enzyme in liver and fatty acid oxidative enzyme increased in hepatic mitochondrial[27]

Anti-Hypertensive Activity

Suzuki et al. studied the anti-hypertensive activity of water-soluble green coffee bean extract on spontaneously hypertensive rats. They found that 5-CQA decrease the blood pressure and reduction in blood pressure occurred due to ferulic acid (50mg/kg P.O) which is a metabolite of 5-CQA. After the injection of atropine sulphate (5mg/kg SC) the depressor effect of FA (50 mg/kg, P.O) was attenuated which suggested that the hypotensive effect of FA in SHR might be mediated via the muscarinic acetylcholine receptors.[26,27]

Anti-Inflammatory Activity :

Hwang et al. studied the anti-inflammatory activity in lipopolysaccharide stimulated RAW264.7 murine cells. In this research they found that due to chlorogenic acid production of NO, COX-2, iNOS is inhibited without the cell toxicity. Proinflammatory cytokines (IL-1β &TNF-α) and other inflammatory cells are also inhibited by chlorogenic acid[27,28]

Antidiabetic Activity

Song et al. studied that antiobesity and antidiabetic activity in Male C57BL/6N mice (N = 48) of green coffee extract by attenuate the obesity and insulin resistance. Mice were divided in six dietary groups each group ingested with chow diet, HFD, HFD-supplemented with 0.1%, 0.3% and 0.9% decaffeinated green

IV. CONCLUSION

Extraction is one of the oldest and most essential processes used across pharmaceutical, food, cosmetic, and chemical industries to isolate bioactive compounds from natural sources. Traditional extraction methods such as infusion, decoction, maceration, percolation, reflux, and Soxhlet extraction have been used for centuries because of their simplicity and effectiveness. However, these methods often require large amounts of solvent, long extraction times, and high energy input, which increases cost and environmental impact. With growing demand for sustainable production, green extraction technologies have become increasingly important. Modern techniques such as Pressurized Liquid Extraction (PLE), Supercritical Fluid Extraction (SFE), Microwave-Assisted Extraction (MAE), Ultrasound-Assisted Extraction (UAE), Enzyme-Assisted Extraction (EAE), and Pulsed Electric Field (PEF) offer significant advantages over conventional methods. These advanced techniques reduce solvent usage, shorten extraction time, enhance extraction yield, and minimize thermal degradation of sensitive bioactive compounds like polyphenols.

Green extraction supports environmental protection by using renewable resources, safer solvents, and energy-efficient technologies. Moreover, process intensification—through combined methods such as microwave with ultrasound or supercritical fluid with ultrafiltration—further improves extraction performance and lowers production cost. Overall, the shift from traditional to green extraction methods aligns with modern industrial needs for efficiency, sustainability, and high-quality natural products. These technologies ensure better recovery of valuable bioactive compounds from plants, making extraction processes more economical, environmentally responsible, and technologically advanced. Green Coffee has various health benefits. The article focuses on the few of those which includes anticancer,

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antifungal, anti-inflammatory, antihypertensive activities etc. Green Coffee is used world-wide both as stimulant and for medicinal purposes.

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