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Feasibility and sustainability evaluation of customary extraction methods of ginger bioactive compounds – A Review

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***Abstract— Zingiber officinale* Roscoe (ginger) contains a high concentration of bioactive phytochemicals, which are desirable because of their important properties. The choice of suitable extraction methods is essential for practical applications of the bioactive compounds as it determine the properties of the extractable compounds. Several customary methods have been widely used by the scientists to extract the bioactive compounds of ginger. In this paper, a critical analysis of relative advantages and disadvantages was carried out for 6 types of extraction processes namely hydrodistillation, maceration, Soxhlet extraction, solvent-solvent extraction, decoction and infusion. This review discusses the different conventional methods, followed by a discussion of the importance of advancing the extraction techniques considering the environmental benefit and efficiency of the process. The application of innovative developed technologies is deemed environmentally beneficial, more efficient in terms of extraction yield and eliminate the issues connected with traditional extraction processes. The advanced extraction techniques discussed in this paper include microwave-assisted extraction, ultrasound-assisted extraction, enzyme-assisted extraction and supercritical fluid extraction. The technical data that are available in this review paper are beneficial for the scientist and the industry who work with ginger extraction. A clear direction of future studies is offered in this paper in which researchers must investigate the possibility of applying the advanced extraction method for retrieving bioactive compounds from ginger as well as study degrading effects of each new technique on phytochemical compounds and their metabolites intermediates.**

Keywords*—bioactive compounds, extraction, ginger, *Zingiber

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I. INTRODUCTION

The study of extraction of bioactive compounds from various plants as well as the application of the bioactive compounds in foods are still emerging topics nowadays [1-4]. As such, plant extract is used to prevent or cure diseases in therapeutic practices, to give a specific flavor or to prolong the shelf-life of foods [5]. Extraction, which aims at desorbing compounds of interest from the plant matrix's active spots, is essential as it substantially affects the effectiveness and selectivity of the extractable compounds [6].

Zingiber officinale (ginger) is one of the most important tropical Zingiberaceae plants due to its nutritional and therapeutic properties. This species is of the most commonly used in traditional cooking as a flavoring agent, including for sauces and soups in Asian cuisine as well as in traditional medicine as a treatment for generations. Ginger is a tropical herbaceous perennial plant up to 90 cm high, whose evergreen leaves grow in sunny and humid areas [7]. The rhizome of this plant consisting branched globose tubercles is the most used part in therapeutics (**Figure. 1**). It has about 10 cm in length, up to 2 cm in width and 1,5 cm in thickness with juicy pale-yellow flesh and spicy flavor [8]. Of Indian origin, it first crossed the

Mediterranean with the Phoenicians and reached Europe under the Roman Empire from the 1st century. Ginger is currently grown in many tropical and subtropical countries around the world [9-11]. Nowadays, ginger is widely used in the food industry, especially in gingerbread and biscuits, jams and spice mixes.

Secondary metabolites of ginger, notably shagaol and gingerol, provides various biological properties, including anti-inflammatory, antibacterial, anticancer, and antioxidant actions. Furthermore, shagaol and gingerol content in ginger demonstrates several biological effects and numerous pharmacological and clinical properties including antimicrobial [12], antiparasitic and antiviral properties, anticancer, anti-inflammatory, antiemetic, antidiabetic and antioxidant properties [13]. Thus, it is reasonable that this plant has a history of medicinal use in traditional systems of medicine and also has been a condiment and medicinal plant for over 3000 years. Over the last decades, this plant has been the subject of significant pharmacological and clinical studies [8]. Its specific constituents also significantly influence the taste, aroma and healing properties of ginger. The presence of shogaol, paradol and zingerone causes "pseudo-heat" when consuming ginger. The intensity of this flavor depends on the origin of the variant and the condition of the rhizomes (fresh or dried). It was reported that drying caused in one hand a reduction of gingerol content, and in the other hand a rise of shogaol concentration [14].

Several other compounds of ginger have been demonstrated by numerous researchers including starch, fats, essential oil and resin [15]. Ginger also contains some flavonoids and phenolic acids such as quercetin, rutin, morine fisetin, ferulic acid, gallic acid and vanillic acid. It was reported that 63 compounds have successfully been identified in fresh ginger and 115 compounds identified in dry ginger. About 45 of these compounds are in common both in fresh and dry ginger [16,17]. Knowledge on the phytochemical composition of ginger encourages researchers to find the most effective method for extracting the targeted bioactive compounds.

There are some established methods to get bioactive compounds from ginger including hydrodistillation [18,19], maceration [20], Soxhlet [21], solvent extraction [22] and reflux [23]. The afore-mentioned techniques are considered as traditional or conventional extraction methods. Even though the traditional techniques are still used due to its simplicity and cheapness, these methods normally have some limitations including time consuming and tedious as well as require large amounts of environmentally unfriendly organic solvent with low extraction yields.

In this paper, therefore, a critical analysis of relative advantages and disadvantages was carried out for these customary extraction processes followed by a discussion of the importance of advancing the extraction techniques considering the environmental benefit and efficiency of the process. At the end, a clear recommendation for future studies is offered.

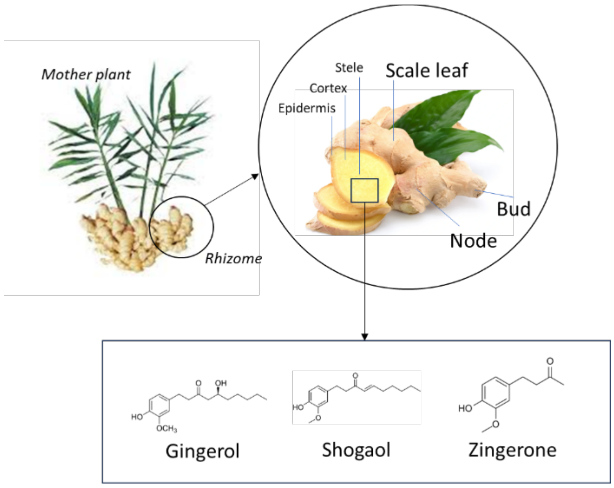

Fig. 1. Illustration of ginger rhizome and its dominant bioactive compounds

II. METHODS

Three main databases were used to collect the information including Google Scholar, Scopus and Web of Science by using keywords of "ginger" and "extraction". No specific duration was used for collecting the information. Additional keywords related to the extraction technique were also used, including "hydrodistillation", "maceration", "Soxhlet extraction", "solvent-solvent Extraction", "decoction" and "infusion"

III. CUSTOMARY EXTRACTION METHODS

A. Hydrodistillation

Hydrodistillation is a method for extracting bioactive chemicals and essential oils from plants that has been used for centuries. It does not require the use of organic solvents and can be done prior to the dehydration of plant materials [24]. Previous research focusing on the influence of the treatment parameters using the hydrodistillation technique on the yield and 6-gingerol content of Zingiber officinale extract has been successfully conducted [25]. It was reported that the optimal operating condition were as follows: extraction time of 90 min, ratio (solid-solvent) of 1:20 and temperature of sample drying at 50°C. The optimal parameter was identified on the basis of its maximum yield (7.02%w/w) with 6-gingerol content of the extract of 35.34 mg/L.. The extraction of ginger using the hydrodistillation technique was also carried out to examine the phytochemical profile and antibacterial activity of the extract, and furthermore this technique was then compared to the supercritical CO_2 extraction technique [26]. It was remarkable that the chemical profiles measured by gas chromatography/mass spectroscopy (GC/MS) were identical for both procedures, but the amounts of extracted chemicals differed. It was shown that the greatest yield by hydrrodistillation was 1.79 %, while the maximum yield by supercritical CO_2 was 2.62 %. In supercritical CO2, pressure and temperature have a positive effect on extraction efficiency. α-curcumene, gerarial, and camphene were the most common compounds found in the hydrodistillation extracts, whereas a-zingiberene, β-sesquiphellandrene, a-curcumene, a-farnesene, and β-bisabolene were found in the supercritical CO_2 extract. Due to the difference in the phytochemical composition, the essential oil obtained by hydrodistillation had a weaker ability to inhibit *Pseudomonas aeroginosa* bacteria than the supercritical extract.

Recently, it was discovered that enzymatic pre-treatment before hydrodistillation, using crude multi-enzymatic extracts (CME) consisting endoglycanases, xylanases and amyloglycosidases promoted degradation of the cell wall and raised the yield of ginger essential oil by 47.95%, particularly in the operational condition of 40°C for 130 min [27]. The predominant compound of the essential oil was α-zingibène (25,20%). The use of CME in the extraction of ginger essential oil eliminated the requirement for drying in this type of plant material as well as cuts both the energy consumption of the process and the volatilization of the chemical components.

Hydrodistillation is the most currently used technique for extracting essential oils from plants up till now. Extraction by this method requires no organic solvents, and thus this technique is relatively cheap, simple, environmentally friendly and produces high quality oil [28]. Hydrodistillation is appropriate to prevent damage. Charring and degradation could be avoided because the plant matrix is not directly heated. In the hydrodistillation, it is always important not to add too much water, as this can cause an increase in energy consumption and trigger a hydrolytic effect which decreases the yield and quality of the oil [29,30]. However, it is noteworthy that the fundamental issue with hydrodistillation is that the slow extraction process, which can lead to the destruction of heat-sensitive chemicals and, as a result, lower product efficiency and the quality of the oil (unpleasant taste) [31]. Furthermore, complete extraction with this technique is not possible. This approach also has disadvantages such as high energy and water consumption, high waste as well as high cost [20, 32].

B. Maceration

For a long time, maceration was a popular artisanal approach for making tonics that was also very inexpensive. Furthermore, this approach was used to extract active compounds from plant-based materials [33]. In general, the maceration process is carried out in a closed container with the suitable solvent, and then the solvent is removed using filtration, and finally the solid residue from the extraction process is squeezed to produce the best amount of occluded solution. To remove unwanted components, the squeezed liquid and filtered solvent are combined together and filtered. Extraction is usually aided by frequent agitation during the maceration in two ways: (1) it improves diffusion, and (2) it separates the concentrated solution from the sample's surface by introducing a new solvent to the menstruum to increase extraction yield [34].

It was found that the total phenolic compounds and flavonoid in the fresh ginger extract was 22% higher than that in the dry root extract when extracted using maceration [20]. The root cell walls of many plants are impregnated with hydrophobic substances, which causes the microspores and narrow capillaries in the cell walls to be blocked when they dry. As a result, the diffusion between the solvent and the plant material is hindered (or non-existent), which disrupts the extraction process and duration of the dry material [35]. Since the dry root maceration method is a static extraction method and does not always provide the maximum extract yield, in the next stage of the research, the researchers extracted fresh ginger in a Soxhlet device. The results showed that the quantitative content of total polyphenol and total flavonoid after 5 h of extraction in the Soxhlet device was the same as that of fresh roots after 1 month of immersion. The advantage of this extraction method is to shorten the extraction time and achieve a high release of active substances in a short time. This study further shows that sonication followed by maceration at room temperature (20 C°) is the best method for extracting active compounds from ginger rhizomes, with the highest yields of 2.48% and 1.3% for total phenolic compounds and total flavonoid, respectively. According to Rasul [30], maceration is a simple procedure that requires uncomplicated equipment and saves a lot of energy. It's suitable for some compounds that aren't very soluble in solvent and just need to be in contact with it for a lengthy time. It's also a good strategy for less strong and less expensive medications. Unfortunately, the extraction process takes a long time and can take up to weeks. Extraction of the medication is not complete and the amount of solvent required is higher.

C. Soxhlet Extraction

Soxhlet extraction has been the standard technique for more than a century, and authors have successfully extracted important compounds from different types of plants. Soxhlet extraction is a percolation process for selective extraction of certain compounds in which a fresh solvent runs over a solid matrix. Azwanida [36] explained that Soxhlet extraction process uses solvents at boiling temperatures and low pressure (ambient pressure). The solvent is evaporated, condensed, and collected in the glass chamber of the Soxhlet as part of the extraction process. The solvent automatically falls back into the beaker and evaporates when the solvent level approaches the photoelectric cell line

The impact of a longer Soxhlet extraction time at a moderate temperature on compound degradation was investigated [37]. According to this study, after 8 h of Soxhlet extraction, all bioactive compounds (6-, 8-, 10-gingerols, and 6-shogaol) had the maximum concentration in which 6-gingerol was the highest bioactive ingredient contained in the extract with a yield of 14 mg/g. The greatest extraction yields of 6-, 8-, and 10-gingerols, as well as 6-shogaol, were respectively ,13.948, 7.12, 10.312 and 2.306 mg/g. However, it was notable that the concentration of 6- and 10-gingerols decreased after 8 h of extraction. Interestingly, the concentration of 6-shogaol was increased after 10 h of extraction. This is possibly due to the fact that a dehydration reaction caused transformation of 6-gingerol converted to 6-shogaol. The use of a stagnant film encircling the solid matrix works as a resistance in the Soxhlet extraction, reducing diffusivity and necessitating a longer time to breakdown the chemicals after prolonged exposure to temperature. Extraction and deterioration could happen at the same time. After a long period of extraction at a reasonable temperature, the chemicals may degrade.

A study to investigate how different solvents affect the extraction and to examine how extraction time affects the extraction was previously performed in the extraction of ginger oil using Soxhlet distillation apparatus [38]. The study used four different solvents: methanol, dichloromethane, benzene, and acetone, with extraction times ranging from 4 to 6 h, 8 h, and 10 h. It was shown that at an extraction time of 8 h, methanol produced the maximum yield of ginger oil, accounting for 27.33% of the total yield.

In another study, a Soxhlet extraction technique was used with a water-based extraction solution containing 50% ethanol to obtain ginger extract. The chemical composition of ginger was investigated using gas chromatography/mass spectroscopy (GC/MS). Triterpene acids are the bioactive compounds found in the extracts. Interestingly, the extract was effective in inhibiting the growth of harmful bacteria such as *Staphylococcus aureus*, *Pseudomonas aeruginosa*, *Escherichia coli*, *Listeria monocytogenes* and *Klebsiella pneumoniae* [39].

In the Soxhlet extraction the sample is repeatedly brought into contact with fresh portions of the solvent, which always remains pure after condensation, this is the most important advantage of this extraction. Furthermore, a filtration is not necessary after the leaching stage [30, 40]. The Soxhlet also allows for the extraction of a significant amount of plant material at once, with the solvent being reused. The type of matrix has no bearing on this procedure. It is a fairly straightforward method, and thus this approach has the advantage of shifting the transfer equilibrium by continually interacting fresh solvent with the solid matrix [30].

Nevertheless, the Soxhlet technique is widely criticized. The most serious disadvantages of this technique are the time and so much organic solvent that is used which raises the extraction cost. Furthermore, the high temperature and long extraction time raise the risk of compound thermal degradation and isomerization [41]. In addition, the long extraction time and the large amount of extraction waste, which is not only expensive to dispose of, but also can cause additional environmental problems [30, 40].

D. Solvent-solvent extraction (SSE)

A plethora articles was found in the literature describing liquid-liquid extraction techniques which is also known as solvent-solvent extraction (SSE). Some of them studied the application of SSE for extracting bioactive compounds from ginger. These methods allow the extraction of compounds having boiling temperatures in the vicinity [42]. In a study carried out by Adaramola and Onigbinde [43], the ginger was extracted using the SSEtechnique, and the results were compared to extraction by the Soxhlet and maceration in terms of yield and antioxidant capacity of the extractable oil. It was found that the oil extracted using the SSE, which did not use heat or reflux, had the lowest quantities of flavonoids, phenolics, and antioxidant activity of all the minerals tested except calcium (Ca) and zinc (Zn). The Soxhlet extraction technique also provides the highest oil yield. The oil obtained by solvent extraction has shown the lowest concentration of specific minerals except zinc (0.63 mg/100g) and calcium (1.08 mg/100g) which were the lowest in the oil accessed by cold maceration. On the other hand, phosphorus was found in the highest quantity in all oils when compared to other minerals. The oil extracted from Soxhlet contained the highest concentrations of flavonoids (118.00 mg QE/g) and phenolics (217.33± 1.53 mg GAE/g), as well as the highest average recovery capacity of DPPH radicals (55.56±0.04%) and average total reduction power (0.88±0.002). Whereas the lowest concentration of flavonoids (44.45± 2.97 mg QE/g), phenolics (112.43± 1.42 mg GAE/g), average DPPH radicals (19.73± 0.01%) and average total reducing power (0.55± 0.030) were obtained for the oil obtained by the solvent extraction technique. The results have demonstrated that the heat and reflux condition involved in the Soxhlet extraction technique enhanced the extraction of minerals and constituents from the ginger as well as the antioxidant capacity of the ginger extract. High efficiency, reliable extrapolation and high flexibility are the main advantages of the SSE technique. In addition, this technique does not require large equipment or reagent investments. It, furthermore, has the possibility of extracting a very wide range of molecules which covers a multitude of applications going beyond the food industrial application including food, pharmaceutical and petrochemical industry [44]. This method, however, has many drawbacks, given the consumption of large volumes of solvents, especially when it comes to multiple extractions. This disadvantage can be minimized by the reduction of the sample taken, which spares the solvent and is made possible by better detection tools available. Indeed, this technique is based on the solvents that are toxic products [45]. Solvent polarity-dependent and time-consuming techniques are also the limitations of this method.

E. Decoction and infusion

Decoction is a good procedure for extracting compounds soluble in water that will not be destroyed by heat [46]. In this technique, the liquid preparation is created by boiling the plants with water. Decoction is commonly used when the plant is fibrous or tough, or when working with roots, barks or plants with water soluble components. In this process, the plant material is broken down into very small pieces, the extract obtained after boiling is cooled and then filtered. Meanwhile, according to Singh [47], infusion is a method of extracting a plant's active components or aromas by dissolving it in a hot liquid and then allowing it to cool. Water, oil and alcohol can be used as the solvent. The basic principle is to infuse the plants by pouring hot water over them. The duration of the infusion can range from 5 to 20 min. Flowers are the components of the plant that are usually used to make an infusion.

Infusion and decoction were the two extraction methods used to extract three varieties of ginger [48]. In three types of ginger, extraction by infusion is as effective as extraction by decoction in terms of antioxidant activity. The total phenolic content of the extract obtained by decoction is higher than that of by infusion. In the decoction, ginger type of *"emprit"* has more antioxidant activity than red ginger. Decoction is suitable for the extraction of thermostable compounds, this procedure does not necessitate the purchase of additional and costly equipment, it is simple to carry out. Regrettably, it is not recommended for the extraction of heat-sensitive components [30]. The advantages and disadvantages of decoction and other customary methods are summarized in **Table 1**.

TABLE I
ADVANTAGES AND DISADVANTAGES OF CUSTOMARY EXTRACTION METHODS

Method	Advantages	Disadvantages
Soxhlet	Simple, no filtration required	High extraction cost (high quantity of solvent), high extraction time, degradation of compounds by high temperature, high quantity of waste
Hydrodistillation	Simple, environmentally friendly (minimal organic solvent), high quality product	Slow process, low efficiency, high waste, not complete extraction
Maceration	Simple, energy efficient	Very slow process, needs a lot of organic solvent
Solvent-solvent extraction	Efficiency, reliable extrapolation, high flexibility, low cost	Technique based on the most toxic solvents, difficulty to extract polar molecules, thermal deterioration of the constituents even if minimal
Decoction and infusion	Simple and fast	not recommended for the extraction of heat-sensitive components

IV. ADVANCED EXTRACTION APPROACHES

The disadvantages of the previous techniques as shown in **Table 1** have been used as starting points for the development of other more modern techniques, while retaining or even improving the advantages of the already existing technique. Higher efficiency than the conventional extractor was achieved by combining auxiliary energies or other efficient method.

A. Microwave-assisted extraction (MAE)

MAE uses microwave energy to assist extraction process. This method has been applied for extracting bioactive compounds from ginger. It was demonstrated that under optimal conditions (528 W microwave power, 26 mL/g liquid/solid ratio, 31s extraction period and 78% ethanol proportion), large amount of 6-gingerol and total polyphenols was successfully extracted (15.35mg/g). The results were better that the properties of the extract obtained by conventional methods such as maceration (7.49± 0.64 mg/g) thermal reflux (12.71 ±0.92 mg/g), agitation (8.32± 0.48 mg/g) and ultrasonic assisted extraction (13.38 ±0.76 mg/g). Microwave extraction has shown to be more efficient than conventional extraction methods, with shorter extraction times and higher overall polyphenol level. In comparison to traditional methods, the MAE method has demonstrated remarkable abilities to trap DPPH and ABTS-+ radicals. The DPPH and ABTS radical scavenging capacity of the extract was presented by order from the highest to lowest as follows: microwave assisted extraction, ultrasound assisted extraction, thermal reflux, agitation and maceration [49].

In another research, the extraction yield of phenolic compounds reached 27.89 ±1.99 mg GAE/g of dry matter in ginger [50]. It was reported by Huyen&Quoc [50], that the ethanol concentration of 60% with the ethanol/material ratio of 48.6/1 (m/v) and the extraction period of 1 min were the optimum microwave assisted extraction conditions. The antioxidant capacity (determined by the color of the 1,10-phenanthroline solution in methanol) is 12.24± 0.04 mmol Fe/g dry matter (DM).

Using the microwave technique, a one-minute exposure to radiation was considered to be sufficient and gave a higher recovery with better quality in a very short period. It was reported that 1 minute extraction using microwave had better performance in polyphenols and 6-gingerol (223.4 mg/g) and release of 1.51% than 10 min of conventional extraction (185.6 mg/g and 1.06% respectively) [51]. Also, a previous study showed that an extraction of the 6-, 8-, and 10-gingerols and the 6-, 8-, and 10-shogaols of ginger with the microwave technique based on a series of ionic liquids microwave-assisted extraction (ILMAE) miscible with water had been successfully performed. This research demonstrates that the highest extraction efficiency was the ILMAE technique (0.716 ±0.051%) compared to the two techniques: methanol marinated extraction (MME) and microwave-based methanol (MMAE) [52].

MAE is a simple, cost-effective, along with various additional benefits including shorter extraction time, reduced solvent consumption and higher compound extraction rates It has been shown by several studies that intermittent radiation improves the recovery of the bioactive components of ginger and the antioxidant activity. Even though the thermal deterioration of the compounds cannot be avoided, but it is minimized in relation to the traditional methods. Microwave extraction is limited also by the higher investment cost compared to conventional extraction. Heat-sensitive components can be degraded by the microwave-generated temperate [53].

Further application of microwave is in assisting hydrodistillation process which is also called microwave-assisted hydrodistillation (MAHD). This is a solvent-free extraction process for obtaining essential oils from a plant. The essential oil from ginger was effectively extracted using this method [54]. The obtained essential oil yield was maximum with an energy ratio of 0.40 kWh/kg. α-Pinene, camphene, zingiberene, α-curcumene, sesquiphellandrene, and β-sélinène were the main isolated components found by GC/MS. The exposure of the sample with high powers had shorter extraction time. The essential oil's total efficiency is proportional to the amount of power used. This is due to the fact that when the aqueous phase is heated, oil distillation is more efficient. Rapid heating increases the volatility of oily fractions while reducing heat transfer to bulk plant material conserves some of the most volatile components of essential oils.

In a different study by Argo et al. [55], the efficiency, density, and refractive index of ginger essential oil were examined using different microwave powers (450, 600, and 800 W) and material-water ratios (w/v) (1:8, 1:9, and 1:10). Microwave power and material-water ratio have a considerable impact on the efficiency, density, and zinc-free content of ginger essential oil. With a material-solvent ratio (w/v) of 1:8, the highest yield was found at 600 W. With a material-water ratio (b/v) of 1:10, the best density of ginger essential oil was produced at 600 W. At 800 W and a material-water ratio (b/v) of 1:8, the best refractive index value of ginger essential oil was attained. The presence of carbon chains and double bonds in the oil, free fatty acid levels, oxidation processes, and temperature affected the refractive index of essential oils. At 600 W and a material-solvent ratio (w/v) of 1:8, the highest quantities of zingiberin in the essential oil were achieved.

A very interesting comparative study was carried out to compare conventional hydrodistillation with MAHD. MAHD has proved to be a method with many advantages over conventional hydrodistillation. MAHD had a shorter extraction time, 24 min compared to 136 min, a higher yield of essential oil, 7.10% versus 5.81%, higher content of oxygenates, 78.89% versus 76.82%, with an electricity consumption of 0.240 kWh compared to 1.360 kWh as well as a CO2 emission of 0.19 kg versus 1.09 kg [56]. Thus, MAHD can be a good alternative technique for the extraction of essential oil, which is a very environmentally friendly and cost-effective approach, and is also economical in terms of time and energy [57]. MAHD, like all technologies, has downsides, such as the quick injection of energy into the total volume of the solvent/sample, resulting in a rapid rise in temperature. The temperature inside plant cells is similar to the temperature outside the cells, which can cause heat-sensitive oils to degrade [58]. Up to now, several studies have shown that microwave irradiation can speed up the extraction of essential oils [59]. Hence, optimizing the conditions for essential oil extraction from ginger is required

Microwave is also commonly coupled with other methods. One of the examples is Microwave hydrodiffusion and gravity (MHG), developed by Chemat in 2008 [60]. This method is a solvent-free or water-free microwave extraction technique. When receiving energy in the form of micro-energy waves, water and natural constituents in the vegetal material evaporate and are condensed and deposited in a collector by terrestrial gravity [61]. This process was also used to extract essential oil of ginger rhizome.

Microwaves' specific absorption rate (SAR) is a crucial component of the MHG process. The effect of increasing the SAR and the addition of saturated steam to the system on extraction efficiency were studied previously [62]. The best results were obtained when the SAR value was moderate, and also saturated steam was added to the system. It was found that the extraction site duration and specific microwave energy were roughly 5 times and 3 times lower than that of MHD, respectively.

In another study, MHG was used to extract the rhizomes essential oil from ginger in a study conducted by Piarasd et al. [63]. and this technique was compared to conventional hydrodistillation in terms of extraction time, phytochemical composition, cost and energy use. The findings of this research showed that microwave diffusion and gravity were both favorable, as they cost less to extract and used less energy while giving richer phytochemicals (45 compounds for MHG and 4 compounds for HD). To put it another way, the optimal MHG power required to extract essential oil from 500 g of ginger was 720 W in 35 min, and thus resulted in the total yield of 0.292 %. Because it is quick, cheap, and effective, the MHG process is ideal for extracting essential oil from a variety of aromatic plants.

As aforementioned, MHG is a method for extracting essential oil that combines microwave heating with gravity. MHG has a number of benefits such as streamlined procedures, lower energy consumption and higher product purity [64]. Because it is solvent-free process and does not require any additional grinding of the rhizomes after trenching, the MHG procedure for extracting essential oils is easier than the MHD method. The raw material's short residence time in the extraction vessel is a significant benefit of this method. In addition, it is not necessary to heat the raw material for an extended period of time to create the essential oil with water vapor as the compounds of interest is collected in liquid form by gravity. Consequently, an effective stirring mechanism is required to achieve a moderate and uniform heating of the plant material.

B. Ultrasound-assisted extraction (UAE)

UAE, also called as ultrasonication, is one of advanced but simple and efficient extraction techniques to extract analytes from plants in shorter times than with other extraction methods [65,66]. The extraction of polyphenols from ginger by UAE was successfully proven [67]. It was reposted that using response surface methodology (RSM), the optimized extract had significant DPPH radical scavenging activity (54.5%) and strong antimicrobial activity against *E. coli*, *S. coli*, *B. cereus* and *S. aureus*, with diameter of inhibition zone (DIZ) values of 14.49 mm, 15.10 mm, 16.74 mm and 13.88 mm, respectively, and minimum inhibition concentration (MIC) values ranging from 3.75 to 7.5 mg/ml. The total phenolic and flavonoid content of ginger was found to be 1039.64 mg Gallic acid equivalent (GAE)/g and 492.57 ± 3.5 mg Quercetin equivalent (QE)/g of ginger extract (dry weight), respectively. UAE allows for higher yields of polyphenols without requiring excessive volumes of solvents. It also reduces extraction time and temperature and can be used for the extraction of polyphenols.

Another study investigating the effect of ultrasound-assisted extraction on the release of ginger antioxidants in aqueous media and their bioavailability in vitro has been successfully conducted [68]. The central compound rotation design is used to obtain the best extraction conditions; the variables studied are amplitude (80–90%) and temperature (30–50 °C). It was demonstrated that amplitude is the main parameter that affects the extraction of antioxidants. In their study, ginger extract showed about 30% bioavailability.

Various solvent can be used in the UAE. An emerging type of solvent used in the extraction is natural deep eutectic solvents (NaDES). For ginger extraction, this solvent in combination with ultrasound assisted extraction is considered as green solvent for the preparation of high value extracts of ginger. Under optimal conditions extraction time (23.8 min), power (60 W), NaDES/dry ginger ratio (25:1 w/w), the total phenolic compound was detected at 20.10 ± 0.26 mg GAE/g dry ginger. The maximum antioxidant activity towards DPPH radical scavenging reached IC50 at the concentration of 18.16 mg/mL after 120 min reaction [69]. In a further study, 6-gingerol related compounds were successfully recovered and separated from ginger using NaDES. Several NaDES combinations were generated using evaporation and heating procedures. HPLC analysis confirmed the presence of gingerols and shogaols in high amounts in the ginger extracts. The NaDES extracts have much stronger antioxidant activity than the organic solvent extracts. The combination of L-Proline and Lactic Acid (1:1) showed the highest antioxidant potential among the different NaDES extract combinations [70].

C. Enzyme-assisted extraction (EAE)

Enzyme-assisted extraction (EAE) technique utilizes hydrolytic enzymes to deteriorate the structural integrity of cell wall, and thus the extraction becomes easier [71]. The impact of enzymes including α-amylase, viscozyme, protease, cellulase and pectinase on ginger's oleoresin yield and 6-gingerol concentration has been studied [72]. In comparison to the control, pre-treatment of ginger with a-amylase or viscozyme followed by extraction with acetone resulted in higher yield of oleoresin and gingerol. Extraction of ginger pre-treated with enzymes followed by extraction with ethanol yielded a larger yield of gingerol (6.2–6.3%) than the control (5.5%) with equivalent oleoresin yields (31–32%). The study concluded that the enzymatic technique would be advantageous to the spice industry if the enzymes were used at optimal dosages, as oleoresins are commercially important value-added goods. EAE can be combined with environmentally friendly approach such as UAE, EAE or PLE (Pressured Liquid Extraction).

PLE uses constant high-pressure for the extraction process facilitating the improvement of cell permeability. It was demonstrated that the extract obtained from enzyme-assisted PLE showed good antioxidant activity [73]. As such, enzymatic pre-treatment of ginger powder by α-amylase before the PLE extraction increased total polyphenol content as well as total gingerol and shogaol concentrations by 2.8 and 2.22 times, respectively. Under these conditions, the total polyphenol content obtained was 5325 µg GAE/g dried ginger and the concentration of total gingerols and shogaol was 2990.5 µg bioactive compound/g dried ginger.

Nevertheless, it is noteworthy that the extraction process with PLE may cause a degradation of ginger compounds after the optimum extraction duration. By rapid water extraction at 140°C, the maximum yields for 6-, 8-, and 10-gingerols, as well as 6-shogaol were 68.97 mg/g at 3 min, 18.98 mg/g at 5 min, 5.16 mg/g at 3 min and 14.57 mg/g, respectively. After the concentration of each bioactive compound reached its ideal level, the compounds began to degrade rapidly; for example, after 3 min, the 6-shogaol concentration increased rapidly while the recovery of 6-gingerol decreased [37]. This deterioration is due to the high temperature and high-pressure extraction procedure.

D. Supercritical fluid extraction (SFE)

Supercritical fluid extraction (SFE) is also considered as an advanced environmentally friendly process. This technique uses supercritical CO_2 (SC-CO_2) or other supercritical solvent as an extraction solvent for improving the extraction efficiency. Experiment was carried out to evaluate the effect of the temperature (35, 40, 45°C) and the duration of the extraction process (2, 4, 6 h) of the compounds from the ginger using the SFE [74]. It is suggested that the use of 40°C temperature and 4500 Psi pressure for 4 h as it resulted in the best efficiency of ginger extract (2.9%). The change in temperature significantly affected both the solvent and vapor pressure of the diluted ginger compounds (curcumin, zingiberin and β –sesquipellandrene) influencing the overall yield and composition of the extract.

Another earlier study looked into the best extraction conditions as well as the antioxidant properties of 6-gingerol and 6-shogaol extracted from ginger pulp and skin using subcritical water extraction (SWE) [75]. It was proven that by increasing extraction temperature, conversion of 6-gingerol to 6-shogaol occurred throughout the SWE process. The levels of 6-gingerol and 6-shogaol in the peel were found to be lower than those in the pulp, but showed a similar pattern as extraction temperature and time increased. The antioxidant activity of the extract was measured using the FRAP method, and the results were similar to those obtained for the amount of 6-shogaol. These findings imply that 6-shogaol has a significant impact on the Zingiber extract's antioxidant activity. The active chemicals' SWE selectivity may have practical implications.

Taguchi's orthogonal array approach was used to optimize SFE for extracting ginger oil using a laboratory scale device [76]. At pressures of 10–15 MPa, 35–45°C, and 10–20 g/min, the effects of extraction pressure, temperature, and carbon dioxide (CO_2) flow rate on extraction yield and 6-gingerol content in ginger oil were examined. The results were compared to those obtained from high-pressure Soxhlet extraction with liquid CO_2, Soxhlet extraction with n-hexane and also ethanol percolation (96%). Using SFE at 15 MPa, 35°C, and 15 g/min, the highest oil yield (3.10 %) and highest content of 6-gingerol in ginger extract (20.69 %) were achieved. At optimum conditions, the measured oil production and 6-gingerol content matched the values anticipated by the computational approach. The scaling-up process to a commercial size apparatus was carried out based on the optimization process results, while keeping the solvent-to-feed (SF) ratio constant. SFE of ginger oil was effectively scaled-up by fifty-folds under ideal conditions, with higher oil production (3.83 %) and reduced 6-gingerol concentration (18.00 %). **Table 2** shows the advantages and limitations of SFE and other advantages extraction techniques.

TABLE 2
ADVANTAGES AND LIMITATIONS OF ADVANCED EXTRACTION METHODS

Method	Advantages	Limitations
Microwave-assisted extraction	Simple, cost-effective, reduced solvent consumption, higher compound extraction rates	Possible thermal deterioration of bioactive compounds, higher investment cost
Ultrasound-assisted extraction	Simple, efficient, shorter times, higher yields without requiring excessive volumes of solvents	Higher investment cost
Enzyme-assisted extraction	higher yield, mild conditions (low temperature and short periods)	high expenses, less popular
Supercritical fluid extraction	Non-toxic, reduce solvent waste, possible to get new useful compounds	Longer time, expensive and complex equipment

V. CONCLUSION AND OUTLOOK

To sum up, conventional extraction necessitates the use of organic solvents and takes a long time even though it is simple and easy operation. The application of innovative developed technologies is required to apply as it is deemed environmentally beneficial and eliminate the issues connected with traditional extraction processes. In addition, they are also believed to be more efficient in terms of extraction yield when compared to traditional methods. However, this hypothesis still needs validation by further researches. The yield may be increased even more by using a mix of these strategies. A combination of at least two new technologies may be used to increase extractability of compounds. However, combining different methods does not always yield satisfactory results; therefore, the extraction technique must be optimized for each ginger plant material and each extraction equipment used in order to provide excellent results in terms of extraction yield and biological activity preservation. The type of substrate matter, extraction solvent, and extraction parameters in the microenvironment all have a substantial impact on the results, yield, and quality of the target components. Depending on the energy source and extraction process, these approaches remove compounds from the plant in different ways. During the extraction process, some generate heat, which can destroy the targeted molecules, while others necessitate additional purifying and cleaning stages.

This review, moreover, clearly shows that some new technologies are not already in place to extract compounds from ginger, researchers working in this field should consider integrating such important information in order to understand the impact of each new extraction process on the yield and quality of compounds in ginger. Furthermore, researchers must investigate the degrading effects of each new technique on phytochemical compounds and their metabolites intermediates, as well as their biological implications in vitro and in vivo, in order to determine the process's safety for use in food and other applications. Further studies also are needed to clarify the effect of each technique and the pre-treatments that precede extraction on the structural change of the components after and before extraction.

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CONFLICT OF INTEREST

Authors declare no conflict of interest to disclose.

USE OF ARTIFICIAL INTELLIGENCE (AI) TOOLS STATEMENT

We used Grammarly (Grammarly Inc., 2025) to improve the clarity and grammar of the manuscript. The authors reviewed and approved all changes

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