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Extraction techniques for phenolic compounds from *Zingiber officinale*: a review of traditional, microwave-assisted, and ultrasound-assisted methods

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ABSTRACT

Background: The rhizome of *Zingiber officinale* (ginger) is widely recognized for its pharmacological properties, particularly its antioxidant activity, which is largely attributed to phenolic compounds such as gingerol, shogaol, paradol, and zingerone. Efficient extraction of these compounds requires suitable techniques to maximize yield while maintaining compound stability.

Objective: This review aims to evaluate extraction techniques for phenolic compounds from ginger rhizomes, comparing traditional and modern approaches, and to identify methods that produce the highest total phenolic content (TPC).

Methods: A literature review was conducted on original research articles published between 2015 and 2025 that reported phenolic extraction from *Z. officinale* using maceration, soxhlet extraction, reflux, microwave-assisted extraction (MAE), or ultrasound-assisted extraction (UAE). Articles were retrieved from Google Scholar and ScienceDirect databases and assessed against defined inclusion and exclusion criteria.

Results: Six eligible studies were included, revealing substantial methodological heterogeneity that complicates direct method comparisons. UAE with 50% ethanol produced the highest TPC (155.19 ± 2.81 mg GAE/g dry weight), followed by soxhlet extraction (31.10 ± 0.28 mg GAE/g) and MAE (27.89 ± 1.99 mg GAE/g). Reflux and maceration yielded comparatively lower TPC values, with results influenced by solvent type, concentration, temperature, and extraction time.

Conclusion: UAE with 50% ethanol is the most effective technique for extracting phenolic compounds from ginger, offering both high yield and compound stability. MAE, while producing lower yields, remains advantageous for its shorter extraction duration.

Keywords: extraction methods, method validation, microwave-assisted extraction, total phenolic content, ultrasound-assisted extraction, *Zingiber officinale*

Introduction

Antioxidants are compounds with the ability to neutralize free radicals, which are reactive molecules that can damage cells and biological tissues and contribute to degenerative diseases such as cancer, diabetes mellitus, and cardiovascular disorders [1]. Growing public awareness of the dangers of oxidative stress has driven the search for safe, effective, and sustainable natural sources of antioxidants. Medicinal plants are a promising source because they are rich in secondary metabolites such as phenolics, flavonoids, and terpenoids, all of which have been demonstrated to exhibit antioxidant activity in both *in vitro* and *in vivo* studies [2].

Zingiber officinale Roscoe (ginger) is one such medicinal plant, widely used in traditional medicine

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as well as in modern pharmaceutical formulations. Ginger has been reported to exert pharmacological activities including anti-inflammatory, antimicrobial, immunomodulatory, and antioxidant effects [3]. These biological activities are largely attributed to phenolic compounds such as gingerol, shogaol, paradol, and zingerone. These compounds not only protect cells from oxidative damage but also underpin the potential of ginger in the development of phytopharmaceuticals and health supplements [4].

The extraction of phenolic compounds from ginger requires an appropriate method to maximize yield while preserving their chemical integrity. Conventional methods such as maceration, percolation, and soxhlet extraction are still in use due to their simplicity, but they have limitations in terms of time efficiency, solvent consumption, and the risk of thermal degradation of sensitive compounds [5]. Modern approaches such as microwave-assisted extraction (MAE) and ultrasound-assisted extraction (UAE) have been developed to overcome these limitations by offering shorter processing times, reduced solvent use, and improved preservation of thermolabile phenolics [6].

The objective of this review is to provide a comprehensive overview of extraction methods for phenolic compounds from *Z. officinale*, including traditional techniques such as maceration, soxhlet extraction, and reflux, as well as modern methods such as MAE and UAE.

Method

Study design

This research employed a literature review approach to examine and analyze various extraction methods for phenolic compounds from *Zingiber officinale*.

Population and sample

The population in this study comprised all scientific articles discussing phenolic compound extraction methods from *Zingiber officinale*. Article selection was conducted through inclusion criteria consisting of original research articles published between 2015 and 2025, discussing the use of conventional extraction methods, Microwave Assisted Extraction (MAE), or Ultrasonic Assisted Extraction (UAE) for phenolic compounds from *Zingiber officinale*, and available in full text. Articles available only as abstracts or lacking information on total phenolic content and *Zingiber officinale* extraction methods were excluded from the analysis.

Instrumentation

Literature searches were conducted through two primary databases: Google Scholar and ScienceDirect. Keywords used in the search included: "isolation phenolic compounds *Zingiber officinale*", "ginger phenolics extraction", "traditional extraction ginger", "Microwave Assisted Extraction *Zingiber officinale*", and "Ultrasonic Assisted Extraction *Zingiber officinale*".

Analysis

Selected articles were then analyzed qualitatively with focus on extraction methods used, extraction efficiency, operational conditions such as temperature, time, and solvents, as well as the potential application of these methods in research and industrial scale. Data from each article were synthesized narratively to compare the advantages and limitations of each extraction technique.

Results

The literature search yielded six studies that met the established inclusion criteria (Figure 1). These studies employed diverse extraction methodologies and solvent systems for phenolic compound recovery from *Zingiber officinale* rhizomes, encompassing both traditional approaches (maceration, soxhlet extraction, reflux) and modern techniques (ultrasound-assisted extraction, microwave-assisted extraction).

The methodological distribution across the reviewed studies revealed considerable variation in experimental design (Table 1). Two studies employed maceration as their primary extraction technique [8,9], while individual studies focused on soxhlet extraction [7], ultrasound-assisted extraction [11], and microwave-assisted extraction [12] respectively. One study provided comparative data across multiple methods, specifically examining maceration, reflux, and ultrasound-assisted extraction within the same experimental framework [8]. This methodological diversity, while offering broad coverage of available techniques, presents challenges for direct quantitative comparison due to differences in sample preparation, analytical protocols, and operational parameters.

Critical examination of the experimental conditions across studies reveals substantial heterogeneity that

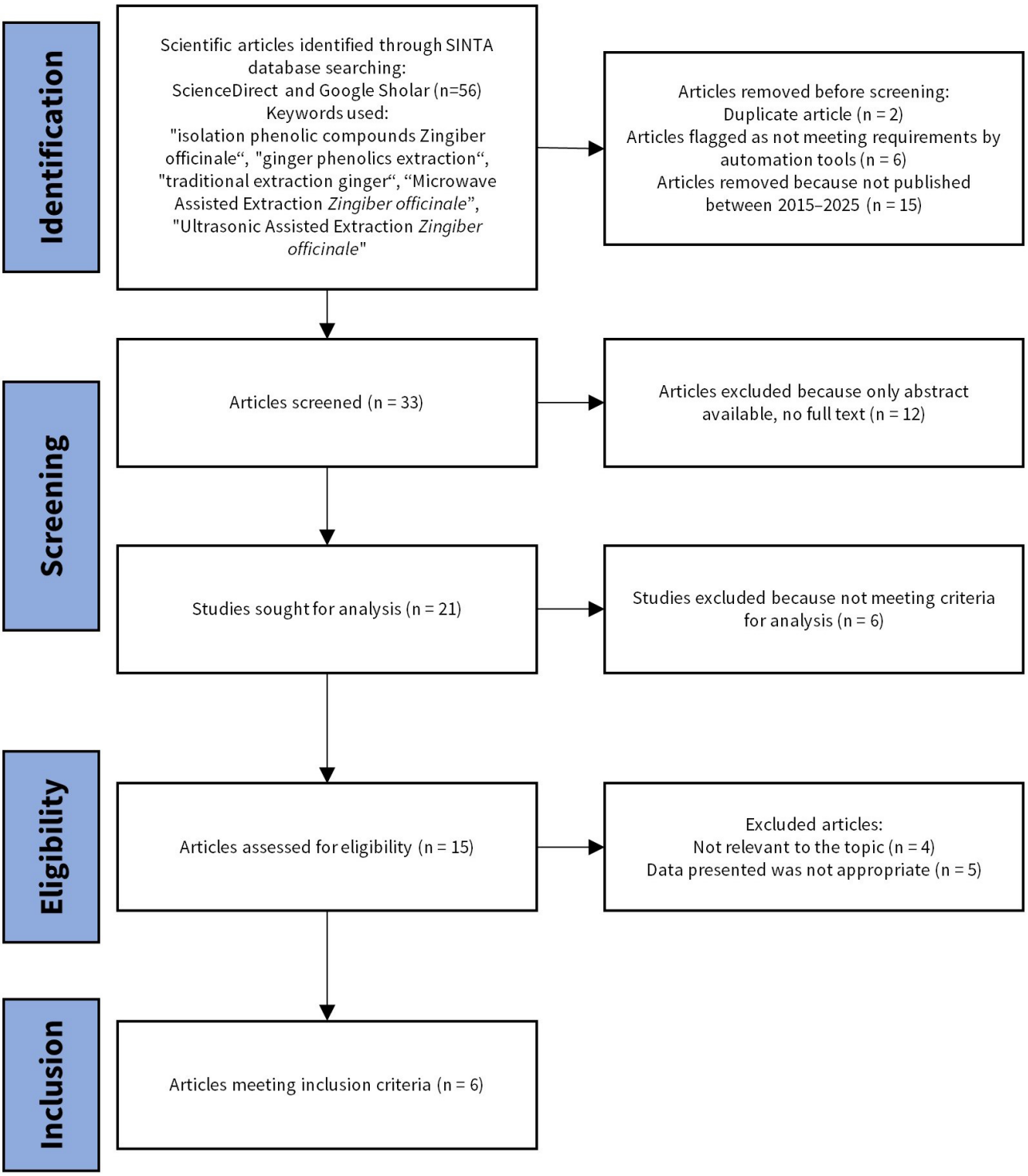

Figure 1. Flowchart of the literature selection process for the review

affects the interpretation of comparative results. Sample preparation methods varied from fresh ginger processing to different drying protocols, with particle sizes ranging from whole rhizomes to finely ground powders. Temperature conditions spanned from ambient temperature applications to elevated thermal treatments reaching 85°C [8], while extraction durations extended from single-minute microwave treatments [12] to multi-day maceration periods [9]. These methodological variations represent significant confounding factors that must be considered when evaluating the apparent superiority of specific extraction approaches.

Table 1. Comparative analysis of phenolic extraction methods from ginger rhizome

Method	Reference	Sample preparation	Operational parameters	Analytical method	TPC results (mg GAE/g DW)[a]	Quality indicators
Traditional methods						
Soxhlet	[7]	30 g dried powder	Acetone, 60°C, 4 h	UV-Vis (760 nm)	31.10 ± 0.28	Consistent, reproducible
Reflux	[8]	Air-dried powder (3.125 mg/mL)	Methanol, 85°C, 1-12 h	UV-Vis (765 nm)	9.42-9.79 ± 0.32[b]	Time-stable plateau
Maceration	[8]	Dried powder (3.125 mg/mL)	Methanol, 25°C, 24 h	UV-Vis (765 nm)	10.04 ± 0.14	Standard conditions
	[9]	50 g fresh rhizome	96% ethanol, RT, 24-48 h	UV-Vis (769 nm)	504 ± 0.08[c]	Anomalous result
	[10]	Dried material	96% ethanol, 36.3°C	UV-Vis (765 nm)	701.5 ± 1[d]	Unit inconsistency
Modern methods						
UAE	[11]	100 g material	50% ethanol, 4°C, 10 min	UV-Vis (765 nm)	155.19 ± 2.81	Optimal conditions
	[11]	100 g material	75% ethanol, 4°C, 10 min	UV-Vis (765 nm)	114.60 ± 3.38	Suboptimal solvent
	[8]	Powder (3.125 mg/mL)	70-100% ethanol, 40°C, 40 min	HPLC/UV-Vis (765 nm)	9.82 ± 0.22	Different conditions
MAE	[12]	Powder	60% ethanol, 60°C, 1 min, 500W	UV-Vis (738 nm)	27.89 ± 1.99	Rapid extraction

Footnotes: [a] All values converted to mg GAE/g dry weight where possible for comparison [b] Range represents time-course results showing minimal time dependence [c] Exceptionally high value requires verification; may indicate analytical discrepancy [d] Original units mg GAE/L; conversion requires additional sample information

Soxhlet extraction

The soxhlet extraction method is one of the conventional extraction techniques based on the principle of continuous solvent circulation through heating and condensation, allowing the solvent to be in constant contact with the sample [13]. Extraction of dried ginger rhizome using acetone solvent with the soxhlet method at 60°C for 4 hours yielded a total phenolic content of 31.10 ± 0.28 mg GAE/g dry weight [7]. Acetone effectively dissolves phenolic compounds under these conditions, making it more suitable for extracting semi-polar phenolic compounds from ginger.

The ratio between powder and solvent plays an important role in extraction results. A higher ratio of solvent to powder allows for maximum diffusion of phenolic compounds because the solvent does not become saturated quickly, resulting in higher measured phenolic content. Too low a ratio will reduce results due to limitations in the solvent's ability to dissolve bioactive compounds. Using excessive amounts of solvent can increase chemical consumption, prolong evaporation time, and be less efficient on an industrial scale [7].

The advantage of this method lies in its high extraction capability for phenolic compounds because the process occurs repeatedly and consistently. The closed system used also reduces compound loss due to evaporation. The disadvantages of this method include the long extraction duration and high temperatures used, which can increase the risk of degradation of phenolic compounds that are sensitive to heat. The substantial solvent and energy requirements are also considerations, especially for industrial-scale applications [14].

Maceration method

The maceration method is a simple extraction technique performed by soaking plant powder in solvent for a certain period of time. This process allows active compounds, such as phenolic compounds, to diffuse passively from the plant matrix into the solvent [15]. Maceration methods exhibit the most variable performance among reviewed techniques, with results ranging from 10.037 mg GAE/g [8] to an exceptional 504 mg GAE/g [9]. This extreme variation raises concerns about methodological standardization and analytical consistency. The particularly high value reported by Andriyani et al. [9] appears inconsistent with other maceration results and exceeds even optimized modern extraction techniques, suggesting potential analytical discrepancies or unique experimental conditions not adequately documented in the available literature. The same authors observed that extending maceration time from 24 to 48 hours decreased phenolic recovery from 504 to 431 mg GAE/g [9], indicating potential compound degradation during prolonged extraction periods.

Ethanol 96% at room temperature gives better results because it has semi-polar properties suitable for dissolving phenolic compounds, is safe to use, and can effectively penetrate plant cell walls, thereby increasing extraction efficiency. The advantages of the maceration method include simplicity, no need for special equipment, and suitability for heat-sensitive compounds. The main disadvantages of this method are the relatively long extraction time and lower dissolution efficiency compared to techniques involving agitation or additional energy [16].

Reflux extraction

The reflux method is an extraction technique that involves heating solvent in a closed system so that solvent vapor condenses and returns to the sample repeatedly. This process accelerates the dissolution of active compounds because high temperature increases compound diffusion from the material matrix [17].

The reflux extraction results reported by Jorge-Montalvo et al. [8] demonstrate consistency across different time points, with minimal variation between 1-hour (9.422 ± 0.327 mg GAE/g) and 12-hour (9.487 ± 0.354 mg GAE/g) extraction periods. This plateau effect suggests rapid achievement of extraction equilibrium, beyond which extended processing provides minimal additional benefit while potentially increasing thermal degradation risks. Quantitative analysis was performed using UV-Vis spectrophotometry at 765 nm wavelength, which is the standard method for total phenolic determination. These results indicate that variation in extraction time does not provide significant differences in the amount of phenolic compounds obtained, with relatively stable values in the tested time range [18].

The advantage of the reflux method lies in its efficiency in extracting phenolic compounds in shorter time compared to maceration. Continuous solvent heating maintains stable extraction processes and increases the amount of dissolved compounds. The limitations of this method include the risk of phenolic compound degradation due to high temperature, considering that phenolics are compounds sensitive to heat [14]. This can be seen from research results showing decreased phenolic content at 70% ethanol concentration, making the use of cooling equipment important to maintain compound stability during the extraction process [18].

Ultrasound-assisted extraction

The exceptional performance of ultrasound-assisted extraction with 50% ethanol (155.19 ± 2.81 mg GAE/g) [11] can be attributed to the acoustic cavitation phenomenon, which generates microscopic bubble formation and collapse within the extraction medium [19]. This process creates localized high-pressure and high-temperature zones that effectively disrupt cellular matrices while maintaining bulk solution temperatures conducive to phenolic compound stability. The optimization of solvent composition at 50% ethanol concentration represents a critical finding [8], as this mixture provides optimal polarity balance for extracting both hydrophilic and lipophilic phenolic compounds present in ginger.

The observed decrease in extraction efficiency at higher ethanol concentrations (75% ethanol yielding 114.60 ± 3.38 mg GAE/g) [11] suggests that excessive organic solvent content may reduce the effectiveness of acoustic cavitation or limit the solubility of certain phenolic compounds. The substantially lower performance when using fresh ginger samples (54.01 ± 2.81 mg GAE/g with 75% ethanol) [11] indicates that moisture content significantly impacts extraction efficiency, likely through dilution effects and reduced cavitation intensity.

Interestingly, Jorge-Montalvo et al. [8] reported significantly lower ultrasound-assisted extraction

results (9.823 ± 0.221 mg GAE/g) under different operational conditions (70-100% ethanol, 40°C, 40 minutes), demonstrating the critical importance of parameter optimization for achieving maximum extraction efficiency. This substantial difference highlights how operational variables such as solvent concentration, temperature, and extraction duration profoundly influence phenolic recovery.

The 75% acetone solvent produced the lowest TPC of 34.50 ± 2.35 mg GAE/g, indicating that acetone's chemical properties are less suitable for extracting phenolic compounds from ginger. The advantages of the UAE method lie in its time efficiency, low-temperature operation, and ability to maintain phenolic compound stability. This technique is also more environmentally friendly as it reduces the need for large quantities of solvent. The ultrasonic method has the disadvantage of potential phenolic compound degradation if the power or extraction time is excessive, as this can trigger temperature increases and free radical formation due to cavitation effects. UAE represents an effective modern alternative for extracting phenolic compounds, particularly in processes requiring short duration and good temperature control [11].

Microwave-assisted extraction

Microwave Assisted Extraction (MAE) is a modern extraction technique that uses microwave energy to heat solvent and sample rapidly and uniformly [20]. This heating increases pressure inside plant cells, causing cell structure to rupture and phenolic compounds to dissolve more easily into the solvent.

Microwave-assisted extraction achieves moderate efficiency (27.89 ± 1.99 mg GAE/g) [12] while offering substantial advantages in processing time and energy consumption. The rapid heating mechanism through dielectric loss enables efficient cell wall disruption and enhanced mass transfer rates. The optimization parameters reported by Huyen and Quoc [12], including 60% ethanol concentration and 48.6 mL/g solvent-to-material ratio, represent practical conditions suitable for potential industrial applications. The extremely short extraction time of one minute demonstrates the remarkable efficiency of microwave energy in accelerating extraction processes.

Methodological concerns and study quality assessment

Several critical limitations affect the reliability of comparative conclusions drawn from this review. The absence of standardized analytical protocols represents a fundamental concern, as different spectrophotometric methods, wavelength selections, and calibration standards could introduce systematic variations in phenolic quantification. The variation in measurement wavelengths from 738 nm [12] to 769 nm [9] across studies may contribute to apparent differences in phenolic content.

Sample preparation inconsistencies further complicate comparative analysis. The use of different drying methods, storage conditions, and particle size distributions affects both initial phenolic composition and extraction accessibility. Geographic origin and cultivar variations, when inadequately controlled or reported, introduce additional biological variability that confounds method-specific comparisons.

The limited sample size of six studies constrains the statistical power for definitive conclusions regarding method superiority. Additionally, the absence of studies directly comparing multiple extraction methods under identical analytical conditions limits the ability to attribute observed differences solely to extraction methodology rather than experimental variation. Jorge-Montalvo et al. [8] provide the most reliable comparative data by examining multiple methods under consistent analytical conditions, although their results suggest more modest differences between techniques than observed across separate studies.

Implications for industrial applications

From a practical perspective, ultrasound-assisted extraction emerges as the most promising approach for commercial phenolic compound recovery from ginger, particularly when optimized conditions similar to those reported by Jan et al. [11] are employed. The combination of high extraction efficiency, reduced processing time, and lower temperature requirements presents significant advantages for preserving bioactive compound integrity while maintaining economic viability [21]. The optimal solvent composition of 50% ethanol provides a favorable balance between extraction efficiency and subsequent processing requirements for commercial applications (Figure 2).

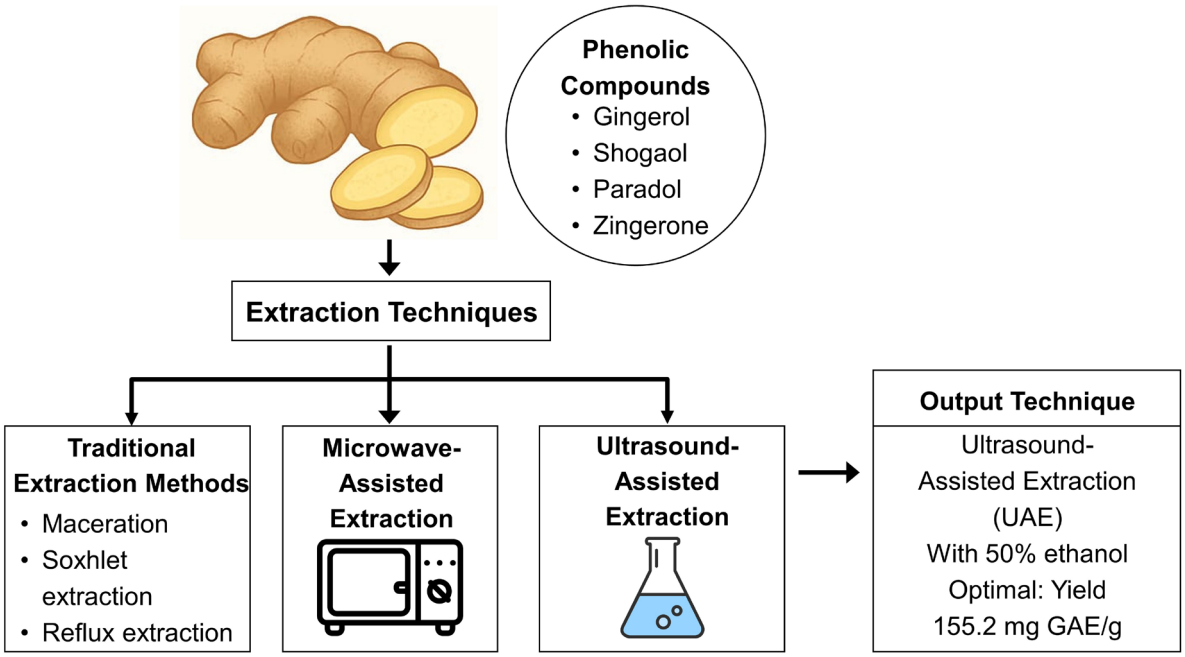

Figure 2. Extraction techniques for phenolic compound from *Z. officinale*

Microwave-assisted extraction offers an attractive alternative for applications prioritizing rapid processing and energy efficiency over maximum extraction yield [12]. The substantially reduced extraction time and moderate solvent requirements may justify the lower phenolic recovery in specific industrial contexts where processing speed and operational simplicity are paramount considerations.

Recommendations for future research

Future investigations should prioritize standardized experimental protocols to enable meaningful method comparisons. This includes establishing uniform analytical methods, sample preparation procedures, and quality control standards across research groups. Multi-laboratory validation studies would strengthen the reliability of performance comparisons and identify method-specific advantages under controlled conditions.

Additionally, comprehensive optimization studies examining the interaction effects between extraction parameters, solvent systems, and sample characteristics would provide more robust guidelines for industrial implementation. Economic feasibility assessments incorporating capital costs, operating expenses, and downstream processing requirements would further inform practical method selection decisions.

Conclusion

The review results show that extraction method greatly affects the phenolic content of ginger rhizome. Conventional methods such as maceration, soxhlet extraction, and reflux are less efficient because they produce lower phenolic values and require long time. Modern methods, especially UAE with 50% ethanol, proved most effective with the highest result of 155.19 ± 2.81 mg GAE/g, while MAE excels in shorter extraction duration.

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Conflict of interest

The authors confirm that the entire research process and writing of this literature review are free from conflicts of interest.

Author contributions

NKDF and NMPS designed this research. NKDF, MNPS, LPMKD contributed to data collection. NKDF and LPMKD wrote the initial draft of the manuscript.

NKDF, NMPS, and LPMKD contributed to data analysis. All authors participated in result interpretation and approved the final version of the manuscript.

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