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Advances in Extraction Techniques of Bioactive Compounds: A Comparative Review of Maceration, Soxhlet, Microwave, and Sonication Methods with Environmental and Chemical Perspectives

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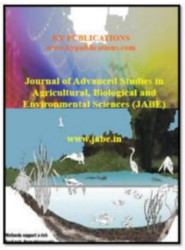

ABSTRACT

Extraction methods play a crucial role in isolating bioactive compounds from natural products for applications in pharmaceuticals, food, and environmental science. This review highlights recent advances (2015–2025) in maceration, Soxhlet extraction, microwave-assisted extraction (MAE), and ultrasound-assisted extraction (UAE/sonication). Maceration, a traditional method, remains widely used for its simplicity and ability to preserve thermolabile compounds, as demonstrated in studies on *Clitoria ternatea*, *Citrus sinensis*, *Etlingera hemisphaerica*, and *Carica papaya*. Soxhlet extraction continues to provide high yields of phytochemicals but requires longer processing time and higher solvent use. In contrast, modern techniques such as MAE and UAE have gained prominence due to their efficiency, shorter extraction times, and reduced environmental impact. These methods have been successfully applied to *Flacourtia rukam*, *Ganoderma lucidum*, *Moringa oleifera*, and coffee waste, yielding extracts with enhanced antioxidant, antibacterial, and anti-inflammatory activities. Comparative evaluations indicate that greener methods, particularly UAE and MAE, align better with sustainable chemistry principles, while maceration and Soxhlet remain valuable in preliminary screening and yield optimization. The integration of conventional and modern approaches offers a balanced pathway toward maximizing efficiency, selectivity, and eco-friendly extraction in natural product research.

Keywords: Bioactive compounds, maceration, Soxhlet extraction, microwave-assisted extraction, ultrasound-assisted extraction, green chemistry.

Background

Indonesia is among the countries with the richest biodiversity in the world, hosting thousands of medicinal plant species that serve as potential sources for phytopharmaceuticals and traditional medicine. To harness the bioactive compounds contained in these plants, extraction plays a pivotal role

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by isolating active substances from natural materials through the use of solvents. This process is critical, as it directly influences the quality, quantity, and stability of the extracted compounds. Consequently, the choice of extraction method has a significant impact on both the yield and the pharmacological efficacy of the final extract.

With technological advancement, a variety of extraction techniques have been developed. Traditional methods such as maceration remain widely used due to their simplicity, minimal equipment requirements, and suitability for heat-sensitive compounds (Triyanti et al., 2025). Meanwhile, Soxhlet extraction provides higher efficiency through repeated heating cycles, allowing faster extraction. However, this method carries the risk of degrading thermolabile compounds due to the elevated temperatures applied during the repeated process (Handayani et al., 2024).

Contemporary techniques such as sonication and microwave-assisted extraction (MAE) are increasingly adopted for their ability to enhance extraction efficiency, facilitate mass transfer, and minimize solvent consumption. Sonication employs ultrasonic waves to generate microcavitation in the solvent, leading to cell wall disruption and rapid release of active compounds (Asnawi & Kalla, 2024). Another emerging approach is ultrasound-assisted extraction (UAE), which offers the advantage of improved efficiency while maintaining relatively low temperatures, making it ideal for heat-sensitive compounds. UAE generates cavitation bubbles that enable solvent infiltration into the plant matrix, thereby enhancing the diffusion of active substances and improving yield in a shorter time frame (Rahmadevi et al., 2020).

Theoretical Review

Extraction is a standardized method used to separate bioactive components from plants by employing specific solvents. The main objective of extraction is to isolate soluble plant metabolites from insoluble residues, thereby obtaining the desired compounds. The process generally involves two key steps: solvent penetration into the solid matrix and collection of the solubilized compounds (Zhang & Ye, 2018; Salsabila Khoerunniyssa et al., 2024). In essence, extraction aims to isolate or separate compounds from simple or complex mixtures, and the choice of method depends on the chemical nature of the target compounds, the solvent used, and the availability of equipment.

A variety of extraction techniques are commonly applied to isolate natural compounds from plants, which can be broadly divided into traditional and modern approaches. Traditional methods are usually conducted under atmospheric pressure, while modern methods often involve elevated temperatures or pressures (Rasul, 2018). Modern techniques, though more efficient, frequently require large volumes of organic solvents and longer extraction times compared to traditional techniques (Zhang & Ye, 2018; Salsabila Khoerunniyssa et al., 2024). Extraction is not limited to medicinal plants but is also applied to animals and marine organisms, with the goal of obtaining pharmacologically active substances. The success of the process largely depends on selecting an appropriate method and solvent, since active compounds may differ in chemical stability. For example, thermolabile compounds are prone to degradation under heat, while thermostable compounds can withstand higher temperatures. Thus, extraction techniques must be carefully adapted to the chemical characteristics of the targeted bioactive compounds.

Broadly, extraction can be carried out through two main approaches: cold methods and hot methods (Muhammad Ichsan Nurfahmi et al., 2024). Cold methods such as maceration are suitable for

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thermolabile compounds, as they are performed at room temperature without heating. Maceration involves soaking plant material in a solvent with occasional stirring and may be repeated through re-maceration. This method is simple, cost-effective, and particularly suitable for small-scale industries since it does not require complex equipment. However, its disadvantages include longer processing times, lower yields, and greater solvent consumption. Conversely, hot extraction methods such as reflux are more appropriate for heat-stable compounds, as elevated temperatures improve solubility and extraction efficiency (Nurfahmi et al., 2024; Cao et al., 2025). Soxhlet extraction, in particular, is advantageous due to its continuous solvent circulation, higher efficiency compared to maceration, reduced solvent use, and partial automation, which minimizes the need for labor-intensive manual filtration.

Extraction Method Considerations

One major drawback of hot extraction methods is the prolonged use of high temperatures, which increases the risk of degradation of heat-sensitive compounds such as polyphenols and catechins, making them unsuitable for thermolabile materials (Osorio-Tobón, 2020). In contrast, ultrasound-assisted extraction (UAE) offers advantages including shorter extraction times, high efficiency, low solvent consumption, and lower operating temperatures, making it ideal for sensitive compounds. Furthermore, UAE is considered more environmentally friendly and cost-effective compared to microwave-assisted extraction (MAE) and supercritical fluid extraction (SFE). However, improper optimization of extraction parameters may lead to cavitation-induced compound degradation, and the equipment is relatively expensive, requiring routine maintenance (Özdemir et al., 2025). MAE, on the other hand, provides extremely rapid extraction, high efficiency, uniform heating, and reduced solvent and energy use. Nevertheless, its limitations include unsuitability for non-polar or volatile compounds, susceptibility to thermal degradation, the requirement for solvents with high dielectric constants, and high equipment costs (Osorio-Tobón, 2020).

Given the significant differences among extraction methods in terms of yield and phytochemical activity, conducting a systematic review of their effectiveness is essential. This study aims to provide a comprehensive overview of the most appropriate methods for extracting specific bioactive compounds, serving as a reference for the development of herbal products, phytopharmaceuticals, and functional foods derived from natural resources. Although researchers are increasingly seeking extraction techniques that are more efficient and cost-effective, comprehensive reviews focusing specifically on modern extraction methods for total phenolic compounds from natural products remain limited.

Research Methodology

This study employs a **systematic literature review approach**. Data were collected from reputable scientific databases, including Google Scholar, ResearchGate, and Publish or Perish, using keywords such as *maceration method*, *sonication (UAE)*, *Soxhlet extraction*, *microwave-assisted extraction (MAE)*, *extract activity assays*, and *extraction yield*, along with related terminologies. Inclusion criteria comprised peer-reviewed journal articles, conference proceedings, textbooks, and official guidelines published within the last five years, focusing on natural product extraction methods with relevant parameters such as biological activity assays and extract yield percentages.

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Each retrieved source was carefully evaluated for relevance, with emphasis on the operational principles of extraction techniques, the influence of process parameters on yield percentages, and reported outcomes on extract activities, including antioxidant, antibacterial, and other bioactivities.

Data Synthesis

Data synthesis was conducted descriptively and thematically to create a cohesive narrative outlining the comparative effectiveness of each extraction method in achieving optimal yield and superior biological activity. The synthesis also highlights the strengths, limitations, and practical applications of each method in the development of phytopharmaceuticals and natural derivative products.

Results and Discussion

This study demonstrates that extraction methods exert a significant influence on both the yield and biological activity of phytochemical compounds. Compared to maceration and Soxhlet extraction, ultrasound-assisted extraction (UAE) and microwave-assisted extraction (MAE) were found to be more efficient in terms of time, solvent use, and extract yield. However, their effectiveness is strongly dependent on the type of raw material and the chemical characteristics of the compounds involved. While UAE offers advantages for thermolabile compounds due to its lower operating temperature, MAE ensures rapid and uniform heating, making it suitable for stable compounds with higher dielectric properties. Conversely, traditional methods such as maceration and Soxhlet extraction, though less efficient, remain valuable for small-scale applications and for compounds requiring gentle processing. Since this study is based on a systematic literature review, no direct experimental validation was performed (Tables 1-4). Therefore, the findings should be interpreted as a synthesized evaluation of existing evidence rather than empirical testing.

Table 1. Maceration Method for Different Plant Materials

Plant Material	Yield	Bioactivity	Procedure	Reference
Clitoria ternatea L. (Butterfly pea flower)	Thick extract (high viscosity)	Antibacterial	100 g simplicia soaked in 70% ethanol (1:10) for 24 h with occasional stirring. Filtrate re-extracted, evaporated using rotary evaporator (78 °C) and water bath (<65 °C) to obtain concentrated extract.	Yurisna et al., 2022
Citrus sinensis (Sweet orange peel)	25% extract yield	Antibacterial, Antioxidant	Dried at 60 °C for 24 h, powdered (70 mesh). 30 g powder macerated in 300 mL ethanol, stirred 500 rpm for 2 h, left 24 h. Filtrate evaporated at 50 °C (2 h), concentrated, dissolved in distilled water (1% b/v), heated 70 °C for 30 min.	Dewi, 2019

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Etlingera hemisphaerica (Wild torch ginger flower)	18.69% (w/w)	Antioxidant	750 g powdered flower macerated in 96% ethanol; soaked 6 h with stirring, left 18 h, repeated three times. Combined filtrates evaporated to obtain concentrated extract.	Sholikhah et al., 2023
Carica papaya L. (Papaya leaves)	3.48%	Anti-inflammatory	500 g dried leaf powder macerated with 96% ethanol for 3 days; stirred daily for 15 min. Filtrate air-dried to yield concentrated extract.	Karim, 2022
Uncaria sclerophylla (Kait leaves)	n-Hexane: 32.20 g; Ethyl acetate: 21.11 g; Polar fraction (water): 72.65 g	DPP-4 enzyme inhibitor	Leaves extracted by successive maceration with n-hexane, dichloromethane, ethyl acetate, and methanol (1:20), following Triadisti et al. (2017) with modified solvent volume. Extracts evaporated and dried with dehydrator.	Triadisti, Elya, Hanafi, & Hasyim, 2025

Table 2; Sonication Method (Ultrasonic-Assisted Extraction, UAE)

Plant/Material	Yield	Activity	Procedure	Reference
Imperata cylindrica L. Beauv (Alang-alang rhizome)	14.13%	Highest antioxidant from alang-alang rhizome extract	10 g of rhizome powder extracted with 40–90% ethanol (1:10 b/v) using ultrasonic (47 kHz) for 30 min at room temperature. The extract was filtered (Whatman No.1) and evaporated with a rotary evaporator at 30°C to obtain crude extract.	Puspitaningtyas et al., 2021
Stachytarpheta jamaicensis (L.) (Horseweed)	25.78%	Antioxidant	100 g of powder extracted with 500 mL of 96% ethanol (1:5) using sonicator (20 kHz, 30°C) for 60 min. Process repeated 3 times, filtrates	Jumawardi et al., 2021

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			combined, then evaporated at 40°C.	
Muntingia calabura L. (Kersen leaves)	Ethanol: 10.35% n-Hexane: 5.13%	Antioxidant	Extraction with ultrasonic bath at 30°C (10 min), 40°C (20 min), and 50°C (30 min), 47 kHz. Filtrate evaporated (100 mbar, 40–60°C), then concentrated in water bath for 12 h.	Nindyasari & Hidayatullah, 2024
Dragon fruit peel	3.74%	Extraction	5 g of peel extracted with 25 mL methanol (1:10 b/v) using sonication (60 kHz, 1 h). Mixture filtered (Whatman No.42), then 1 mL dried at 64.7°C. Extract weighed for concentration analysis.	Triyanti et al., 2025
Biodiesel waste (Glycerol conversion)	48.41%	Reaction kinetics	Glycerol reacted in a sonication reactor (500 mL) with glycerol:water ratio 1:8, 1% H_2SO_4 catalyst. Sonication at 40 kHz for 20–40 min at 30–50°C. Analyzed volumetrically.	Asnawi & Kalla, 2024
Cod liver oil (Oleum Iecoris Aselli)	Droplet size macro (1,172 µm)	Nanoemulsion	Optimization of surfactant/cosurfactant ratios with Tween. Evaluated formula (F0), droplet size, transmittance, viscosity, and emulsion type following Indonesian Pharmacopeia V.	Rahmadevi et al., 2020
Urena lobata Linn (Pulutan leaves)	36.36% (30% ethanol), 19.27% (60%), 8.48% (90%)	Antibacterial	Pulutan leaf powder extracted via sonication with ethanol. Antibacterial activity tested against *Propionibacterium acnes* and *Staphylococcus epidermidis* using disc diffusion.	Fadillah, 2024

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Fish oil	91.38% (10 min, 0.5% KOH)	Extraction	Transesterification of fish oil via sonication. Tested ester quality, behavior, and data analysis.	Haryani et al., 2023
Isoeugenol synthesis	82.97% and 97.87%	Extraction	25 g of sample mixed with $RuCl_3$ catalyst (0.24% w/w) in ethanol. First vial sonicated 30 min (76 MHz, 60°C), second vial microwaved 2 min (250 W, 70°C). Product distilled and characterized.	Mardatillah, 2023
Black rice yeast (Nanocapsulation)	Not specified	Nanocapsulation	Sample prepared for nanocapsule formulation. Characterized by particle size/distribution, zeta potential, and morphology.	Amyliana & Agustini, 2021
Crescentia cujete L. (Maja fruit peel)	Tannin content 5.89%	Extraction	30 g dried peel powder extracted with ethanol, sonicated 30 min, macerated 2 days, filtered, evaporated. Applied for bioactivity testing.	Kurniawan et al., 2023
Ficus carica L. (Fig leaves, Iraq variety)	10.64% (50% ethanol), 10.45% (70%), 8.70% (96%)	Antioxidant	Extraction, phytochemical screening (flavonoids, saponins, tannins, etc.), and antioxidant activity tested with DPPH (IC_{50} determination).	Qodriah et al., 2021

Table 13. Soxhlet Extraction Method (Soxhletation) and Its Applications

Plant/Material	Yield	Activity	Procedure	Reference
Psidium guajava L. (Guava leaves)	Highest tannin yield 17.06% (from dried leaves)	Extraction	1) Preparation of guava leaves 2) Extraction and tannin analysis	Niawanti et al., 2023

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Household Corn, Moringa flour, and Rice bran (using domestic electric stove)	Crude fat yield: Corn 3.99%, Moringa flour 4.65%, Rice bran 7.81%	Extraction	Samples placed in macro Soxhlet tubes lined with fat-free cotton, tightly sealed, connected to a fat flask and condenser. ±250 mL petroleum benzene added, extracted for 4–6 h.	Sulastri et al., 2023
Moringa seeds (Moringa oleifera Lam.)	Highest oil yield: 41.73% (at 70°C, 6 h)	Extraction	1) Preparation of mature dried moringa seeds (kernel ground) 2) Soxhlet extraction	Handayani et al., 2024
Curcuma xanthorrhiza Roxb. (Temulawak rhizome)	–	Antibacterial	Extraction methods: 1) Maceration 2) Soxhletation 3) Ultrasonic-Assisted Extraction (UAE) 4) Antibacterial activity assay	Yasacaxena et al., 2023
Pometia pinnata (Matoa leaves)	Highest: 35.00% (70% ethanol, 4 h); Lowest: 19.36% (90% ethanol, 6 h)	Extraction	1) Preparation of matoa leaf powder 2) Extraction process 3) Evaluation of variables	Wijaya et al., 2022
Carica papaya L. (Papaya seeds)	Soxhlet yield: 10.7% vs. Maceration: 10.0%	Extraction & Phytochemical Analysis	1) Sample preparation 2) Soxhlet extraction 3) Organoleptic test, phytochemical screening, total phenolic content	Oktaviani et al., 2020
Musa paradisiaca L. (Banana stem borer beetle)	Highest yield from reflux method with water: 8.68%	Natural dye extraction	1) Sample preparation 2) Extraction process 3) Pigment identification (color test for tannins, flavonoids, carotenoids) 4) UV-Vis spectrophotometric analysis	Mahardika & Wiratnyana Putera, 2023
Sesbania grandiflora L. (Turi stem)	Highest: 7.76% (Soxhletation), Average maceration: 6.13%	Extraction	1) Plant identification 2) Extraction using maceration and Soxhletation 3)	Wijaya et al., 2022

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			Comparative yield analysis	

Table 4. Microwave-Assisted Extraction (MAE) Method and Its Applications

Plant/Material	Yield	Activity	Procedure	Reference
Manihot utilissima Pohl. (Cassava leaves)	19.84%	Extraction & Antioxidant assay	Cassava leaf powder blended, sieved (60 mesh), extracted with solvent (water, ethanol 90%, acetone, methanol, or ethyl acetate) at 1:25 ratio using MAE (450 W, 8 min). Filtrate filtered (Whatman No.1), evaporated with rotary evaporator.	Wahyuni et al., 2021
Ganoderma lucidum (Lingzhi mushroom)	10.91%	Antioxidant activity of polysaccharides	Dry sample extracted with distilled water (1:30), heated with microwave (7 min, <60°C).	Listriyani et al., 2023
Flacourtia rukam (Rukam fruit)	Ethanol extract: 12%; Acetone extract: 7.5%	Extraction & Antioxidant assay	±0.1 g fruit powder extracted with 10 mL acetone or ethanol in microwave (MARS 6, 60°C, 1200 W, 2450 MHz, 10 min). Filtrate evaporated to obtain crude extract.	Fadiyah et al., 2020
Averrhoa bilimbi L. (Belimbing wuluh leaves)	26.75%	Extraction & Antioxidant assay	10 g powdered leaves extracted with 70% ethanol (1:10) using microwave (300 W, 3–13 min). Filtrate evaporated at 40°C, 100 rpm.	Swara et al., 2023
Eleiodoxa conferta (Kelubi fruit)	34.76%	Antibacterial assay	2 g powdered fruit extracted with 20 mL ethanol using MARS 6 (60°C, 1200 W, 30 min). Filtrate evaporated, crude extract tested for antibacterial activity.	Surtina et al., 2020

Conclusion and Recommendations

This review concludes that the choice of extraction method plays a crucial role in determining both the yield and the bioactivity of natural product extracts. UAE and MAE represent promising techniques due to their higher efficiency, reduced solvent consumption, and shorter extraction times.

Nevertheless, the selection of extraction methods for herbal products should carefully consider factors such as solvent compatibility, compound stability, process efficiency, and economic feasibility. Future research should involve direct experimental validation of optimized extraction parameters, with particular attention to scaling up for industrial applications in the production of phytopharmaceuticals and functional foods. Additionally, integrating green chemistry principles—such as minimizing solvent use and energy consumption—should be prioritized in advancing sustainable extraction practices.

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