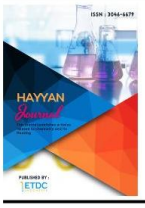

HAYYAN JOURNAL
Vol. 3 No. 1, February 2026, page. 53-63
ISSN: 3046-6679

Phytochemical Fingerprinting, Green Extraction, and Nanobiotechnology of Jahe Emprit *(Zingiber officinale* var. *amarum*): A Mini Review

Subakir Salnus[1*]

[1]Universitas Negeri Makassar, Makassar, Indonesia
**Corresponding Address:* akil.ladzinrank@gmail.com

Received: December 21, 2025 *Accepted: January22, 2026* *Online Published: February28, 2026*

ABSTRACT

Jahe emprit (*Zingiber officinale* var. *amarum*) has attracted growing scientific attention because its gingerols, shogaols, zingerone, essential oils, and related metabolites support functional food and phytopharmaceutical development. This review synthesizes recent evidence on phytochemical fingerprinting, green extraction, nanobiotechnological delivery, bioactivities, and translational barriers of jahe emprit and closely related ginger materials. Literature was selected through systematic query expansion, screening, citation chaining, and relevance ranking of studies published mainly between 2017 and 2026. The reviewed studies show that chromatographic, spectroscopic, metabolomic, and chemometric approaches can improve authentication and quality marker identification, especially for 6-gingerol, 6-shogaol, zingerone, alpha-zingiberene, and location-sensitive essential oil profiles. Green extraction methods, particularly supercritical CO2 extraction, microwave-assisted extraction, ultrasound-assisted extraction, and enzyme-assisted extraction, improve yield, selectivity, and bioactive preservation compared with conventional methods. Nanocarriers such as liposomes, polymeric nanoparticles, solid lipid nanoparticles, and plant-derived exosome-like nanoparticles enhance solubility, stability, bioavailability, and targeted delivery in preclinical models. Nevertheless, clinical translation remains constrained by inconsistent quality standards, limited pharmacokinetic data, scale-up uncertainty, regulatory ambiguity, and insufficient long-term safety evidence. Standardized quality markers, reproducible extraction protocols, validated nanoformulations, and rigorous clinical trials are needed to convert jahe emprit from promising bioresource into scalable therapeutic products.

Keywords: Zingiber officinale var. amarum; phytochemical fingerprinting; green extraction; nanobiotechnology; bioactivity

I. INTRODUCTION

The study of jahe emprit (*Zingiber officinale* var. *amarum*) sits at the intersection of natural product chemistry, sustainable processing, food science, and nanomedicine. Ginger is widely recognized for a complex phytochemical profile that includes gingerols, shogaols, zingerone, zingiberene, and other volatile and non-volatile metabolites associated with antioxidant, anti-inflammatory, antimicrobial, anticancer, and gastrointestinal benefits (Alolga et al., 2022; Ashfaq et al., 2022; Li et al., 2022; Ma et al., 2021). For jahe emprit, the research question is no longer whether the plant contains valuable compounds, because that point has been repeatedly supported. The more demanding question is how those compounds can be identified, extracted, standardized, protected, delivered, and translated into products that are scientifically defensible.

This question matters because herbal products often fail not from lack of biological promise but from weak quality control. Phytochemical content varies across geographic origin, cultivation condition, harvest stage, storage, and processing method. Studies on Indonesian emprit ginger have shown that Fourier-transform infrared spectroscopy, gas chromatography-mass spectrometry, chemometrics, and pattern recognition can discriminate samples by origin and associate chemical profiles with antioxidant or antibacterial activity (Styawan et al., 2022; Styawan et al., 2024a; Styawan et al., 2024b). Such findings make phytochemical fingerprinting central to standardization. Without reliable markers, claims about efficacy become charmingly optimistic paperwork, which science has suffered enough of already.

A second issue is extraction. Conventional approaches such as maceration, hydrodistillation, and Soxhlet extraction remain useful, yet they may require higher solvent use, longer processing time, or harsher conditions that reduce sustainability and potentially degrade sensitive compounds. Current reviews and optimization studies increasingly emphasize green extraction technologies, including supercritical fluid extraction, microwave-assisted extraction, ultrasound-assisted extraction, and enzyme-assisted extraction, because these methods can improve selectivity, yield, and bioactive preservation while reducing environmental burden (Aisyah et al., 2025; Ayouaz et al., 2025; Huang et al., 2025; Munankarmi et al., 2025; Salea et al., 2017). For an ingredient intended for food, nutraceutical, or pharmaceutical use, extraction is not merely a technical step; it shapes the chemical identity of the final product.

The third issue is bioavailability. Many ginger-derived bioactives have limited aqueous solubility, chemical instability, rapid metabolism, or insufficient tissue targeting. Nanobiotechnological systems address these weaknesses by packaging phytochemicals into carriers such as liposomes, polymeric nanoparticles, solid lipid nanoparticles, nanoemulsions, and plant-derived exosome-like nanoparticles. Reviews on ginger and broader herbal nanoformulations report enhanced solubility, stability, pharmacokinetics, cellular uptake, and targeted delivery (Ansari et al., 2025; Ashfaq et al., 2022; Parvin et al., 2025; Sonia & Sonia, 2025; Srivastava, 2025). In the specific context of emprit ginger, plant-derived exosome-like nanoparticles have opened a promising line of functional food research by linking metabolite profiles to biocompatible delivery platforms (Rukmi et al., 2025).

Despite these advances, the translational pathway remains incomplete. Preclinical evidence is stronger than clinical evidence, and many nanoformulation studies still lack long-term safety data, standardized manufacturing procedures, and clear regulatory alignment. Clinical analysis of ginger research indicates growing interest, but mature human evidence remains uneven across indications and formulations (Matin et al., 2024). The novelty of this review is therefore its integrated focus: phytochemical fingerprinting is treated as the basis of quality control, green extraction as the basis of sustainable and reproducible production, and nanobiotechnology as the basis of improved delivery. The objective is to synthesize current knowledge on these three domains and identify the main gaps that prevent jahe emprit from moving more confidently from laboratory promise to clinical and industrial application.

II. METHODS

This article was prepared as a narrative-systematic review based on the supplied literature review corpus on phytochemical fingerprinting, green extraction, nanobiotechnological potential, quality markers, bioactivities, and translational gaps of jahe emprit. The search strategy in the source review began with the broad concept of “Phytochemical Fingerprinting, Green Extraction, Nanobiotechnological Potential, Jahe Emprit, *Zingiber officinale* var. *amarum*, Quality Markers, Bioactivities, Translational Gaps” and transformed it into targeted

queries related to gingerol and shogaol ratios, zingerone, ar-curcumene, plant-derived nanoparticles, ginger essential oil nanocarriers, and translational pathways.

The literature selection process combined database searching, screening, backward citation chaining, forward citation chaining, and relevance scoring. The initial search identified 212 papers. Citation chaining added 75 papers, producing 287 candidate papers. Relevance ranking then identified 286 relevant papers, of which 50 were considered highly relevant for detailed synthesis. Inclusion emphasized studies published mainly from 2017 to 2026 that addressed phytochemical profiling, green extraction technologies, nanocarrier formulation, bioactivity assessment, clinical research, quality control, or translational barriers of jahe emprit, ginger, or comparable herbal bioactives. Studies outside the core themes, studies without clear methodological relevance, and papers with limited applicability to quality standardization or delivery were treated as lower-priority evidence.

The analysis used thematic synthesis. Evidence was grouped into five domains: phytochemical fingerprinting and quality markers; extraction efficiency and sustainability; nanocarrier performance; bioactivity validation; and translational readiness. The approach was suitable because the reviewed studies were methodologically heterogeneous, ranging from analytical chemistry and extraction optimization to preclinical pharmacology, food science, and nanomedicine. Rather than forcing incompatible data into a single pooled estimate, the review compared convergence and divergence across methods, compounds, and application contexts. The synthesis also considered practical implications for product development, including quality control, process scale-up, safety, and regulatory feasibility.

III. RESULTS AND DISCUSSION

Descriptive Summary of the Studies

This section maps the research landscape of the literature on Phytochemical Fingerprinting, Green Extraction, Nanobiotechnological Potential, Jahe Emprit, *Zingiber officinale* var. *amarum*, Quality Markers, Bioactivities, Translational Gaps, encompassing multidisciplinary investigations into phytochemical profiling, sustainable extraction, nanotechnology applications, and bioactivity validations. The studies span analytical chemistry, pharmacology, nanomedicine, and food science, with a notable focus on emprit ginger's unique phytochemical composition and bioactive potential. Comparative analysis highlights advances in green extraction methods, nanocarrier systems, and quality marker identification, while also revealing translational challenges in clinical and industrial adoption. This synthesis informs targeted research directions to bridge gaps between bench research and practical applications in herbal therapeutics.

Tabel 1. Summary of Phytochemical, Extraction, Nanocarrier, Bioactivity, and Translational Findings of *Zingiber officinale* var. *amarum*

Study	Phytochemical Fingerprinting Accuracy	Extraction Efficiency and Sustainability	Nanocarrier Performance	Bioactivity Validation	Translational Readiness
(Huang et al., 2025)	High precision via advanced green extraction and encapsulation methods	Emphasizes supercritical fluid and enzyme-assisted extraction with improved yield and sustainability	Encapsulation enhances stability and bioavailability of ginger oleoresin	Demonstrated antioxidant, antimicrobial, and anti-inflammatory activities in vitro	Calls for mechanistic studies and clinical validation for translation

(Ayouaz et al., 2025)	Conventional methods characterized; limited fingerprinting precision	Critical analysis of hydrodistillation, maceration, and Soxhlet; advocates advanced green methods for better yield and eco-friendliness	Not extensively covered	Focus on extraction impact on bioactive preservation	Highlights need for environmental benefit and process optimization
(Ashfaq et al., 2022)	Identification of key bioactives such as gingerols and shogaols with moderate analytical detail	Discusses extraction impact on bioactive compound integrity	Nanoformulations improve absorption and targeted delivery	Validated antioxidant, anti-inflammatory, and anticancer effects in vitro/in vivo	Notes translational gaps due to limited clinical pharmacokinetic data
(Rashpa et al., 2025)	Focus on zingerone profiling with advanced analytical techniques	Extraction methods not primary focus	Nanoparticles and liposomal formulations improve zingerone delivery	Preclinical validation of broad pharmacological effects	Early-stage clinical trials underway; regulatory and safety data limited
(Akhlaghi & Najafpour-Darzi, 2023)	Phytochemical profiling less emphasized; focus on bioactive compound diversity	Highlights green extraction for bioactive recovery in food and pharma	Discusses nanoparticle synthesis using ginger as biomaterial	Reports antimicrobial and antioxidant bioactivities	Notes challenges in scaling and standardization for industrial use
(Satapathy et al., 2025)	Detailed molecular profiling of anticancer bioactives such as gingerol and shogaol	Extraction methods briefly mentioned; focus on bioactive efficacy	Nanocarrier use for enhanced delivery in cancer therapy	Strong preclinical anticancer activity demonstrated	Clinical research limited; translational hurdles remain
(Najafi et al., 2025)	General phytochemical fingerprinting of herbal bioactives	Extraction efficiency not primary focus	Nanocarriers such as nanoparticles and liposomes improve stability and targeted delivery	Enhanced therapeutic efficacy in preclinical models	Emphasizes regulatory and scalability challenges
(Srinivas et al., 2026)	Phytochemical standardization critical for reproducibility	Green extraction methods support sustainability	Nanomedicines enhance solubility, bioavailability, and targeted release	Preclinical efficacy in multiple disease models	Regulatory and safety challenges impede clinical translation
(Parvin et al., 2025)	Identification of major phytochemical classes with nanocarrier encapsulation	Extraction sustainability not detailed	Nanocarriers improve pharmacokinetics and disease targeting	Improved bioactivity and reduced toxicity in preclinical studies	Discusses regulatory and manufacturing hurdles
(Ansari et al., 2025)	Analytical methods for phytochemical quantification in nanoformulations	Extraction methods secondary; focus on formulation	Nanoformulations enhance solubility, stability, and controlled release	Demonstrated anti-inflammatory and anticancer activities	Regulatory, safety, and scalability issues noted
(Srivastava, 2025)	Use of chemometric and spectroscopic methods for precise phytochemical fingerprinting	Extraction efficiency not primary focus	Nanoencapsulation improves bioavailability and organ targeting	Preclinical efficacy in neurodegenerative and inflammatory models	Calls for universal guidelines and clinical trials

(Zafar et al., 2025)	Phytochemical profiling linked to anticancer bioactives	Extraction methods briefly mentioned	Nanocarriers improve solubility, targeting, and therapeutic outcomes	Enhanced anticancer efficacy in vitro and in vivo	Clinical translation limited by regulatory and standardization gaps
(Pande & Sabale, 2025)	Detailed phytochemical characterization for cancer therapeutics	Extraction not focus	Advanced nanocarriers improve pharmacokinetics and tumor targeting	Validated anticancer efficacy and reduced toxicity	Manufacturing and regulatory challenges impede clinical use
(Ma et al., 2021)	Detailed phytochemical profiling of ginger bioactives	Extraction methods linked to bioactive retention	Nanoformulations improve bioavailability and therapeutic potential	Validated antioxidant, anticancer, and anti-inflammatory effects	Clinical data limited; translational gaps identified
(Abdo et al., 2018)	Chemometric and chromatographic methods enable precise quality marker detection	Extraction efficiency not primary focus	Nanotechnology applications not detailed	Bioactivity validation limited	Quality control methods support standardization efforts
(Rukmi et al., 2025)	Metabolite profiling of emprit ginger exosome-like nanoparticles with high accuracy	Extraction of PDENs optimized for bioactive content	PDENs show enhanced bioactive delivery potential	Antioxidant capacity and functional food potential demonstrated	Early-stage translational research; functional food applications
(Styawan et al., 2024)	GC-MS profiling reveals essential oil composition variability by location	Steam distillation and GC-MS used; extraction yield varies by method	Nanotechnology not addressed	Antibacterial activity against Staphylococcus aureus validated	Highlights need for standardization based on geographic origin
(Styawan et al., 2022)	FTIR and chemometrics enable discrimination of emprit ginger by origin	Extraction impact on phytochemical content analyzed	Nanotechnology not covered	Antioxidant activity correlated with phytochemical content	Supports quality control and authentication efforts
(Kanai et al., 2024)	Combined NMR and GC-MS with OPLS modeling for marker identification	Extraction methods optimized for marker yield	Nanotechnology not focus	Quality markers linked to bioactivity	Facilitates rapid quality control and standardization
(Munankarmi et al., 2025)	Supercritical CO2 extraction optimized for yield and bioactivity	SFE yields higher oil and bioactive content than conventional methods	Nanotechnology not addressed	Antioxidant and cytotoxic activities enhanced	Demonstrates scalable green extraction potential
(Salea et al., 2017)	SCFE optimized for oil yield and 6-gingerol content	Scale-up process validated with maintained extraction efficiency	Nanotechnology not covered	Bioactive content quantified	Supports industrial scale green extraction
(Aisyah et al., 2025)	MAE optimized for β-sesquiphellandrene and zingerone yield	Green extraction with RSM improves bioactive recovery	Nanotechnology not focus	Enhanced bioactive compound yield	Eco-friendly extraction method with industrial relevance
(Silva et al., 2026)	Comparison of hydrodistillation and solvent	Solvent extraction superior in yield	Nanotechnology not addressed	Antioxidant and anti-inflammatory potential confirmed	Supports extraction method

	extraction for bioactives	and bioactive content			selection for quality extracts
(Styawan et al., 2024)	Chemometrics combined with spectroscopy for gingerol quantification	Extraction methods impact fingerprinting accuracy	Nanotechnology not discussed	Phytochemical levels linked to antioxidant activity	Enables rapid, sensitive quality assessment
(Foudah et al., 2020)	Green RP-HPTLC method for simultaneous 6-shogaol and 6-gingerol quantification	Ultrasonication-assisted extraction improves yield	Nanotechnology not focus	Accurate quantification supports bioactivity correlation	Provides green analytical method for quality control

Evidence Landscape

The reviewed literature shows a rapidly expanding but uneven field. Analytical studies have become increasingly precise in identifying chemical fingerprints and quality markers, while extraction studies have shifted from yield-centered methods toward sustainability and compound preservation. Nanobiotechnology studies are expanding the therapeutic imagination of ginger bioactives, but many remain preclinical. This imbalance creates a familiar research pattern: the laboratory is sprinting, the clinic is walking, and regulation is filling out forms somewhere in the back office.

Across the highly relevant studies, five themes dominate. First, emprit ginger can be authenticated and evaluated through chemometric and spectroscopic methods. Second, green extraction can improve recovery of target bioactives while supporting environmental goals. Third, nanoformulations can address solubility, stability, and delivery limitations. Fourth, bioactivities are broad and mechanistically plausible but not equally validated in humans. Fifth, translational readiness is limited by standardization, manufacturing reproducibility, long-term safety, and regulatory uncertainty.

Table 2. Synthesis of major evidence domains in jahe emprit review

Review domain	Main evidence pattern	Implication for product development	Persistent gap
Phytochemical fingerprinting	GC-MS, FTIR, NMR, HPTLC, metabolomics, and chemometrics identify marker compounds and sample variability.	Supports authentication, batch consistency, and rational quality control.	Universal marker panels and validated analytical protocols remain limited.
Green extraction	SFE, MAE, UAE, enzyme-assisted extraction, and green HPTLC improve selectivity, yield, or sustainability.	Improves preservation of gingerols, shogaols, zingerone, oleoresin, and essential oil fractions.	Comparative metrics, industrial scale-up data, and stability studies are still uneven.
Nanobiotechnology	Liposomes, polymeric nanoparticles, solid lipid nanoparticles, nanoemulsions, and plant-derived exosome-like nanoparticles enhance delivery.	Improves solubility, stability, bioavailability, controlled release, and targeting.	Clinical validation, long-term safety, and manufacturing reproducibility remain insufficient.
Bioactivities	Studies report antioxidant, anti-inflammatory,	Supports functional food and phytopharmaceutical development.	Human evidence and dose-response data remain

	antimicrobial, anticancer, and gastrointestinal effects.		weaker than in vitro and animal evidence.
Translational readiness	Growing clinical and patent interest exists, but standardization and regulation lag behind formulation innovation.	Encourages integrated development from raw material control to clinical testing.	Regulatory pathways for nano-herbal products remain ambiguous.

Source: Synthesized by the author from the reviewed literature corpus.

Phytochemical Fingerprinting and Quality Markers

Phytochemical fingerprinting is the strongest foundation for jahe emprit standardization. Studies using chromatographic and spectroscopic platforms show that ginger quality cannot be reduced to a single compound. The most important markers include 6-gingerol, 6-shogaol, zingerone, alpha-zingiberene, beta-sesquiphellandrene, and other essential oil constituents. Foudah et al. (2020) demonstrated a green RP-HPTLC densitometry method for simultaneous 6-gingerol and 6-shogaol determination, showing that analytical methods themselves can be aligned with green chemistry. Kanai et al. (2024) combined metabolic profiling with marker identification for processed ginger rhizome, reinforcing the idea that processing affects marker relevance.

For Indonesian emprit ginger, Styawan et al. (2022) used FTIR spectra and pattern recognition to classify samples based on antioxidant activities and chemical signatures. Styawan et al. (2024a) compared essential oil profiles from different locations and reported antibacterial activity against Staphylococcus aureus, indicating that geographic origin shapes both chemistry and biological function. A later review by Styawan et al. (2024b) emphasized the usefulness of chemometrics combined with molecular spectroscopy and chromatography for determining gingerol levels. These studies suggest that reliable quality control requires a marker panel and a pattern-based fingerprint, not a heroic dependence on one chemical celebrity.

The main limitation is the absence of universally accepted quality markers for jahe emprit. Gingerol and shogaol markers are useful but insufficient because volatile oils, origin-sensitive metabolites, and processing-induced changes also influence activity. Future standards should integrate major pungent compounds, essential oil profiles, and chemometric classification. This would allow raw materials, extracts, and nanoformulations to be compared across batches, laboratories, and manufacturers.

Green Extraction and Bioactive Preservation

Extraction determines the chemical and functional identity of jahe emprit extracts. Huang et al. (2025) reviewed ginger oleoresin extraction and encapsulation technologies, showing that supercritical fluid extraction and enzyme-assisted extraction can improve recovery while supporting bioactive preservation. Ayouaz et al. (2025) argued that conventional extraction methods remain feasible but require stronger sustainability evaluation because environmental cost, solvent consumption, and process efficiency affect industrial value. In practical terms, an extract cannot be called high quality only because it comes from a famous plant; it must also be produced through a controlled and reproducible process.

Several optimization studies support this direction. Salea et al. (2017) optimized and scaled up supercritical fluid extraction of ginger oil from *Zingiber officinale* var. *amarum*, demonstrating that industrial scale-up is possible when pressure, temperature, and process time are controlled. Munankarmi et al. (2025) optimized supercritical CO2 extraction and compared the resulting essential oil profiles and biological activities with steam and simultaneous distillation. Aisyah et al. (2025) used microwave-assisted extraction and response surface methodology to improve beta-sesquiphellandrene and zingerone yield. Together, these studies

indicate that green extraction is not decorative sustainability language; it directly affects the concentration and integrity of active compounds.

However, green extraction does not automatically solve all problems. Different methods favor different compound classes. Supercritical CO2 may be strong for non-polar constituents and essential oil fractions, while microwave or ultrasound-assisted extraction may improve recovery of other target compounds depending on solvent, temperature, and matrix conditions. Comparative studies therefore need standardized metrics, including yield, marker concentration, solvent use, energy input, extract stability, and bioactivity retention. Without those metrics, method comparison becomes the academic equivalent of comparing umbrellas and submarines because both are somehow related to water.

Nanobiotechnological Delivery Systems

Nanobiotechnology addresses the delivery limitations of ginger bioactives. Gingerols, shogaols, and zingerone have pharmacological potential, but their performance may be restricted by solubility, stability, metabolism, and tissue distribution. Nanoformulations can increase surface area, protect sensitive compounds, improve absorption, and enable controlled or targeted release. Ashfaq et al. (2022) reviewed ginger bioactive compounds and noted the potential of nanoformulations to improve absorption and targeted delivery. Broader reviews on herbal nanocarriers similarly report improvements in solubility, stability, pharmacokinetics, and therapeutic efficacy (Ansari et al., 2025; Parvin et al., 2025; Srivastava, 2025; Zafar et al., 2025).

For jahe emprit, plant-derived exosome-like nanoparticles are especially relevant. Rukmi et al. (2025) investigated plant-derived exosome-like nanoparticles from emprit ginger and their potential metabolites as functional food ingredients. This approach is attractive because it links the plant matrix itself to delivery potential, rather than treating ginger only as a supplier of isolated compounds. Plant-derived nanovesicles may offer biocompatibility and functional food relevance, although their composition is still sensitive to raw material origin and processing conditions. Min et al. (2026) showed that raw material geographic origin shapes the quality of ginger-derived exosome-like nanovesicles, reinforcing the link between agricultural source and nanoformulation quality.

The translational challenge is that nano-herbal products must satisfy both herbal product standards and nanomedicine safety expectations. Particle size, polydispersity, zeta potential, encapsulation efficiency, release profile, stability, sterility, residual solvent, and batch reproducibility are all relevant. Yet many studies stop at promising in vitro or animal results. Reviews by Hassan et al. (2025), Sonia and Sonia (2025), and Patadiya et al. (2025) emphasize that regulatory guidance, manufacturing scale-up, and long-term safety remain major hurdles. The field has impressive delivery vehicles, but the road signs are still missing.

Bioactivities and Translational Readiness

The bioactivity evidence for ginger and jahe emprit is broad. Antioxidant and anti-inflammatory activities are consistently reported across ginger studies, while antimicrobial, anticancer, and gastrointestinal effects are also supported by preclinical data (Alolga et al., 2022; Huang et al., 2025; Li et al., 2022; Ma et al., 2021). Satapathy et al. (2025) reviewed the anticancer potential of bioactive compounds from *Zingiber officinale*, while Zafar et al. (2025) and Pande and Sabale (2025) discussed nanocarrier strategies for plant-derived anticancer phytoconstituents. The antimicrobial direction is also relevant, with Vatandoust et al. (2025) discussing preclinical insights for *Zingiber officinale* in oral health and Styawan et al. (2024a) reporting activity against Staphylococcus aureus.

Nevertheless, biological plausibility must not be confused with clinical readiness. Many studies use extracts with different chemical compositions, different doses, different extraction methods, and different biological models. This makes direct comparison difficult. A ginger extract produced through steam distillation is not equivalent to a supercritical CO2 extract, and neither is equivalent to a nanoparticle-loaded formulation. The same plant name on a label does not guarantee the same pharmacological behavior. This is why fingerprinting, extraction control, and formulation characterization must be integrated before clinical claims are made.

Clinical translation is still the weakest point. Matin et al. (2024) found that ginger clinical research is growing, but the field still requires stronger clinical designs, clearer formulation descriptions, and more consistent outcome measures. For jahe emprit nanoformulations, the gap is even wider because evidence is mostly preclinical or functional-food oriented. The most urgent next step is not simply "more studies," that beloved academic escape hatch. The next step is better studies: standardized raw material authentication, marker-based extracts, validated green extraction parameters, reproducible nanocarrier characterization, pharmacokinetic assessment, long-term safety testing, and randomized clinical trials for specific indications.

Conceptual Integration

An integrated translational framework can be proposed from the literature. The first stage is raw material standardization through geographic documentation, botanical authentication, and chemical fingerprinting. The second stage is extraction optimization, where target markers and sustainability indicators are measured together. The third stage is formulation, where nanocarrier selection is justified by the chemical properties and intended therapeutic or functional-food use. The fourth stage is biological validation, beginning with mechanism-oriented in vitro assays and moving toward relevant animal models. The fifth stage is clinical and regulatory translation, where safety, pharmacokinetics, manufacturing reproducibility, and product claims are tested systematically.

This framework prevents the common fragmentation of herbal research. Analytical chemists often produce excellent fingerprints that never meet clinical endpoints. Pharmacologists may report impressive bioactivity using extracts that nobody can reproduce. Formulation scientists may build elegant nanoparticles from poorly standardized material. Each fragment is useful, but translation requires alignment across the whole chain. For jahe emprit, the strongest future research will connect marker chemistry, green process parameters, nanocarrier properties, and biological outcomes in one continuous development logic.

IV. CONCLUSION

This review concludes that jahe emprit has strong potential as a source of standardized functional food and phytopharmaceutical ingredients, but its translation depends on more disciplined integration of phytochemical fingerprinting, green extraction, and nanobiotechnological delivery. Current evidence supports the use of GC-MS, FTIR, NMR, HPTLC, metabolomics, and chemometrics for marker identification and authentication. Green extraction technologies can improve yield, selectivity, and preservation of bioactive compounds while supporting sustainability. Nanocarrier systems can improve solubility, stability, bioavailability, and targeted delivery, especially in preclinical models.

The most important limitation is not the absence of promising data; it is the lack of standardized, reproducible, and clinically validated development pathways. Future research should establish accepted quality marker panels for jahe emprit, compare extraction methods using standardized sustainability and bioactivity metrics, validate nanoformulations through

full physicochemical characterization, and conduct rigorous pharmacokinetic, safety, and clinical studies. When these steps are connected, jahe emprit can move beyond traditional use and fragmented laboratory evidence toward scientifically credible, scalable, and regulated therapeutic or functional-food applications.

V. ACKNOWLEDGEMENT

The author declares that no external funding was received for the preparation of this review article.

VI. REFERENCES

Aisyah, Amelia, S. Z., Febrianti, A., Nur, A., & Zahra, U. (2025). MAE and RSM optimization on red ginger extraction for enhancement of beta-sesquiphellandrene and zingeron in support of green chemistry. https://doi.org/10.1088/1755-1315/1559/1/012023

Alolga, R. N., Wang, F., Zhang, X., Li, J., Tran, L. P., & Yin, X. (2022). Bioactive compounds from the Zingiberaceae family with known antioxidant activities for possible therapeutic uses. Antioxidants, 11(7), 1281. https://doi.org/10.3390/antiox11071281

Ansari, M. D., Majid, H., Mahmood, S., Sofian, Z. M., Husain, A., Sultana, Y., & Shakeel, F. (2025). Nanotechnology-enabled delivery of phytoconstituents: Recent developments, applications, and regulatory considerations. Asian Pacific Journal of Tropical Biomedicine. https://doi.org/10.4103/apjtb.apjtb_491_25

Ashfaq, M., Hu, W., Hu, Z., Guan, Y., & Zhang, R. (2022). A review of nutritional implications of bioactive compounds of ginger (Zingiber officinale Roscoe), their biological activities and nano-formulations. Italian Journal of Food Science, 34(3), 1-12. https://doi.org/10.15586/ijfs.v34i3.2212

Ayouaz, S., Fibri, D. L. N., Madani, K., & Muhammad, D. R. A. (2025). Feasibility and sustainability evaluation of customary extraction methods of ginger bioactive compounds: A review. Indonesian Food Science and Technology Journal, 8(2), 189-200. https://doi.org/10.22437/ifstj.v8i2.31660

Foudah, A. I., Shakeel, F., Yusufoglu, H. S., Ross, S. A., & Alam, P. (2020). Simultaneous determination of 6-shogaol and 6-gingerol in various ginger (Zingiber officinale Roscoe) extracts and commercial formulations using a green RP-HPTLC-densitometry method. Foods, 9(8). https://doi.org/10.3390/FOODS9081136

Hassan, E. E., Mabrouk, D. M., & Abdel-Aziem, S. H. (2025). Nano herbal therapeutics: A dual-edged sword - comprehensive insights into advantages, challenges, and future prospects. https://doi.org/10.57647/inl.2025.1502.05

Huang, C., Cui, H., Li, X., Askar, G., Yu, J., Hayat, K., Zhang, X., & Ho, C. (2025). Current progress in the ginger oleoresin: Bioactivities, extraction and encapsulation technologies. Critical Reviews in Food Science and Nutrition, 1-20. https://doi.org/10.1080/10408398.2025.2521651

Kanai, T., Shirahata, T., Nakamori, S., Koizumi, Y., Kodaira, E., Sato, N., Fuchino, H., Kawano, N., Kawahara, N., Hoshino, T., Yoshimatsu, K., & Kobayashi, Y. (2024). Development of a determination method for quality control markers utilizing metabolic profiling and its application on processed Zingiber officinale Roscoe rhizome. Journal of Natural Medicines. https://doi.org/10.1007/s11418-024-01837-8

Li, W., Yang, S., Lin, X., Zhang, X., Huang, Y., Zhou, J., Fu, C., Li, R., & Zhang, Z. (2022). Zingiber officinale: A systematic review of botany, phytochemistry and pharmacology of gut microbiota-related gastrointestinal benefits. The American Journal of Chinese Medicine, 50(4), 1007-1042. https://doi.org/10.1142/S0192415X22500410

Ma, R., Ni, Z., Zhu, Y., Thakur, K., Zhang, F., Zhang, Y., Hu, F., Zhang, J., & Wei, Z. (2021). A recent update on the multifaceted health benefits associated with ginger and its bioactive components. Food & Function, 12(2), 519-542. https://doi.org/10.1039/D0FO02834G

Matin, M., Matin, F. B., Ksepka, N., Wysocki, K., Mickael, M., Wieczorek, M., Horbanczuk, J. O., Jozwik, A., & Atanasov, A. G. (2024). The clinical research on ginger (Zingiber officinale): Insights from ClinicalTrials.gov analysis. Planta Medica. https://doi.org/10.1055/a-2357-7064

Min, F., Li, J., & Chen, H. (2026). Untargeted metabolomics reveals raw material geographic origin as a key factor shaping the quality of ginger-derived exosome-like nanovesicles. Foods. https://doi.org/10.3390/foods15020408

Munankarmi, N. N., Shyaula, S. L., Timilsina, P. M., Chaudhary, S., & Gauchan, D. P. (2025). Optimization of supercritical CO2 green extraction of Zingiber officinale Roscoe essential oil and comparative GC-MS

profiling and biological activities with steam and simultaneous distillation. Industrial Crops and Products, 236, 122067. https://doi.org/10.1016/j.indcrop.2025.122067

Pande, S. D., & Sabale, V. (2025). Nanocarrier based strategies to deliver plant-derived bioactive phytoconstituents for cancer treatment: A comprehensive review. https://doi.org/10.38124/ijisrt/25apr1139

Parvin, N., Aslam, M., Joo, S., & Mandal, T. K. (2025). Nano-phytomedicine: Harnessing plant-derived phytochemicals in nanocarriers for targeted human health applications. Molecules, 30(15), 3177. https://doi.org/10.3390/molecules30153177

Patadiya, A., Mehta, D., & Karuppiah, N. (2025). Bridging nature and nanotechnology: A review on the potential of herbal nanoparticles in medicine. https://doi.org/10.1051/e3sconf/202561905005/pdf

Rukmi, P. S. D., Ratnadewi, D., & Wijaya, C. H. (2025). Plant-derived exosome-like nanoparticles from emprit ginger (Zingiber officinale var. amarum) and its potential metabolite as functional food ingredients. Hayati Journal of Biosciences, 33(1), 181-195. https://doi.org/10.4308/hjb.33.1.181-195

Salea, R., Veriansyah, B., & Tjandrawinata, R. R. (2017). Optimization and scale-up process for supercritical fluids extraction of ginger oil from Zingiber officinale var. amarum. Journal of Supercritical Fluids, 120, 285-294. https://doi.org/10.1016/J.SUPFLU.2016.05.035

Satapathy, S., Kuanar, A., & Kar, D. (2025). Treatment of cancer with natural bioactive compounds of Zingiber officinale: A multipotent drug of ancient to recent. Benha Medical Journal, 42(10), 1-13. https://doi.org/10.21608/bmfj.2025.390090.2442

Sonia, Z., & Sonia, Z. (2025). Advancing herbal therapeutics through nanotechnology: Innovations in drug delivery and pharmacokinetic enhancement. Plant Science Today. https://doi.org/10.14719/pst.9646

Srivastava, A. K. (2025). Nanoencapsulation of herbal extracts for enhanced bioavailability. https://doi.org/10.64063/3049-1630.vol.2.issue7.8

Srinivas, T., Pavani, M., & B, T. (2026). A Systematic Overview on The Emerging Landscape of Herbal Nanomedicines. https://doi.org/10.5281/zenodo.18340159

Styawan, A. A., Purwanto, P., Susidarti, R. A., Windarsih, A., & Rohman, A. (2024a). Comparative analysis of essential oil profiles from emprit ginger rhizome (Zingiber officinale var. amarum) grown in different locations and antibacterial activity against Staphylococcus aureus. Indonesian Journal of Tropical and Infectious Disease, 12(2), 82-91. https://doi.org/10.20473/ijtid.v12i2.50423

Styawan, A. A., Susidarti, R. A., Purwanto, P., Irnawati, I., & Rohman, A. (2022). The use of pattern recognition for classification of Indonesian ginger (Zingiber officinale var. amarum) based on antioxidant activities and FTIR spectra. Journal of Applied Pharmaceutical Science. https://doi.org/10.7324/japs.2023.50966

Styawan, A. A., Susidarti, R., Purwanto, P., Kusumadewi, A., & Rohman, A. (2024b). The use of chemometrics in combination with molecular spectroscopy and chromatography methods for determining the levels of gingerol compounds in ginger (Zingiber officinale): A review. Food Research. https://doi.org/10.26656/fr.2017.8(3).165

Vatandoust, A., Talebi, M., Alaee, A., & Talebi, M. (2025). Exploring Zingiber officinale as natural antimicrobial in oral health: Efficacy and preclinical insights. Phytomedicine Plus, 5(4), 100894. https://doi.org/10.1016/j.phyplu.2025.100894

Zafar, A., Alsaidan, O. A., & Mujtaba, M. A. (2025). Nano-carriers based approaches loaded with herbal bioactive compounds for the treatment of cancer: Recent updates and future prospects. Recent Patents on Anti-cancer Drug Discovery, 20. https://doi.org/10.2174/0115748928377734250731191700