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Nutritional and Health-Promoting Properties of Kaempferia *galanga*: A Phytochemical Perspective

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Abstract

Background: Kaempferia *galanga* L. (kencur) is an aromatic rhizome widely used in traditional medicine and functional foods in Southeast Asia. However, a comprehensive synthesis linking its phytochemical composition with its biological activities remains limited.
Aim: This review evaluates the phytochemical profile, nutritional composition, and health benefits of K. *galanga*, focusing on the relationship between bioactive constituents, therapeutic mechanisms, and functional food potential.
Methods: A narrative literature review was conducted by critically analyzing recent studies. Evidence from analytical techniques (GC-MS, HPLC, LC-MS) and biological studies was synthesized to identify major bioactive compounds and their mechanisms.
Results: Ethyl p-methoxycinnamate (EPMC), ethyl cinnamate, kaempferol, and borneol are the principal bioactive compounds identified. These phytochemicals exhibit anti-inflammatory, antioxidant, antimicrobial, anticancer, analgesic, and appetite-stimulating activities via multiple pathways, including COX-2 inhibition, NF-κB suppression, PUMA-mediated apoptosis, and microbial membrane disruption. Additionally, its essential minerals and dietary fiber contribute to metabolic regulation. However, variations in composition due to cultivation and extraction methods present challenges for product standardization and clinical application.
Conclusion: The therapeutic value of K. *galanga* is strongly linked to its diverse phytochemicals, particularly EPMC and flavonoids. Standardization of these constituents alongside further preclinical and clinical investigations are essential to validate its efficacy as a scientifically supported nutraceutical ingredient.

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Introduction

Kaempferia *galanga* L., commonly known as kencur in Indonesia, is an aromatic rhizome belonging to the family Zingiberaceae. It has long been recognized as a traditional medicinal plant and culinary spice, particularly in China, Malaysia, Thailand, Indonesia, and India. Traditionally, K. *galanga* has been utilized both as a flavoring agent in food and as a key ingredient in herbal remedies, reflecting its multifunctional role in daily life (Srivastava et al, 2019).

Figure 1. *Kaempferia galanga L.*, commonly known as *kencur* in Indonesia and their rhizomes

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Beyond its traditional applications, K. *galanga* has attracted increasing scientific interest due to its potential nutritional and health-promoting properties. The rhizome contains various bioactive compounds, including flavonoids, phenolic compounds, and essential oils, which are associated with antioxidants, anti-inflammatory, antimicrobial, and other therapeutic effects. These properties suggest that K. *galanga* may serve not only as a culinary spice but also as a functional ingredient with potential benefits for human health. Nonetheless, the effectiveness of these compounds is not solely determined by their presence, but by how they are consumed and processed by the body (Khairullah et al, 2021).

Despite its widespread use, a comprehensive synthesis that links the nutritional composition of K. *galanga* with its specific phytochemical profile and resulting health benefits is still needed to validate its therapeutic potential. This review aims to provide an in-depth phytochemical perspective on the nutritional and health-promoting properties of this rhizome. By examining the major bioactive constituents and their biological activities, this paper seeks to establish a scientific foundation for the further development of K. *galanga* as a functional food ingredient and a source of natural medicine.

The macronutrients of K. *galanga*, including proteins and dietary fibers highlights their role as a significant functional food ingredient. Proximate and micronutrient analyses reveal that K. *galanga* is particularly rich in essential minerals, such as potassium (K), phosphorus (P), and magnesium (Mg), while also containing significant amounts of iron (Fe), manganese (Mn), zinc (Zn), cobalt (Co), and nickel (Ni). Furthermore, the carbohydrate content of the rhizome is specifically linked to energy metabolism, where its extracts have been shown to enhance glucose uptake and stimulate ATP production through specific signaling pathways (Hashiguchi et al, 2022).

This nutritional synergy is exemplified in beras kencur, where roasted rice acts as a functional food matrix and supplementary energy source. The boiling process induces starch gelatinization, providing the beverage with its characteristic viscosity and mouthfeel. While rice contributes bioactive compounds like γ-oryzanol and chlorogenic acid, its interaction with kencur is scientifically proven to exhibit potent antidiabetic, anti-inflammatory, and antioxidant activities. Studies indicate that this formulation effectively regulates blood glucose and repairs pancreatic damage, while the kencur component specifically drives its traditional role as an appetite enhancer (Rias et al 2020 ; Estiasih et al 2025).

The rhizome of K. *galanga* functions as a complex biochemical system capable of synthesizing diverse secondary metabolites as part of its natural defense mechanisms. Within this matrix, alkaloids represent a significant class of nitrogenous organic compounds, with concentrations reaching 58.008% in micro rhizomes and 31.24% in mini rhizomes. As a collective chemical group, alkaloids are distinguished by their ability to modulate physiological processes through interactions with neurotransmitter systems, such as dopamine, within the central nervous system (Preetha et al 2022).

Based on their physicochemical properties, these metabolites are broadly classified into two major groups for analytical purposes: volatile and non-volatile compounds. Volatile compounds are primarily responsible for the characteristic aroma of the rhizome and are typically obtained through distillation processes, whereas non-volatile compounds are extracted using organic solvents and comprise various bioactive constituents with functional and pharmacological relevance (Preetha et al, 2022 ; Singh et al, 2022) An overview of the experimental workflow is illustrated in Figure 2.

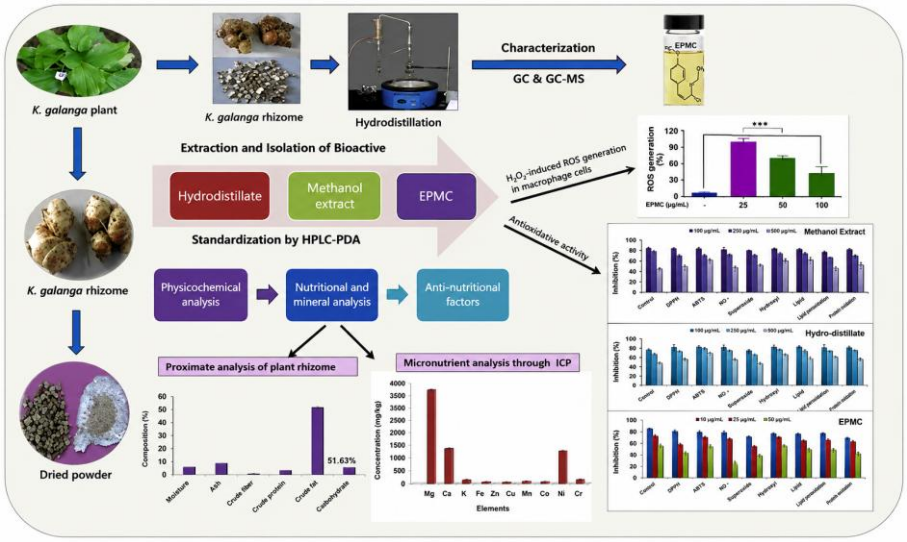

Figure 2. Extraction, isolation, and characterization of bioactive compounds in *Kaempferia galanga L.*, illustrating the analytical methods and bioactivity validation processes**.**

Volatile compounds in K. *galanga* are primarily localized within the aromatic essential oil of the rhizome, typically constituting between 2.4% and 3.9% of its total composition. These metabolites are what determine the plant's characteristic aroma and sensory profile. For precise identification and structural characterization, methodologies such as Gas Chromatography-Mass Spectrometry (GC-MS) and Nuclear Magnetic Resonance (NMR) are employed (Preetha et al, 2022 ; Chittasupho et al, 2022)

Among these compounds, Ethyl p-methoxycinnamate (EPMC) is identified as the most abundant and vital volatile constituent. Its concentration exhibits significant variability across different rhizome types, reaching a peak of 39.42% in mini rhizomes compared to 9.21% in micro rhizomes. This is followed by Ethyl cinnamate, a major ester that defines the plant's aromatic complex, present at 3.57% in mini rhizomes and 1.349% in micro rhizomes. Additionally, the volatile profile includes Borneol, a specific terpenoid measured at 4.49% in mini rhizomes and 1.482% in micro rhizomes [6,8]. Other minor but functional volatile molecules, such as 1,8-cineole, camphene, δ-3-carene, α-pirene, limonene, and pentadecane, further contribute to the antimicrobial and aromatic properties of the essential oil (Chittasupho et al, 2022 ; Wang et al, 2023).

Non-volatile compounds remain stable in solid form or solvent extracts and encompass the plant's nutritional and phenolic constituents, which include specific bioactive markers such as gingerol, shogaol, and gingeron found within the Zingiberaceae family. These are typically analysed through High-Performance Liquid Chromatography (HPLC) and Liquid Chromatography-Mass Spectrometry (LC-MS) to ensure precise characterization, while UV-Visible spectrophotometry is utilized to quantify the Total Phenolic Content (TPC) to estimate the plant's antioxidant potential (Wahyuni et al, 2022).

A major non-volatile phenolic compound is kaempferol, a flavonoid found consistently in all rhizome varieties, noted for its high antioxidant capacity and its role in inhibiting inflammatory enzymes such as COX and NF-κB (Preetha et al, 2022 ; Affandy et al, 2019). The concentration of these non-volatile phenolics is significantly influenced by the geographical accession and altitude of the planting site; for instance, research shows that the Purworejo accession yields the highest total phenolic content at approximately 26.83 mg GAE/g of extract. The recovery of these compounds is highly dependent on the extraction solvent, with 96% ethanol identified as the most effective medium for maximizing phenolic yield compared to 50% ethanol or water (Wahyuni et al, 2022).

Furthermore, the non-volatile matrix reveals a rich essential mineral profile, including high levels of potassium (K), magnesium (Mg), and phosphorus (P), along with trace elements like iron (Fe) and zinc (Zn). These are complemented by substantial macronutrients, with the rhizome being composed of carbohydrates (72.04%), fiber (7.93%), and protein (5.92%), which collectively establish K. *galanga* as a valuable functional food source (Preetha et al, 2022 ; Hashiguchi et al, 2022). Beyond nutrition, these phenolic constituents act as a protective shield for the human body, helping

to prevent oxidative damage and reducing the risk of chronic illnesses such as cancer and coronary heart disease (Wahyuni et al, 2022).

The therapeutic efficacy of K. *galanga* is largely derived from its complex volatile and non-volatile constituents. Ethyl p-methoxycinnamate (EPMC) and ethyl cinnamate, identified as the primary esters in the rhizome extract, have been scientifically proven to suppress inflammatory mediators. At the molecular level, these compounds function by inhibiting the mRNA expression of the nitric oxide synthase gene and suppressing the production of cyclooxygenase-2 (COX-2), which are central to the body's inflammatory response. This significant anti-inflammatory capacity, combined with potent analgesic activity, supports the effectiveness of kencur in managing chronic inflammatory conditions such as rheumatism, asthma, and joint pain, with benefits that extend far beyond temporary pain relief (Khairullah et al, 2021).

Furthermore, Kaempferol, a flavonol also prevalent in Camellia sinensis (tea) and Brassica oleracea (kale), inhibits key inflammatory pathways by suppressing enzymes like COX and transcription factors such as NF-κB (Khairullah et al, 2021 ; Wahyuni et al, 2022). By reducing the production of pro-inflammatory cytokines, kaempferol supports gut health and appetite regulation, as inflammation often disrupts normal digestive functions. Additionally, the presence of Borneol—a terpene also found in Salvia officinalis (sage)—contributes to the plant's analgesic effects by reducing inflammatory mediator levels, positioning K. *galanga* as a comprehensive natural remedy for conditions like arthritis (Affandy et al, 2019 ; Niziński et al, 2025).

Traditionally utilized as an appetite enhancer, scientific evidence confirms that the oral administration of kencur-based preparations, such as the traditional beverage beras kencur, significantly increases appetite levels in subjects (Estiasih et al, 2025). This physiological response is closely linked to the modulation of Ghrelin, an orexigenic peptide predominantly secreted in the stomach that acts as a "hunger hormone" to initiate food intake and regulate energy metabolism (Kadioglu et al, 2015). The potency of K. *galanga* in this regard is attributed to its abundant bioactive constituents, most notably Ethyl p-methoxycinnamate (EPMC). The concentration of EPMC exhibits significant variability depending on the rhizome type, reaching peak levels of 58.008% in micro-rhizomes and 39.42% in mini rhizomes (Khairullah et al, 2021; Preetha et al, 2022).

In addition to stimulating hunger, K. *galanga* and the ghrelin system provide comprehensive gastrointestinal support by influencing vital digestive functions. Ghrelin is known to affect gastric acid secretion, enhance gastric motility, and regulate pancreatic protein output. Furthermore, the plant's bioactive compounds, including EPMC and ethyl cinnamate, exhibit potent anti-inflammatory properties that protect the gastrointestinal tract by suppressing mediators such as cyclooxygenase-2 (COX-2) and nitric oxide (Kadioglu et al, 2015 ; Mohamed and Abdalla, 2015). These actions are instrumental in treating intestinal injuries and promoting the healing of the mucosal epithelium (Khairullah et al, 2021 ; Mohamed and Abdalla, 2015) . In traditional formulations, this support is often complemented by rice, which undergoes starch gelatinization during processing to provide necessary metabolic energy and desired viscosity, thereby fostering a balanced environment for nutrient absorption and overall metabolic energy support (Estiasih et al, 2015).

The anti-cancer potential of K. *galanga* is primarily driven by its major constituent, ethyl p-methoxycinnamate (EPMC). Research indicates that EPMC induces cytotoxicity and apoptosis (programmed cell death) across various cancer cell lines, notably lung cancer (A549 and H1299). A significant finding in its molecular mechanism is the induction of apoptosis via the upregulation of PUMA protein, independent of the p53 pathway. This suggests that EPMC remains a potential therapeutic agent even in cancer cells with p53 mutations, which are often resistant to traditional treatments (Jiao and Luo, 2022). Beyond lung cancer, EPMC exhibits a broad spectrum of activity against colon (SW620), cervical (C33A), breast (MCF-7), oral (HSC-3), and bile duct (cholangiocarcinoma) cancers (Jauhari et al 2020).

Additionally, kaempferol acts as a critical protein modulator, particularly reducing the risks of lung and pancreatic cancers by inhibiting free radicals that drive oncogenesis. To address the low aqueous solubility and bioavailability of EPMC, recent advancements in nanotechnology, such as polydopamine (PDA) nanoparticle delivery systems, have been shown to significantly enhance the efficacy of K. *galanga* extracts in inhibiting colon cancer (HT-29) cell growth (Amuamuta et al 2017).

The antioxidant capacity of K. *galanga* is attributed to its high Total Phenolic Content (TPC) and Total Flavonoid Content (TFC), recorded at 10.93 µg GAE/mg and 5.67 QE µg/mg, respectively

[18]. The essential oil (KGEO) demonstrates robust free-radical scavenging abilities across DPPH, ABTS, and hydroxyl assays. In vivo studies confirm that the rhizome enhances the activity of endogenous antioxidant enzymes, including Superoxide Dismutase (SOD), Catalase (CAT), and GSH-Px, while simultaneously reducing levels of malondialdehyde (MDA), a key marker of oxidative cellular damage (Laksmitawati et al, 2021).

In a comparative review with Red Ginger (Zingiber officinale var. Rubra), K. *galanga* exhibits a higher TPC and TFC. While Red Ginger may show superior results in DPPH and ABTS assays, K. *galanga* is notably more potent in neutralizing hydrogen peroxide (H2O2) and demonstrates a higher Ferric Reducing Antioxidant Power (FRAP) at elevated concentrations. This synergy of EPMC, kaempferol, and other derivatives like ethyl cinnamate and cinnamaldehyde positions K. *galanga* not only as a direct cytotoxic agent against malignancy but also as a protective shield against oxidative stress-induced chronic diseases (Jauhari et al 2020 ; Dana et al, 2025).

K. *galanga* possesses broad-spectrum antimicrobial properties that are highly effective against various bacterial pathogens, including Staphylococcus aureus, Escherichia coli, Listeria monocytogenes, and Bacillus cereus. Its primary constituents, Ethyl-p-methoxycinnamate (EPMC) and essential oils such as borneol and camphene, function by disrupting microbial cell membranes, leading to protein degradation and cell death via lysis (Laksmitawati et al, 2021 ; Fareza et al 2017). Kencur extract exhibits significant synergistic effects when combined with commercial antibiotics like ampicillin, meropenem, and cefuroxime, offering a promising strategy to combat antibiotic resistance (Susilo and Pratomo, 2025). Beyond its antibacterial capabilities, kencur essential oil at concentrations of 0.5% to 1% has been proven to inhibit the growth of dermatophytes, such as Trichophyton rubrum and Trichophyton mentagrophytes (Fahrinda et al 2018).

These antimicrobial characteristics are shared across the Zingiberaceae family; similar terpenes and synergistic properties are found in Curcuma longa (turmeric) and Zingiber officinale (ginger), reflecting a common natural defense mechanism. The clinical and industrial potential of K. *galanga* is vast, as its ability to inhibit multidrug-resistant strains of Mycobacterium tuberculosis suggests a vital role in infection control. Additionally, its efficacy against food-borne pathogens positions it as an effective natural preservative for food products, particularly poultry. By significantly enhancing the inhibitory zones of standard antibiotics, kencur serves as a potent botanical tool for addressing the global challenge of drug-resistant infections (Fareza et al 2017; Susilo and Pratomo, 2025).

Even though K. *galanga* has been used for decade in traditional medicine, there are still issues with scientifically proving its health advantages. Variability in bioactive chemical concentrations, which are impacted by several factors such plant age, extraction techniques, and growing site, is one of the main problems. These variables have a substantial impact on the primary active ingredient, ethyl trans-p-methoxycinnamate, which makes standardization more difficult. Meanwhile, treatment efficacy is impacted by the precision of raw material selection in conventional markets, underscoring the significance of quality control. Its promise as an anti-inflammatory, antibacterial, and appetite-enhancing drug is demonstrated by several bioactivity investigations (Lely et al, 2017 ; Jacob et al, 2025). Antihyperglycemic activity of K. *galanga* in streptozotocin (STZ)-induced diabetic mice and the mechanism by which it elicits its response already published (Tarasuk et al, 2024). K. *galanga* ethanolic extract (KGE) at 350 mg/kg b.w. was selected as the ideal dose. Revealed bio-active compound ethyl-p-methoxy cinnamate found in KGE shows good binding energy with the target protein AKT, GSK3, insulin receptor, protein-tyrosine phosphatase 1B, glucokinase, and phosphoenolpyruvate carboxykinase, indicating a good binding interaction.

The growing demand for natural and health-oriented products positions K. *galanga* as an ideal candidate for nutraceutical innovation. It can be incorporated into various product formats, including herbal beverages, dietary supplements, and functional powders, catering to modern consumer preferences. Moreover, the cultural significance of kencur offers an opportunity to showcase Indonesia's heritage while aligning with sustainability and health trends in global markets (Nonglang et al, 2025).

Taking advantage of its historical use in drinks like beras kencur, K. *galanga* can be used to make herbal drinks like teas or infusions. These beverages can provide customers with natural benefits that improve digestion and appetite, which is consistent with the growing trend of functional beverages that blend convenience and health benefits. It is a good base for ready-to-drink herbal

beverages because procedures like blanching and pasteurization increase antioxidant activity and microbiological safety (Jiang et al, 2021). The bioactive compounds found in K. *galanga*, including essential oils and flavonoids, can be standardized, and encapsulated into dietary supplements. These supplements can provide targeted health benefits, such as anti-inflammatory and antimicrobial effects, appealing to health-conscious individuals seeking natural alternatives (Khairullah et al, 2021).

To reach its full potential in industrial and nutraceutical applications, K. *galanga* requires more extensive research and clinical studies. This is crucial to validate its health benefits, ensure safety, and establish clear dosage guidelines, thereby bridging the gap between traditional and modern medicine (Hidayatullah et al, 2021). For example, by processing it into fine powders, K. *galanga* can be integrated into various food products like smoothies and meal replacements, offering convenience and promoting health-conscious innovation. Its widespread adoption, however, depends on investments in scalable production technology and strict quality control measures. With its strong traditional legacy and promising bioactive profile, K. *galanga* is well-positioned to become a flagship ingredient in the nutraceutical industry, seamlessly blending tradition with innovation (Khairullah et al, 2021 ; Che 2023).

Methode

This study employed a narrative literature review approach to evaluate the nutritional composition, phytochemical profile, and health-promoting properties of *Kaempferia galanga* L. (kencur). The review was conducted through a comprehensive analysis of scientific publications focusing on the identification of bioactive compounds, extraction methods, analytical characterization, and reported biological activities of *K. galanga*.

Relevant literature was collected from peer-reviewed scientific journals, including studies investigating the phytochemical constituents and pharmacological activities of *K. galanga* . Articles describing the chemical composition of kencur rhizomes, particularly volatile and non-volatile metabolites, were prioritized. Studies utilizing analytical approaches such as Gas Chromatography–Mass Spectrometry (GC-MS), High-Performance Liquid Chromatography (HPLC), Liquid Chromatography–Mass Spectrometry (LC-MS), and spectrophotometric analysis were included to assess the reliability of compound identification and quantification.

Result and Discussion

Result

The collected studies were critically reviewed and synthesized according to several major themes: (1) nutritional composition and traditional food applications, (2) phytochemical composition including volatile and non-volatile compounds, (3) biological activities such as antioxidant, anti-inflammatory, antimicrobial, anticancer, analgesic, and appetite-enhancing effects, and (4) challenges associated with standardization and nutraceutical development.

Discussion

Alkaloid concentrations were found to be highly significant, reaching 58.008% in micro rhizomes and 31.24% in mini rhizomes, which are noted for modulating physiological processes through interactions with central nervous system neurotransmitters like dopamine. However, the concentration of the primary bioactive constituent, EPMC, exhibited substantial variability depending on the rhizome type, peaking at 39.42% in mini rhizomes and ranging up to 58.008% in micro rhizomes. The total phenolic content was also significantly influenced by geographic accession and planting altitude, with the Purworejo accession yielding the highest concentration at 26.83 mg GAE/g of extract. Furthermore, the recovery efficiency of these bioactive compounds heavily depends on the extraction solvent, with 96% ethanol identified as the most effective medium compared to 50% ethanol or water. In terms of therapeutic pathways, EPMC was proven effective in inducing cancer cell apoptosis independently of the p53 pathway, making it a potential therapeutic agent against p53-mutated, treatment-resistant cancer cells. To overcome the low aqueous solubility of EPMC, encapsulation into polydopamine (PDA) nanoparticle delivery systems successfully enhanced its efficacy in inhibiting colon cancer (HT-29) cell growth. In a comparative analysis with Red Ginger (Zingiber officinale var. Rubra), K. *galanga* exhibited higher total phenolic content (TPC) and total flavonoid content (TFC), demonstrated superior potency in neutralizing hydrogen peroxide

H_2O_2, and showed higher Ferric Reducing Antioxidant Power (FRAP) at elevated concentrations. The traditional beverage beras kencur was scientifically proven to exhibit potent antidiabetic, anti-inflammatory, and antioxidant activities, effectively regulating blood glucose, repairing pancreatic damage, and modulating the Ghrelin hormone system to enhance appetite and protect the gastrointestinal tract. Finally, kencur extract displayed powerful synergistic effects when combined with commercial antibiotics such as ampicillin, meropenem, and cefuroxime, offering a promising botanical strategy to combat antibiotic resistance, including multidrug-resistant strains of Mycobacterium tuberculosis.

Implications

Kaempferia *galanga* holds strong prospects for integration into the modern functional food and manufacturing industries, including formats like ready-to-drink herbal beverages, encapsulated dietary supplements, and functional meal replacement powders. Its broad-spectrum antimicrobial efficacy against food-borne pathogens positions kencur essential oils or extracts as effective natural preservatives for food products, particularly poultry. Furthermore, leveraging the cultural heritage of kencur, such as traditional jamu, presents a major opportunity to showcase indigenous heritage in global markets while aligning with current sustainability and health-conscious consumer trends.

Research Contribution

This article successfully provides a comprehensive synthesis and an in-depth phytochemical perspective linking the specific nutritional profile of kencur with its resulting biological and therapeutic mechanisms. By doing so, the study establishes a solid scientific foundation to validate the traditional uses of kencur, supporting its structural optimization from a common culinary spice into a scientifically backed nutraceutical and natural medicine ingredient.

Limitations

There is high variability in the concentration of major bioactive compounds, especially the primary active ingredient, ethyl trans-p-methoxycinnamate, due to factors such as plant age, extraction methodologies, and geographical cultivation sites. These variations in raw material selection and quality in traditional markets create challenges for maintaining consistent product quality control and standardization. Additionally, the primary active compound, EPMC, suffers from poor aqueous solubility and low bioavailability within the body.

Suggestions

Stringent standardization of specific secondary metabolites, particularly EPMC and flavonoids, through tightly controlled cultivation and extraction methods is highly required to ensure consistent therapeutic efficacy. Further financial and technical investments are also needed in scalable production technologies and rigorous quality control measures for industrial applications. Ultimately, more extensive future research and human clinical trials are essential to rigorously validate health benefits, guarantee safety profiles, and establish clear, safe dosage guidelines to bridge the gap between traditional use and modern medicine.

Conclusion

This review confirms that the therapeutic and nutritional value of Kaempferia *galanga* L. is intrinsically linked to its complex phytochemical profile, particularly its high concentration of phenylpropanoids and flavonoids. The primary bioactive constituent, ethyl p-methoxycinnamate (EPMC), serves as the cornerstone of its pharmacological activity by suppressing inflammatory mediators, inducing cancer cell apoptosis, and disrupting microbial membranes. These effects are further enhanced by kaempferol and borneol, which provide potent antioxidant scavenging and analgesic properties. From a nutritional perspective, the synergy between these non-volatile phenolics and essential minerals positions K. *galanga* as a superior functional food ingredient capable of modulating physiological processes like appetite stimulation. Consequently, future development must focus on the standardization of these specific secondary metabolites to ensure consistent efficacy in nutraceutical and pharmaceutical applications.

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