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Kaempferia galanga L. - an Aromatic Ginger with Anticancer Properties

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ABSTRACT

***Kaempferia galanga* L. (KG) is a valuable plant of Zingiberaceae family with therapeutic potential. KG, commonly known as aromatic ginger, is widely cultivated in Southeast Asian countries such as Indonesia, Thailand, Malaysia, Vietnam, and Cambodia. However, it is renowned for its high-value essential oil, which has medical and economic importance beyond South Asia because of its multiple pharmacological applications. The chemical composition of its aromatic oil also offers diverse nutritional benefits. KG has antioxidant, antibacterial, anti-inflammatory, and anticancer properties. Extracts and bioactive constituents derived from KG have demonstrated promising inhibitory effects against various tumor types, including colon cancer, gastric cancer, oral cancer, and multiple myeloma. This article provides information on the botanical characteristics, distribution, chemical composition, and anticancer properties of KG, offering an overview of its pharmacological and industrial potential.**

INTRODUCTION

For ages, herbal remedies have served as the major healthcare resource for ethnic and tribal cultures. *Kaempferia galanga* L. (KG) is a well-known perennial herb, widely used as a folk or

traditional remedy in a number of South Asian countries. KG is a stemless, rhizomatous, fragrant perennial plant from the family Zingiberaceae and the genus *Kaempferia*. The underground rhizomes of the plant are extensively utilized in Ayurveda and folklore remedies by local healers in the Indian subcontinent. The scientific documentation of this ethnomedicinal plant's applications may significantly contribute to the identification of novel and safe herbal medications. Researchers have done several ethnobotanical investigations to gather crucial information on the traditional applications of KG. Additionally, the rhizome of KG is distinctly fragrant and has been factually utilized for spices, flavours, scents, and cosmetics (Yao *et al*., 2018). KG is a valuable medicinal plant, recognised in Ayurveda due to its properties as a stimulant, carminative, expectorant, diuretic, anticancerous, and antipyretic. It is particularly utilized in the treatment of indigestion, flatulence, gastroenteritis, intestinal injuries, diarrhoea, cramping in the abdomen, snake venom, ear inflammation, whooping cough, respiratory ailments, dry scalp, hair loss, headaches, osteoarthritis, haematemesis, oral ulcers, menstrual discomfort, high blood pressure, dizziness, asthma, Type 2 diabetes, injury, and fractured bones.

ORIGIN AND DISTRIBUTION

KG is native to Bangladesh, Cambodia, India, Myanmar, South-Central China, Sri Lanka, Thailand, and Vietnam, whereas the species is exotic to Southeast China, Malaya, Maluku, the Philippines, and Taiwan. The species is prevalent in India, and also found in China, Myanmar, Bangladesh, Sri Lanka, Thailand, Indonesia, Japan, Nigeria, Malaysia, Laos, Java, Sudan, Vietnam, and South Africa (reviewed by Kumar, 2020) (Figure 1).



Figure 1. Geographical distribution of *Kaempferia galanga* L. around the globe (Source: https://www.gbif.org)

In the Indian subcontinent, it is extensively found in the north-east states such as Manipur, Meghalaya, Assam, and Arunachal Pradesh, as well as in southern states like Kerala, Andhra Pradesh, and Karnataka, along with eastern regions like West Bengal and Odisha. KG is a fragrant- and rhizomatous-type plant. This species proliferates in damp, open, and partially shaded regions of forests, including forest edges, evergreen and deciduous forests, dense forests of the Eastern Ghats, as well as in grasslands or mountainous regions, and is also cultivated in gardens across diverse types of soils at elevations of 50–400 m. The habitat of this species has diminished significantly because of overexploitation, resulting in its possible

vulnerability in the Indian subcontinent. To figure out the conservation requirement of KG, substantial research needs to be done (Olander, 2020).

BOTANY

KG possesses a small stalk and green, spherical foliage that ranges from 3 to 6 inches in diameter. It typically reaches an ultimate length of 30 cm, but it is frequently smaller and has thick, ovoid, scented, rooted tubers. Often, three (or occasionally more) wide, round leaves that extend parallelly over the soil (Figure 2a) are found. Sessile leaves, oval, thin, deltoid-acuminate, and dark green (Figure 2b). The leaf petioles are compact and channelled; irregular flowers, bisexual, and white, measuring 6–12 cm from the plant's centre between the leaves, fragrant, and opening subsequently. Bracts are lanceolate, green in color, and short in length; long calyces are found as the exterior bracts and are cylindrical. Flowers hold three petals (Figure 3a, b), with a corolla tube measuring 2–2.5 cm in length, lance-shaped, and pure white. Singular stamens, perfect flowers, having short, acute filaments with a two-celled anther with discrete cells. Blooming begins in June and terminates in September. The blooms are white, adorned with a purple patch at the apex of petals (Figure 3c), are transitory, emerging from the middle of the mature plant, and reaching around 2.5 cm in diameter. The plant flourishes and matures especially during the wet season. The blossoms emit a remarkable fragrance reminiscent of orchids. The perfume of the rhizome is fragrant, but its flavour is sharp and piquant. Rhizomes are notably robust and challenging to split, exhibiting a granular break (Figure 2c,e), with tiny, woody fibres dispersed throughout one side.

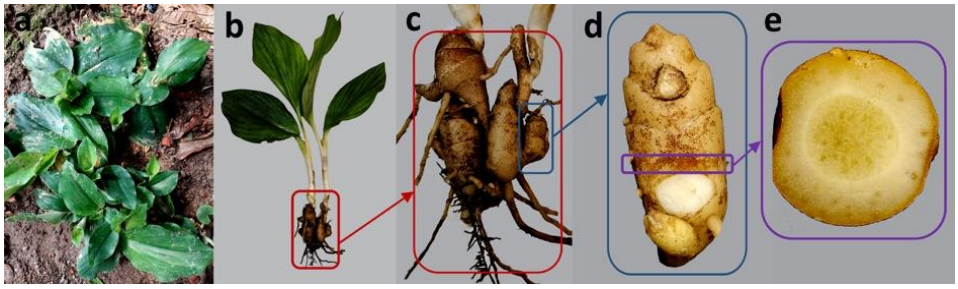


Figure 2. Salient botanical traits of *Kaempferia galanga* L. plant and rhizome. a. full-grown plant, b. matured uprooted plant with rhizomes, c. multiple rhizomes with roots, d. individual rhizome morphology, e. cross section of rhizome (not in scale) (*Source*: unpublished photographs of Saikat Gantait)

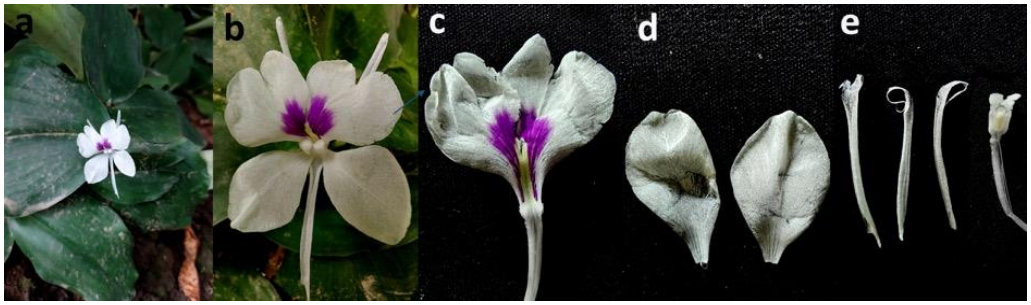


Figure 3. Salient botanical traits of *Kaempferia galanga* L. flower. a. full-grown blooming plant, b. complete flower, c. labellum, d. lateral lobes, and e. stigma (not in scale) (*Source*: unpublished photographs of Saikat Gantait)

PHYTOCHEMISTRY

KG exudes a unique camphoraceous aroma, which is indicative of its rich and complex phytochemical composition. Studies have consistently revealed that predominant volatile esters like ethyl *p*-methoxycinnamate and ethyl cinnamate are present in the essential oils of KG. These biomolecules are largely accountable for the characteristic pungent aroma in plants and serve as key bioactive agents. Amongst the dominant constituents, pentadecane, ethyl *p*-methoxycinnamate, and propanoic acid have been prominently reported (Khairullah *et al*., 2021). In addition to these major volatiles, the essential oil contains a suite of bioactive compounds such as apigenin, alpha-terpineol, borneol, camphene, delta-3-carene, kaempferol, luteolin, caryophyllene, cadinenes, alpha-pinene, eucalyptol, and 1,8-cineole. Several esters, including trans-octa-2,4-dienyl acetate, ethyl cyclohexyl acetate and trans, and ketones like 2-heptadecanone and 2-nonanone, have also been isolated (Sutthanont *et al*., 2010). Comparative studies between the two widely cultivated varieties Kasthuri and Rajani revealed the presence of 58 and 56 volatile constituents, respectively. Despite such variability, ethyl *p*-methoxycinnamate and trans-ethyl cinnamate remain consistently dominant across the varieties. These esters contribute not only to the plant's aroma but also to its bioactivity, including antimicrobial, anticancer, and anti-inflammatory effects. Studies have identified 16 distinct phenolic constituents. These include hydroxybenzoic acid derivatives such as p-methoxybenzoic acid, vanillic acid, and p-hydroxybenzoic acid, along with hydroxycinnamic acid derivatives like ferulic acid, trans-p-hydroxycinnamic acid, and trans-p-methoxycinnamic acid (Figure 4). In KG, the flavonoids identified are primarily free aglycones, including kaempferol, luteolin, and kaempferide. Kaempferol, in particular, exhibits potent anticancer activity.

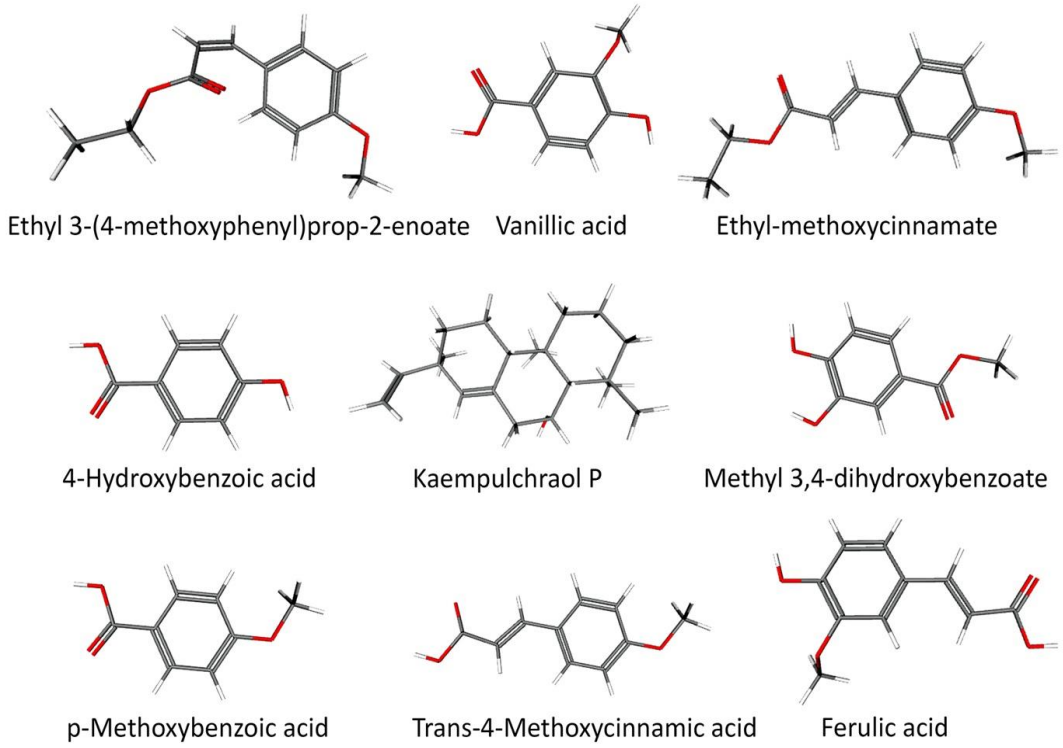


Figure 4. Some of the key phytochemicals found in different parts *Kaempferia galanga* L., known for their anticancer properties
(*Structure source*: https://pubchem.ncbi.nlm.nih.gov/)

ANTICANCER PROPERTIES

Reactive oxygen species (ROS), accumulated during normal metabolic processes like respiration and immune responses, can become detrimental when produced in excess. Overproduction of ROS contributes to the onset and advancement of chronic diseases like cancer, cardiovascular ailments, and inflammatory disorders. ROS-induced damage to DNA, lipids, and proteins plays a critical role in carcinogenesis. The relentless burden of cancer worldwide demands innovative and safe therapeutic strategies. While modern treatments such as chemotherapy and radiation are effective, they are often accompanied by significant side effects. This has increased interest in traditional remedies, particularly plant-based therapeutics, as alternative or complementary options. Despite the widespread use of synthetic antioxidants such as BHT and BHA, safety concerns have driven the search for safer, natural substitutes. In this context, KG emerges as a promising source of phytochemicals with potent antioxidant and antineoplastic properties.

According to several previous studies, extracts and bioactive constituents derived from KG have demonstrated promising inhibitory effects against various tumor types, including colon carcinogenesis, gastric cancer, oral cancer, and multiple myeloma (Wang *et al*., 2018). Research indicates that the anticancer activity of KG is mediated through diverse molecular mechanisms, viz. modulation of apoptosis-related signaling pathways, cell cycle arrest, suppression of angiogenesis, inhibition of metastasis, and immunomodulatory effects. Both cis-and trans-ethyl p-methoxycinnamate, major constituents of KG*,* have demonstrated significant anticarcinogenic effects in vitro. The herb contains a wide array of bioactive constituents, including ethyl p-methoxycinnamate (EPMC), trans-ethyl cinnamate, diarylheptanoids, polysaccharides, and essential oils that exhibit antitumor, antioxidant, and antimicrobial (Ridtitid *et al*., 2008; Hanumantharaju *et al*., 2010). The anticancer efficacy of KG is primarily attributed to a constellation of phytochemicals that orchestrate a multi-targeted therapeutic response. Among its most studied constituents, ethyl p-methoxycinnamate (EPMC) and trans-ethyl cinnamate, which are abundant in the rhizomes, have demonstrated potent cytotoxic effects against various cancer cell lines. Extensive in vitro research has demonstrated the cytotoxic ability of KG against a wide range of human cancer cell lines like HSC-3 and Ca922 oral cancer cells (Ichwan *et al*., 2019) and a spectrum of human cancer cell lines, along with cervical (HeLa), breast (MCF-7), colon (LS174T, SW620), and liver (HepG2) cancers (Mahavorasirikul *et al*., 2010). Volatile oil extracted from KG demonstrated a dose-dependent suppression of MKN-45 gastric cancer cell growth, accompanied by cell cycle arrest at the G0/G1 phase (Xiao *et al*., 2006). Beyond its essential oils, the ethanolic extract of KG and its major bioactive compound, trans-ethyl p-methoxycinnamate, have demonstrated significant cytotoxic effects against CL-6 cholangiocarcinoma cells. Further supporting its cytotoxic capabilities, Rahman *et al*. (2019) demonstrated that methanolic and acetonic extracts of KG leaves exhibited moderate cytotoxicity in a brine shrimp lethality assay. Although preliminary, these bioassays serve as a cost-effective indicator of antitumor activity. The extract exerted its antitumor effects by inducing morphological changes indicative of apoptosis, reducing viable tumor cell counts, and improving hematological parameters. Collectively, these studies underscore the therapeutic relevance of KG and its bioactive constituents in modulating tumorigenesis through both direct cytotoxic effects and immune-mediated mechanisms. In addition to in vitro evidence, several in vivo investigations have confirmed the anticancer efficacy of KG across a range of experimental models. The administration of p-methoxycinnamic acid significantly decreased 1,2-

dimethylhydrazine (DMH)-induced colon cancer in Wistar rats (Gunasekaran *et al*., 2019). In another model, polysaccharides isolated from KG rhizomes inhibited tumor growth alongside enhanced immune response on H22 tumor-bearing mice (Yang *et al*., 2018).

Recently, to enhance the bioavailability and targeting efficiency of KG constituents, polydopamine-based nanoparticles (PDA-KGL) have been developed. These nano-formulations demonstrated superior cytotoxicity and apoptosis induction in HT-29 colorectal cancer cells compared to free EPMC or PDA alone. PDA-KGL also inhibited cell invasion, suggesting its potential as an effective nano-drug dispersion system for colorectal cancer therapy (Dana *et al*., 2025). Polydopamine (PDA)-based nanoparticles have emerged as versatile carriers for anticancer drugs and imaging agents due to their biocompatibility, surface functionalization capability, and photothermal properties. These drug-loaded nanoparticles exhibit effective tumor-targeting behavior, primarily through the enhanced permeability and retention (EPR) effect, which facilitates their accumulation in tumor tissues while minimizing systemic drug leakage (Batul *et al*., 2017; Wang *et al*., 2018).

Together, these compounds exhibit complementary and often overlapping mechanisms ranging from apoptosis induction and immune modulation to oxidative stress mitigation and antimetastatic effects making KG a compelling phytotherapeutic candidate for integrative oncology.

CONCLUSION

There are various bioactive constituents including phenolics, flavonoids, fatty acids, and cyclic dipeptides. Pharmacological studies confirm its anticancer potential, though research has primarily focused on crude extracts (especially volatile oils and ethanol extracts), while the mechanisms and exact targets remain unclear. Notably, the phytochemistry of the leaves remains underexplored. Innovative tools like natural product DNA-encoded libraries (nDEL) offer promise for identifying bioactive targets and advancing compound discovery. To ensure future development, systematic toxicology assessments, genetic improvement strategies, and agrotechnological innovations are essential. Genomic tools and metabolite profiling can support improved cultivation, yield, and therapeutic standardization. Clarifying biosynthetic pathways and integrating proteomics may further enhance bioprospecting. Additionally, dual-quality control systems combining chemical and effect benchmarks should be developed to strengthen product standardization and quality assurance. In a nutshell, KG holds significant therapeutic and economic promise, and targeted research in phytochemistry, molecular biology, and quality control is vital to fully realize its potential.

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