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A comprehensive review of *Kaempferia galanga* L. (Zingiberaceae): A high sought medicinal plant in Tropical Asia

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Abstract
Kaempferia galanga L. (Family Zingiberaceae) is an endangered medicinal plant with potent medicinal activities. The leaves, rhizome and root tubers of the plant possess a number of medicinal applications. The plant is economically important and is over exploited to the extent that there is always scarcity of propagating material (rhizomes) which is the consumable part too. As it is vegetatively propagated, its conservation *via* conventional and non-conventional means is very much crucial. The present review provides broad information of *K. galanga* throwing light on its current status, economic value, agronomy, ethnobotany, phytochemistry, pharmacology and conservation strategies.

Keywords: *Kaempferia galanga*, economic value, agronomy, ethnobotany, phytochemistry, pharmacology, conservation

Introduction
The genus *Kaempferia* L. includes approximately 60 species distributed in Tropical Africa to India and South East Asia [65]. The generic name commemorates Engelbert Kaempfer (1651-1716), a German naturalist and physician [42]. *K. galanga* L., *K. rotunda* L. and *K. scaposa* (Nimmo) Benth. and Hook. are the species present in South India. *Kaempferia elegans* Wall. an ornamental species from Malaysia is grown in gardens and popularly called 'peacock ginger'. *Kaempferia galanga* L. is known as *sugandhavacha* and *chandramulika* in Sanskrit and is used as spice, condiment, medicine and in cosmetics. In Rheede's Hortus Malabaricus, *K. galanga* L. has been described under the name *katsjula kelengu* which shows that the plant was used as a drug source in Kerala in the 17th century [40]. The present review highlights agronomy, phytochemistry, pharmacology, ethnobotanical uses and *in vitro* conservation methods of *K. galanga* and further will be a source reference to studies targeting this high sought medicinal species.

Kaempferia galanga L. (Family Zingiberaceae)
Taxonomic position

Kingdom	: Plantae
Sub Kingdom	: Phanerogamae
Division	: Spermatophyta
Sub Division	: Angiospermae
Class	: Monocotyledonae
Series	: Epigynae
Order	: Scitaminales
Family	: Zingiberaceae
Genus	: *Kaempferia*
Species	: *galanga*.

Parts used
Rhizome, root stock, leaves.

Habit
A perennial aromatic herb with very fragrant underground parts; leaves two or more, spreading flat on the ground, round-ovate, thin, deep green, petioles very short, chanelled (Fig. 1); flowers white with purplish spots in the axillary fascicles, corolla tube 2.5 cm long, connective of anther produced in to a quadrate two-lobed appendage; fruits oblong, 3-celled and 3-valved capsules, seeds arillate [14]. The underground rhizome has one or more prominent, vertically oriented tuberous root stock and many small secondary tubers and roots, their tips becoming tuberous.

Fig 1: *Kaempferia galanga* L. plants in natural habit and their rhizomes

Species status, origin and distribution
K. galanga is an endangered, highly priced medicinal and aromatic plant of the Family Zingiberaceae [27, 62] indigenous to Tropical Asia. Wood (1991) [80] has studied the biogeography and evolution. The plant is native to India, supposed to have been originated in East Asia, most probably in Burma. It is cultivated mainly in South East Asia and China [30]. In India it is mainly cultivated in Kerala, Karnataka, Tamil Nadu and West Bengal.

Agronomy
K. galanga is a shade loving plant and requires warm humid climate thriving up to an elevation of 1,500 m. An annual rain fall of 1500-2500 mm and rich loamy soil with good drainage are suitable for its cultivation. The plant is propagated by splitting of rhizomes which are stored in cool dry place prior to planting. Smoking of rhizome by spreading on *Glycosmis pentaphylla* leaves prior to planting is beneficial for better germination [57]. The type of seed material did not showed significant impact on the morphological characters but with respect to yield characters and oleoresin content; mother rhizomes offered superiority over finger rhizomes [55].

The growth and rhizome yield were higher when *K. galanga* was grown as an intercrop [39]. Monocrop yielded 4.8 t/ha whereas intercrops yielded up to 6.1 t/ha. The essential oil and oleoresin contents were also higher in intercropped rhizomes. The feasibility of growing *K. galanga* under coconut plantations was analyzed [17] wherein higher rate of yield and chemical quality was observed compared to those grown in open field. Mulching with *Azadirachta indica, Chromolaena odorata* and *Gliricidia maculata* leaves gave the highest average fresh weights. The highest rhizome yield was obtained with *Azadirachta indica* mulches and was effective in nematode infection [43]. The performance of ecotypes of the plant as influenced by variations in shade and preparatory cultivation was studied [15] and found that high rhizome yield was correlated with high P, K and Ca contents, while high essential oil with high Mg, S, Mn and Zn contents in the rhizome. Low light intensity increased the biosynthesis of oleoresin and essential oils in the rhizomes as well as the contents of Ca, Mg, Mn and Zn. Regarding the effect of different light transmission levels on the growth and yield, overhead canopy cover have little effect on rhizome yield and yield responses under no over canopy, single strata and multi strata systems were similar [34].

A well-managed plantation of *K. galanga* yielded about 4-6 tonnes of fresh rhizomes per hectare [57]. Generally insects and pests are not reported in this crop. *Pseudomonas solanacearum* is reported to cause bacterial wilt [13]. Leaf spot and rhizome rot diseases occurring during the rainy season can be prevented by spraying with 1% (w/v) Bordeaux mixture [24].

Cytology
The normal somatic chromosome compliment has been determined to be 2n = 22 [63]. There are six pairs of long chromosomes, four pairs of medium sized and one pair of short chromosomes. The basic number of this genus was reported as six [52]. The Asiatic species showed a preponderance of diploids (2n = 22), presumably derived from a basic x = 11; while the African species have either 2n = 28 or 2n = 42 with x = 14 as the basic number [67]. For some authors *K. galanga* is presumably an aneuploid pentaploid as the root tip cells exhibitted 54 chromosomes [56].

Economic importance
The demand for *Kacholam* is over 100 tonnes of dried rhizomes [37]. The crop is economically important because of its increased price value of its dry rhizomes currently having a market value of Rs.300/- per Kg which was Rs.120/- in 2-4 years back. It is reported to have great export potential [73]. Experiments conducted to study the feasibility of intercropping medicinal plants in oil palm plantations showed that it is a profitable intercrop [23]. The price of essential oil varies from US$600-700 per Kg on the international market and is highly exploited by the local people and pharmaceutical industries [10]. The essential oil finds use in perfumery, folk medicine and curry flavourings. Its recognition as a flavouring and perfumery in recent years created a price hike which elevated the crop from restricted cultivation in localized tracts of Kerala to the status of a commercial crop.

Medicinal uses
K. galanga forms a component of over 59 ayurvedic medicines [66] and is extensively used in preparation of ayurvedic drugs, perfumery, cosmetics and as spice ingredients [54]. It is used for treatment of diarrhoea, migraine and it increases energy to

overcome exhaustion and is a constituent of a variety of Ayurvedic preparations [67, 72]. The rhizomes and root stocks are bitter, thermogenic, acrid, carminative, aromatic, depurative, diuretic, expectorant, digestive, vulnerary, antehelmentic, febrifuge and stimulant. They are good for dyspepsia, leprosy, skin diseases, rheumatism, asthma, cough, bronchitis, wounds, ulcers, helminthiasis, fever, malarial fever, splenopathy, inflammatory tumor, nasal obstruction and hemorrhoids [30].

Ethnobotany

The rhizomes of the plant are widely used in East Asia for a wide range of medicinal applications [60]. Indigenous medical practitioners use these rhizomes for treatment of psoriasis, bacterial infections, tumor and it is also applied externally for abdominal pain in women and treatment of rheumatism [19].

Leaves and flowers of *K. galanga* contain flavanoids [16]. For aroma and flavour these are used in food stuff and beverage. Leaves are used as a perfume in washing hairs. In the form of lotions and poultices leaves are used for ophthalmia, swellings, fever, sore throat and rheumatism [78, 26]. The leaves possess antioxidant, antinociceptive and anti-inflammatory activities that help in treatment of mouth ulcers and headaches [69, 8]. Leaf infusions can be used as a beneficial drink for pregnant women [54]. The ashes of leaves are rubbed on swollen breasts after childbirth while fresh leaves are chewed for relieving coughs [69]. In Malaysia, the leaves of *K. galanga* called *cekur* are familiar in *perutikan*, a local favorite dish [38]. The leaves and rhizomes are used in cosmetics and herbal powders [18]. The plant is used in aroma therapy and forms one of the ingredients in pain relief ayurvedic massage blends [20].

Phytochemistry

The chemistry of *Kaempferia* was studied in detail [74]. Its rhizome contains a volatile oil (2.5-4%) [57], several alkaloids, starch, protein, aminoacids, minerals and fatty matter [79]. The volatile oil content was higher in rhizome than in root [6]. The essential oil is reported to contain over 54 components of which the major constituents are ethyl–trans p–methoxy cinnamate (16.5%), pentadecane (9%), 1,8–cineole (5.7%), g–carene (3.3%) and borneole (2.7%). In addition, it contains camphene, kaempferol, kaempferide, cinnamaldehyde, p-methoxycinnamic acid and ethyl cinnamate [4, 68, 71]. Terpene oil constituents amounted up to 16.4% [79]. The essential oil has specific gravity at 30 ˚C 0.8792–0.8914, optical rotation at 30 ˚C 2˚ 36'- 4˚ 30', refractive index at 30 ˚C 1.4173-1.4855, acid value 0.5-1.3 and saponification value 99.5-109.0. Insecticidal constituents [46], Cyclohexane oxide–derivatives and diterpenes were isolated [45]. The chemical components and biological activities of volatile oil has been worked out [71]. Leaves and flowers of *K. galanga* exhibitted antiphlogistic and vitamin P activity [29].

Pharmacology

In Thailand, the dried rhizome has been used as cardiotonic and CNS stimulant [41], whereas acetone extract is found to have an effect on monoamine oxidase inhibition [44]. The methanol extract of rhizome contains ethyl p-methoxy trans cinnamate, which is highly cytotoxic to *He La* cells [33]. Larvicidal and anticancer principles have also been obtained from the rhizome extracts [33, 31]. It was also found to be effective as an amoebicide *in vitro* against three species of *Acanthamoeba* which cause granulomatous amoebic encephalitis and amoebic keratitis. The rhizome extract was found to inhibit the activity of Epstein-Barr virus. Further research has demonstrated that the extract effectively killed the larvae of the mosquito *Culex quinquefasciatus* and repels adult *Aedes aegypti* mosquitoes, both of which are serious disease vectors. The anticancer, antihypertensive and larvicidal activities of the rhizome have been reported [11, 81]. Roasted rhizomes are applied hot in rheumatism and for fostering tumors, where as its extract is useful to relieve irritation produced by stinging caterpillars [10]. As a result of these findings, research is underway to evaluate the plant extract's use as an insect repellent, with preliminary findings suggesting that it is a non-irritant to the skin of rats [26]. It has been reported that the rhizomes contains insecticidal potent chemicals [2]. The wound healing activity is also proved [61]. The cytotoxic activity of the crude alcoholic extract of rhizome in both normal and cancer cell cultures has been reported recently [22]. HPLC analysis and antioxidant activities of hydroethanolic extracts of the leaves were also completed [28].

Crop improvement

'Kasthuri' and 'Rajani', two high yielding varieties with rich flavour have been developed through clonal selection by Kerala Agricultural University. The rhizomes of 'Kasthuri' are large and light brown with a yield of 2.52 tonnes of dry rhizomes per hectare with a driage of 32.78%. It has high volatile oil content and total extractive of 3.4%. The rhizomes of 'Rajani' are medium bold, creamy white and yields 2.55 tonnes of dry rhizomes per hectare with a volatile content of 1% with high total extractives of 7.68% [5, 57, 18]. Both varieties differ morphologically and biochemically [21]. A total number of 58 and 56 compounds respectively have been identified in them. The major component was ethyl-trans-p-methoxy cinnamate and 45 compounds have been found common in both. Mutagenesis also found to have the potential for increasing the genetic variability in *K. galanga*. Rhizome pieces with 1-2 axillary buds were irradiated with gamma radiation to observe the dose inhibiting sprouting of rhizomes and their yield. Low doses of radiation increased leaf number, leaf area and rhizome yield per plant, promoted flowering and in higher doses sprouting was inhibited [35]. Bushy type mutants were noticed with gamma irradiation and at lower doses below 1 kR germination of rhizomes was stimulated [57].

Conservation strategies

K. galanga is one among 100 Red listed medicinal plants to be conserved in Southern India [58]. It is probably extinct in the wild but available under cultivation satisfying the priority criteria for conservation [12]. Conventional propagation is *via* rhizomes, which remains dormant during drought, sprouting in spring. Though few seeds were obtained after cross pollination, the resultant seeds are non-viable. About 840-1700 Kg of rhizome is needed to plant one hectare. The species is annual and 2-4 plants can be obtained in a year from one rhizome. However, it is uneconomic as the tubers constitute the commercial product and as a consequence, there is always scarcity of the propagating material. Considering the present demand (both for economic and medicinal values) and propagation problem of the plant, development of suitable protocols for rapid multiplication and effective conservation from existing elite cultivars has become crucial for meeting the market demand and to replenish highly impoverished populations. *In vitro* propagation of *K. galanga* through multiple shoot induction and organogenesis has been reported by several authors (Table 1). To circumvent the problems associated with conventional field maintenance, *in vitro* and cryopreservation techniques holds great promise for long-term conservation and sustainable utilization of this plant genetic resource and in very recent times it is also reported in *K. galanga* (Fig.2) [48, 49, 50].

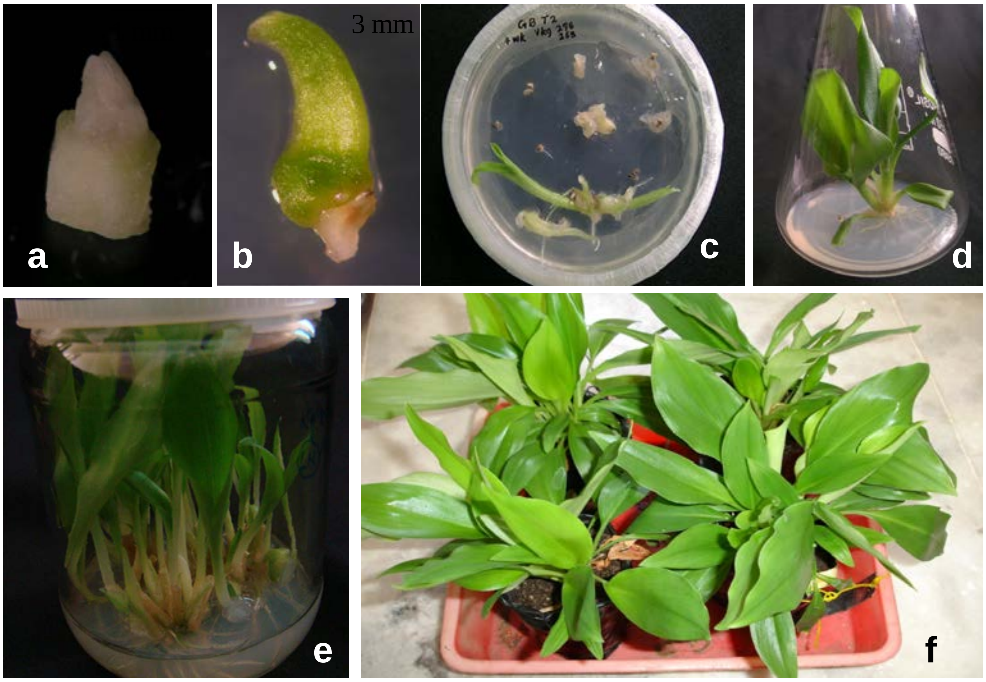

Fig 2: Shoot recovery after cryopreservation of shoot apical meristems of *K. galanga* through vitrification. **a** Shoot tip explant; **b & c** Shoot regeneration after 3 weeks of LN exposure in MS+0.1 mgl^{-1} GA_3+0.5 mgl^{-1} BA; **d** Plantlet production; **e** Multiplication of LN-recovered shoots in MS+0.5 mgl^{-1} NAA+2.0 mgl^{-1} BA; **f** LN-recovered plantlets

Patents filed

Warren Shapiro and Jon Anderson has patented a new and improved cosmetic composition containing a small but effective amount of ethyl p-methoxycinnamate derived from *K. galanga* roots to prevent and treat chemically induced skin irritation, discoloration and protection from the adverse effects of tyrosinase (US7910090). Another one is a medicinal bag for preventing cold (CN 1326777 A). The third one is a sun screen composition containing *K. galanga* extract (US6440402 B1).

Conclusion

The review presented here dealt with the taxonomy, origin, evolution, status, economic value, agronomy, cytology, ethnobotany, phytochemistry, pharmacology, crop improvement and conservation strategies of *K. galanga*. It is a comprehensive account and some of them especially the *in vitro* conservation strategies *via* cryopreservation are new reports concerning *K. galanga*. However, the extensive information provided here in all these aspects will be useful as a concrete support for future experimental studies targeting *K. galanga*.

Table 1: *In vitro* conservation of *K. galanga* L.

Sl. No.	Explant	Medium and growth regulator concentration	Response	References
1	Rhizome	MS+1.0 mgl^{-1} 2,4-D+0.5 mgl^{-1} BA; MS+1.5 mgl^{-1} BA+1.0 mgl^{-1} NAA	Plant regeneration from callus culture	75
2	Rhizome	MS+1.0 mgl^{-1} 2,4-D+0.1 mgl^{-1} BA; MS+1.0 mgl^{-1} BA+0.1 mgl^{-1} NAA	Callus induction; embryoids	76
3	Rhizome	MS+2.0 mgl^{-1} 2,4-D+0.5 mgl^{-1} Kinetin	*In vitro* propagation	77
4	Rhizome	0.75MS+12 μM BA+3 μM NAA	*In vitro* plantlet production	64
5	Rhizome	MS+4 mgl^{-1} BA+1.0 mgl^{-1} Kinetin and NAA	Plantlet production	59
6	Leaf bases	MS+0.5 mgl^{-1} 2,4-D+0.2 mgl^{-1} BA	Somatic embryogenesis and plant regeneration	36
7	Rhizome	MS+2.5 mgl^{-1} BA+0.5 mgl^{-1} IAA	High frequency organogenesis and multiple shoot regeneration	70
8	Rhizome	MS+0.57 μM IAA+4.65 μM kinetin	Microrhizome induction	9
9	Rhizome	8.87 μM BA+2.46 μM IBA+11.7 μM $AgNO_3$	Shoot multiplication and rhizome development	10
10	Leaf base	1.5 mgl^{-1} 2,4-D+1 mgl^{-1} BA; 2.0 mgl^{-1} BA+0.1 mgl^{-1} NAA	Callus induction; somatic embryogenesis	53
11	Leaf base	1.0 mgl^{-1} Dicamba+0.5 mgl^{-1} BA; 0.5 mgl^{-1} BA+0.1 mgl^{-1} NAA	Callus induction; somatic embryogenesis and plantlet regeneration	48
12	Rhizome tip and lateral bud	MS+2.0 mgl^{-1} BA+0.2 mgl^{-1} NAA	Organogenesis and multiple shoot regeneration	25
13	Rhizome	MS+0.5 mgl^{-1} IAA+1.0 mgl^{-1}BA	Shoot multiplication and leaf biomass production	47
14	Rhizome	MS+2.0 mgl^{-1} BA+1.0 mgl^{-1} Kinetin	Multiple shoot induction	32
15	Shoot buds	MS+4 mgl^{-1} BA	Plantlet production	7
16	Rhizome tip and lateral buds	MS+2.0 mgl^{-1} BA+0.2 mgl^{-1} NAA	Organogenesis and multiple shoot regeneration	1

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