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Review Article

Therapeutic Applications and Medicinal Significance of *Dillenia indica* in Healthcare: A Review

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Abstract

Background and aims: The tropical elephant apple, *Dillenia indica* (*D. indica*), is predominantly found throughout South Asia, including Bangladesh. Various parts of this plant have been utilized as traditional herbal remedies for thousands of years. *D. indica* has been recognized for its medicinal properties in treating a range of ailments, including microbial infections, gastrointestinal disorders, fever, headaches, diabetes, malignancies, and cardiovascular diseases. The aim of this review paper is to provide a succinct overview of the botanical description, morphology, pharmacological activity, chemical constituents, and therapeutic applications of *D. indica*.

Methods: Keywords such as *D. indica*, pharmacological action, phytoconstituents, therapeutic use, and traditional medicine were employed to search research databases, including Google Scholar, PubMed, Springer, Science Direct, and NIH, up to May 2025. Data were collected from relevant books and literature, which were then analyzed, discussed, and summarized.

Results: Elephant apples are utilized as supplementary ingredients in various therapeutic and food products, supported by numerous published studies that provide comprehensive scientific insights and information about the tree.

Conclusion: *D. indica* holds significant promise for future development in several fields, particularly in traditional medicine and food processing. As natural products tend to have fewer adverse effects, their application in the prevention and treatment of diseases is increasingly gaining global acceptance.

Keywords: *Dillenia indica,* Traditional use, Pharmacological activity, Morphology, Toxicity

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Introduction

The elephant apple, *Dillenia indica* (*D. indica*) Linnaeus, is a vital medicinal plant widely distributed in Assam and various parts of Asia, belonging to the Dilleniaceae family. Due to their acidic flavor, the young fruits of *D. indica* are commonly used in Assamese cuisine to prepare seasonings and sauces, while mature fruits are processed into pickles, jams, and sauces. In Kannada, it is known as "Bettakanigalu." Other common names include Hondapara tree, Indian catmon, and Ma-tad, with regional names such as Punna and Vazchpunna in Malayalam; Kattaral and Ugakkay in Tamil; Revadi in Telugu; Avartaki, Bhavya, and Bharija in Sanskrit; Chalta in Hindi; and Chalta in Bangla (1).

The flowers of the plant bloom from May to August, with the fruits ripening between September and February. The fruits are commonly incorporated into various dishes. In the tribal regions of Mizoram, India, traditional practices involve combining the leaves and bark juices for oral consumption to treat diarrhea and cancer (2). Reports indicate that the bark and leaves possess astringent and laxative properties (3). The fruit features five imbricate sepals that encase numerous seeds embedded in a thick pulp. The raw plant parts emit an unpleasant odor and are characterized by a greenish-yellow color. The final product, prepared from the thick sepals, has a bitter flavor and is typically used to enhance the taste of dishes and to make jam (4).

Traditionally, the fruits, leaves, and bark of *D. indica* have been utilized to address ailments such as fever, diarrhea, constipation, and abdominal pain (5). Decoctions of the fruit have been employed to enhance immunity, manage diabetes, and treat hair loss. A cough syrup with a cooling effect can be prepared by combining *D. indica* juice with sugar and water. In Asia, the entire plant is used for medicinal purposes, and the fruits are commonly included in culinary applications (6). Oral and topical preparations of *D. indica* are utilized to treat diabetes, cough, diarrhea, fever, joint and abdominal pain, as well as to alleviate fatigue and tone the nervous system (Table 1) (7). The majority of the traditional folk medicine applications of *D. indica* are associated with its anti-inflammatory properties (7). In Brazil, the fruits are used in skincare products that aim to reduce inflammation (8).

Table 1. Common therapeutic potential exhibited by *D. indica*

Serial No.	Therapeutic potential	Serial No.	Therapeutic potential
1	Treating joint pain, arthritis, and muscle soreness	7	Treating skin infections, wounds, and microbial diseases
2	Reducing swelling in inflammatory conditions	8	Reduces fasting blood sugar levels
3	Managing fever and inflammatory disorders	9	Enhances liver function and detoxification
4	Prevents cellular damage and aging	10	Treating gastric ulcers and indigestion
5	Protects against neurodegenerative diseases like Alzheimer's and Parkinson's	11	Suppresses cancer cell proliferation
6	Reduces the risk of cardiovascular diseases	12	Enhances insulin sensitivity

Remedial folklore frequently employs *D. indica* as a hair tonic and for the treatment of various ailments, including cancer, wounds, jaundice, cough, fever, diabetes mellitus, and diarrhea. Additionally, the plants of this genus are cultivated as ornamental specimens due to their palatable fruits. Recent studies have identified the presence of flavonoids, triterpenoids, and other bioactive compounds within the genus. Extracts of *D. indica* have demonstrated a range of pharmacological properties, including antibacterial, anti-inflammatory, anti-diabetic, cytotoxic, antioxidant, antidiarrheal, and antiprotozoal effects. Furthermore, the mucilage derived from its fruit has potential applications in medicinal formulations (9). This review paper aims to provide a comprehensive overview of the botanical description, morphology, pharmacological activity, chemical constituents, and therapeutic uses of *D. indica*, focusing on both its pharmacological properties and therapeutic applications.

Materials and Methods

Keywords such as *D. indica*, pharmacological action, phytoconstituents, therapeutic use, and traditional medicine were utilized to search research databases, including Google Scholar, PubMed, Springer, Science Direct, and NIH, up to May 2025. A thorough review of relevant books and scientific literature from these databases was conducted. The collected data were analyzed, discussed, and summarized. Only literature published in the English language was selected for inclusion in this study.

Results and Discussion

Biological Description

D. indica, commonly known as the elephant apple, is an evergreen shrub or tree that typically grows to a height of 6 to 15 meters. It features thick bark and sturdy branches. The leaves are generally 15 to 36 cm long, characterized by a conspicuously corrugated surface with impressed veins. They are broadly elliptic to oblong-lanceolate in shape, acuminate, and regularly serrate, with 30 to 40 pairs of secondary veins that terminate in the serrations. The petiole is channeled, sheathing, and densely tomentose at the base, measuring 2 to 4 cm in length. The flowers of *D. indica* have oblong white petals and numerous yellow stamens. They are bisexual, terminal, solitary, and have a smooth, clavate pedicel. The sepals are orbicular and concave. The fruits are primarily edible, displaying a greenish-yellow coloration. Each fruit is an aggregation of 15 carpels, with each carpel containing five seeds embedded in an edible fibrous pulp. The seeds are numerous, small, and hairy along the edges. The fruit is indehiscent and covered by a permanent calyx. The trunk of the shrub can reach heights of 30 to 80 feet and has a circumference of about 6 feet, featuring a dense rounded crown (10, 11). *D. indica* is a medium to large-sized evergreen tree belonging to the family Dilleniaceae and exhibits distinct morphological characteristics that enhance its identification and medicinal significance.

Taxonomical Classification

D. indica L. belongs to the family Dilleniaceae. Its taxonomical classification, as reported in the literature (12), is as follows:

- **Kingdom:** Plantae
- **Division:** Magnoliophyta
- **Subdivision:** Angiospermae
- **Class:** Magnoliopsida
- **Subclass:** Dilleniidae
- **Order:** Dilleniales
- **Family:** Dilleniaceae
- **Genus:** Dillenia
- **Species:** *indica* Linnaeus

Environmental Conditions for Cultivation

The recorded temperatures in its natural habitat range from a minimum of 35 to 65°F to a maximum of 95 to 105°F, with annual rainfall ranging from 200 to 500 cm. The tree is also found in Bangladesh, Nepal, Sri Lanka, Malaysia, Myanmar, and Thailand (13). *D. indica* thrives at temperatures between 30 and 40°C and prefers a mean annual rainfall of 3,000 to 4,000 mm. The plant grows best in rich, slightly acidic soils, with an optimal pH range of 5.5 to 7. It favors well-drained sandy loam and sunny weather for optimal growth (14).

Geographical Location

D. indica L. occurs in the moist and evergreen forests of the sub-Himalayan tract, extending from Kumaon and Garhwal eastward to Assam and Bengal, and southward to central and southern India. This plant is native to regions including Assam, Bangladesh, Borneo, Cambodia, South-Central China, Southeast China, the East Himalaya, India, Java, Laos, Malaya, Myanmar, Nepal, the Philippines, Sri Lanka, Sumatra, Thailand, and Vietnam. Additionally,

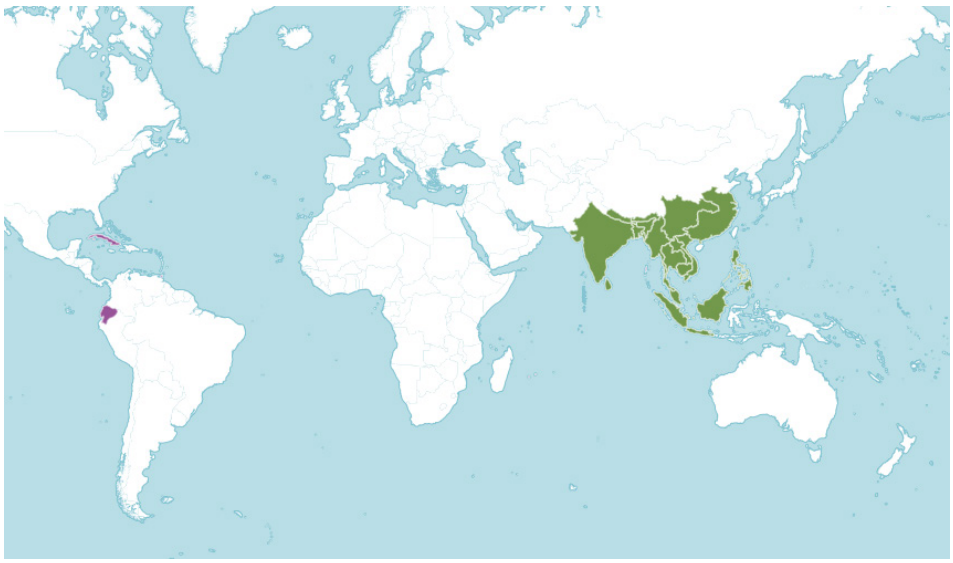


Figure 1. Geographical distribution of *D. indica*. The green color represents native countries, while the purple color indicates non-native countries

it has been introduced to non-native countries such as Comoros, Cuba, Ecuador, the Gulf of Guinea, and Mauritius (Figure 1). *D. indica* is commonly found along the banks of forest streams (15).

Leaves

The leaves of *D. indica* are large, simple, and alternate, measuring 15 to 35 cm in length and 8 to 15 cm in width. They are elliptic to oblong in shape, with prominently serrated margins. The leaf surface is leathery, dark green, and glossy, with distinct venation. Young leaves often exhibit a reddish hue before maturing (16).

Flowers

The flowers of *D. indica* are large, showy, and solitary, measuring approximately 12 to 20 cm in diameter. They possess five broad white petals and numerous yellow stamens, contributing to their striking appearance. The flowers are fragrant and bloom primarily during the summer and monsoon seasons, attracting pollinators such as bees and butterflies (17).

Fruit

The fruit is a large, globose, woody structure, measuring 10 to 25 cm in diameter (Figure 2). It consists of numerous carpels surrounded by thick, fleshy sepals that turn yellowish-green upon ripening. The inner pulp is fibrous and contains numerous small, dark brown seeds embedded in a mucilaginous matrix. The fruit is highly aromatic and edible, though it has a sour taste. It is commonly used in traditional medicine and local cuisines (17). The fruits of *D. indica* contain various minerals and nutrients, as shown in (Table 2).

Bark and Stem

The bark of *D. indica* is dark brown to grayish, rough, and deeply fissured. The tree's branches spread widely, forming a dense, umbrella-like canopy. The wood is hard and durable, suitable for various applications, including construction and fuel (18).

Figure 2. Fruits of *D. indica*

Root

D. indica possesses a well-developed, deep root system that enables it to adapt to various soil types. The roots contribute to soil stability and play a role in traditional medicinal preparations (19). The distinct morphological features of *D. indica* not only facilitate its identification but also support its widespread use in traditional medicine. These characteristics contribute to its pharmacological potential, including its analgesic and anti-inflammatory properties, which are explored in this study.

Phytochemical Compositions

The alcoholic extract of *D. indica* exhibits a wide range of pharmacological properties, including anti-inflammatory, anti-cancer, and anti-malarial effects. These properties are attributed to the substantial quantity of phytochemicals present in the extract (20). The alcoholic extracts (methanolic and ethanolic) of *D. indica* reveal the presence of flavonoids (Table 3), alkaloids, tannins, sulfur-containing proteins, carbohydrates, starch, and saponin glycosides (21).

Previous literature demonstrates that various parts

of the plant contain numerous primary and secondary metabolites, including 10% tannins, dillenetin, betunaldehyde, dipoloic acid, betulinic acid, lupeol, sitosterol, stigmasterol, myricitrin, chromane, quercetin, kaempferol (Table 4), and myricetin derivatives found in the stem bark of *D. indica* (22). Additionally, the plant contains several alkaloids, such as hydroxymethylserine, triethanolamine, alpha-aminobutyric acid, 5-acetyl-2,4-dimethylthiazole, 2-(glucosyloxy)isobutyraldoxime, L-α-amino suberic acid, 4-methylthiazole-5-propionic acid, N-isopylhydrazine carboxamide, and linamarin (16).

The seeds of *D. indica* contain free amino acids, terpenoids, steroids, glycosides, coloring matter, fixed oils, and sugars. Furthermore, the plant exhibits various characteristics, including ash content, water-soluble ash, acid-insoluble ash, swelling index, foaming index, and organoleptic value. Phytochemical screening of the plant sample has identified alkaloids, terpenoids, glycosides, tannins, and numerous other phytoconstituents (22-24) (Tables 5, 6).

Pharmacological Activities of D. indica

D. indica, commonly known as the elephant apple, is a medicinal plant renowned for its wide range of pharmacological properties. Various parts of the plant, including the fruit, bark, and leaves, contain bioactive compounds (Table 7) that contribute to its anti-inflammatory, analgesic, antioxidant, antimicrobial, antidiabetic, hepatoprotective, cardioprotective, digestive, laxative, anthelmintic, gastroprotective, and anticancer activities (25).

Anti-Inflammatory Activity

The ethanol extract of *D. indica* has demonstrated significant analgesic and anti-inflammatory effects. Studies indicate that the extract inhibits prostaglandin synthesis, thereby reducing pain and inflammation (26). Experimental models, such as carrageenan-induced paw edema in rats, have shown a dose-dependent reduction in swelling, confirming its anti-inflammatory potential (27). The mechanism of action includes the inhibition of cyclooxygenase (COX-2) and lipoxygenase pathways, as well as the suppression of inflammatory cytokines (IL-1β, TNF-α).

Table 2. Nutritional value per 100 g of the edible portion of *D. indica* (elephant apple)

Component	Amount	Component	Amount
Protein	0.8%	Phosphorus	26 mg
Fat	0.5-2.5%	Ascorbic acid	4 mg
Fiber	1-3%	Calories	59 Kcal

(Information source available at: https://naturestudysociety.org/chalta-elephant-apple/)

Antioxidant Activity

D. indica exhibits potent antioxidant activity due to the presence of phenolic and flavonoid compounds. The methanolic extract effectively scavenges free radicals, such as DPPH (2,2-diphenyl-1-picrylhydrazyl) and ABTS + (2,2'-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid)), thereby preventing oxidative stress-related diseases (28, 29).

Antibacterial and Antimicrobial Activity

The fruit extract of *D. indica* demonstrates broad-spectrum antimicrobial activity against both gram-positive and gram-negative bacteria, including *Escherichia coli*, *Staphylococcus aureus*, *Bacillus subtilis*, *Pseudomonas aeruginosa*, and *Candida albicans* (30). The mechanisms of action include disruption of bacterial cell membranes, inhibition of bacterial DNA replication and protein synthesis, and induction of oxidative stress in microbial cells.

Anti-Diabetic Activity

D. indica has been reported to lower blood glucose levels in diabetic animal models. The methanolic extract enhances insulin secretion, improves glucose metabolism, and protects pancreatic β-cells from damage. Mechanisms include improved glucose tolerance and insulin sensitivity, as well as inhibition of α-glucosidase and α-amylase enzymes, which delay carbohydrate digestion and absorption (31).

Gastro-Protective and Anti-Ulcer Activity

The fruit extract of *D. indica* has demonstrated anti-ulcer

Table 3. Flavonoid contents found in *Dillenia* species along with their molecular formulas

Flavonoids	Molecular formula	Flavonoids	Molecular formula
Kaempferol	$C_{15}H_{10}O_6$	3'-Methoxy-dihydroquercetin	$C_{16}H_{14}O_7$
Quercetin	$C_{15}H_{10}O_7$	Dihydroisorhamnetin	$C_{16}H_{14}O_7$
Dillenetin	$C_{17}H_{14}O_7$	Naringenin	$C_{15}H_{12}O_5$
Rhamnetin	$C_{16}H_{12}O_7$	Rhamnetin-3-O-rhamnopyranoside	$C_{34}H_{42}O_{20}$
Isorhamnetin	$C_{16}H_{12}O_7$	Myricetin-3-O-glucopyranoside	$C_{21}H_{20}O_{13}$
Kaempferol 3-O-diglucoside	$C_{27}H_{30}O_{16}$	Azaleatin	$C_{16}H_{12}O_7$
Tiliro-side	$C_{30}H_{26}O_{13}$	Quercetin-3, 7-di-O-glucopyranoside	$C_{27}H_{30}O_{17}$
Kaempferol 4'-methyl ether	$C_{34}H_{42}O_{19}$	Dihydrokaempferide 7-diglucoside	$C_{27}H_{30}O_{16}$
Naringenin -diglucoside	$C_{27}H_{32}O_{15}$	5,7-dihydroxy-4'-methoxyfla-vone-3-O-b-Dglucopyranoside	$C_{22}H_{22}O_{10}$

Table 4. Major phytochemical constituents in *D. indica* along with their structural formulas

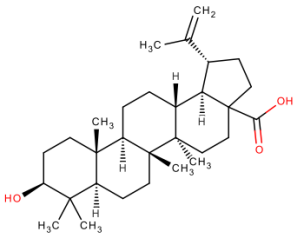
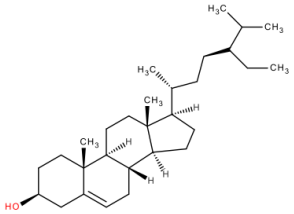
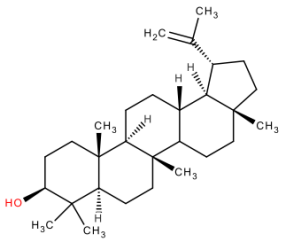
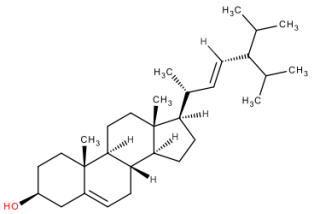
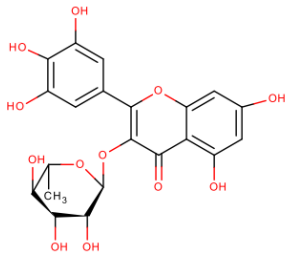
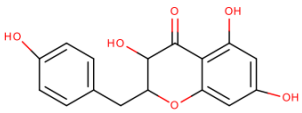
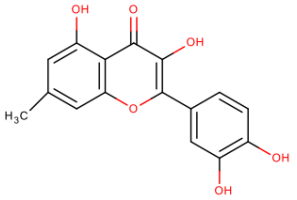
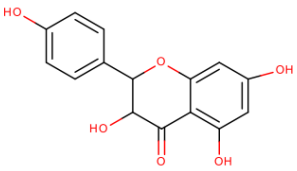
Phytochemicals	Chemical Structure
Betulinic acid	
Sitosterol	
Lupeol	
Stigma sterol	
Myricitrin	
Chromane	
Quercetin	
Kaempferol	

Table 4. Continued.

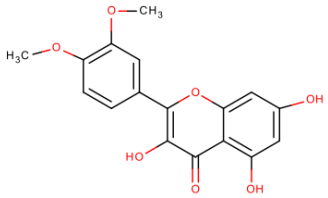
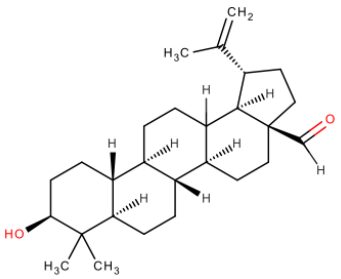
Phytochemicals	Chemical Structure
Dillentin	
Betulinic aldehyde	

Table 5. Amino acids present in the fruit extract of *D. indica*

Amino acid	Concentration (µg/g)	Amino acid	Concentration (µg/g)
Arginine	392.80	Tyrosine	138
Leucine	408.30	Histidine	139.1
Serine	440	Threonine	193.40
Phenylamine	545.20	Methionine	203.63
Aspartic acid	640	Isoleucine	217.20
Glutamic acid	746.25	Valine	282.40
Proline	2643	Lysine	346.67
Glycine	3780.80	Alanine	373.75

activity by reducing gastric acid secretion and increasing mucosal protection. It is beneficial in treating gastric ulcers and acid reflux diseases. The extract inhibits the H^+/K^+ ATPase enzyme (exhibiting a proton pump inhibitor-like effect), enhances mucus secretion, strengthens gastric mucosal defense, and suppresses inflammatory cytokines in gastric tissue (16).

Cardio-Protective Activity

D. indica has shown protective effects against cardiovascular diseases by lowering cholesterol levels and preventing atherosclerosis (32). It reduces LDL (bad cholesterol) while increasing HDL (good cholesterol), prevents lipid peroxidation in cardiac tissues, and improves endothelial function and blood circulation (32).

Anticancer Activity

Preliminary studies suggest that *D. indica* extracts exhibit anticancer properties by inhibiting the growth of cancerous cells and inducing apoptosis (programmed cell death) (33). Observed effects in cancer studies include the induction of cell cycle arrest in cancer cells and the inhibition of tumor growth and metastasis.

Anti-Leukemic Activity

Human leukemic cell lines U937, HL60, and K562

Table 6. Terpenoid contents found in *Dillenia* species along with their molecular formulas

Terpenoids	Molecular formula	Terpenoids	Molecular formula
Lupeol	$C_{30}H_{46}O$	Stigmasterol-3 glycoside	$C_{35}H_{58}O_6$
20 -hydroxy-lupan-3-one	$C_{30}H_{48}O_3$	Stigmasteryl palmitate	$C_{45}H_{78}O_3$
Betulinaldehyde	$C_{30}H_{48}O_2$	Cycloartenone	$C_{30}H_{48}O$
Betulinic acid	$C_{30}H_{48}O_3$	Dipoloic acid	$C_{20}H_{30}O_3$
Koetjapic acid	$C_{30}H_{46}O_4$	a-l-rhamnopyranosyl-3b-hy-droxy-lup-20(29)-en-28	$C_{47}H_{76}O_{17}$
(3β)-3-hydroxy-lup-20(29)-en-28-oic acid	$C_{30}H_{48}O_4$	Stigmasterol	$C_{29}H_{48}O$

Table 7. Overview of common phytochemicals found in *D. indica* and their relevant pharmacological activities

Phytochemicals	Pharmacological Activity	Phytochemicals	Pharmacological Activity
Myricetin, quercetin, and dillenetin, kaempferol	Antioxidant effect	Chromane	Anti-diabetic effect
Dillenetin, betulinic acid, stigmasterol	Anti-inflammatory effect	Lupeol, betulinaldehyde, betulinic acid, and stigmasterol	Antimicrobial effect
Betulin and betulinic acid, kaempferol	Anticancer effect	Betulinic acid	Antiulcer effect
Lupeol, betulinaldehyde, betulinic acid	Hepato-protective effect	Betulinic acid	Anti-leukemic effect
Lupeol, and stigmasterol	Wound healing effect	Glycosides and tannins	Anthelmintic effect
Betulin and betulinic acid	CNS depressant effect	Dillenetin, sitosterol	Digestive effect
Betulinic acid, lupeol, and flavonoids	Cardio-protective effect	Betulin and betulinic acid, flavonoids	Laxative effect
Kaempferol, rhamnetin, myricetin, and quercetin	Analgesic effect		

demonstrated notable anti-leukemic activity in response to the methanolic extract of *D. indica* fruits. Based on this discovery, the methanolic extract was fractionated according to polarity, revealing that the ethyl acetate fraction exhibited the strongest anti-leukemic effectiveness. Betulinic acid, a significant compound, was separated from the ethyl acetate fraction using silica gel column chromatography and subsequently identified. The anti-leukemic properties of both the methanolic extract and the ethyl acetate fraction may be attributed to betulinic acid (34).

Antidiarrheal Activity

The methanolic extract of *D. indica* leaves was investigated using a castor oil-induced diarrhea model. Results indicated that phytoconstituents such as flavonoids and tannins may be responsible for the activity, with inhibition of diarrhea and prolongation of onset attributed to the inhibition of inflammatory mediator release (35).

Hepatoprotective Activity

The hepatoprotective properties of *D. indica* were evaluated against carbon tetrachloride-induced hepatotoxicity using an ethanolic leaf extract (300 mg/kg p.o.), with silymarin (25 mg/kg) as the standard medication. Histological investigations indicated that the plant extract promoted regeneration from necrosis in treated rats. The extract demonstrated significant ($p < 0.001$) hepatoprotective efficacy against hepatic injury induced by carbon tetrachloride, suggesting that the ethanolic leaf extract possesses hepatoprotective properties (36).

Anthelmintic Activity

For assessing anthelmintic action, a methanolic extract of the stem bark was prepared in distilled water at various doses (10, 15, 20, and 25 mg/mL). Albendazole (10 mg/mL) served as the standard medication. The paralysis and death periods of earthworms were observed, revealing that the methanolic extract exhibited modest anthelmintic activity compared to albendazole (37).

Wound Healing Activity

A 10% concentration of *D. indica* leaf ethanol extract resulted in 100% healing of burns within 12 days and incision wounds within 5 days (38). A glycolic extract derived from *D. indica* fruits demonstrated notable wound-healing properties when applied alone or in combination with microcurrent stimulation to surgically created skin lesions on the backs of Wistar rats (39). The presence of flavonoids in *D. indica* is believed to promote wound healing.

Other Activities

The therapeutic properties of *D. indica* have led to its widespread use. Its leaves and bark are utilized as astringents and laxatives, while the fruit juice serves as a cooling beverage that calms the nervous system and acts as a cough remedy. In Ayurveda, *D. indica* is employed as a "pitta" supplement and "vat" suppressor. The fruit juice can be combined with sugar and water to create a cooling beverage for fevers and cough mixtures. The plant's leaves, fruit, and bark are used in traditional medicine to alleviate stomach discomfort and regulate body temperature. The fruit also combats fatigue and energizes the nervous system, while roots provide a phytochemical remedy for cholera and aid in treating chest and stomach burning. Additionally, the upper portion of the plant is used to treat oral infections.

Pharmaceutical Potential of D. indica

Research on the natural mucilaginous extract of elephant apples has predominantly focused on its use as a pharmaceutical excipient for drug delivery. Characterization of the natural mucilaginous substances isolated from elephant apple seeds through Fourier Transformation Infrared Spectroscopy (FTIR), X-ray diffraction (XRD), and thermogravimetric analysis (TGA) revealed a high swelling output with significant mucous adhesive force. The zeta potential of the mucilage was found to increase positively to 17.2. Following the determination of in vitro swelling and mucoadhesion features, it was shown that the mucilage, with high swelling capabilities, possessed notable mucoadhesive strength. Analytical investigations indicated that the mucilage is amorphous and undergoes a one-step mass loss event. Consequently, elephant apple mucilage, a naturally occurring mucoadhesive polymer, holds potential for developing various drug delivery systems (16). The mucilaginous material extracted from *D. indica* fruit has been evaluated for the creation of felodipine mucoadhesive nasal gels, demonstrating superior effectiveness compared to synthetic polymers like hydroxypropylmethylcellulose (HPMC). During permeation tests, gels derived from the natural mucilaginous components of elephant apples exhibited advantageous mucoadhesive qualities, leading to prolonged adhesion to the nasal mucosa and enhancing intranasal absorption through excised goat nasal mucosa (40).

As a proton pump inhibitor, pantoprazole is a medication used to treat stomach ulcers and gastroesophageal disorders. Due to its instability in acidic environments, enteric delivery systems are necessary for its absorption in the gastrointestinal tract. To create microbeads containing pantoprazole, the mucilaginous extract from elephant apples is combined with sodium alginate using the ionotropic gelation process, followed by coating with Eudragit L100-55. Studies have demonstrated that the resulting spherical microbeads exhibit sufficient swelling, mucoadhesive properties, and acid resistance. These characteristics are crucial for their application in the administration of mucoadhesive medications, particularly for controlled-release drug delivery (41).

Economic Value of D. indica

The plant *D. indica*, commonly known as elephant apple or chalta, holds significant economic importance in various parts of the world. Its leaves, fruit, and wood are valued for multiple reasons. The heartwood is prized for carving and ornamental work, while the robust sapwood is utilized in a variety of construction and handicraft applications. The fruit, known for its therapeutic properties, is also palatable and is used commercially in curries, chutneys, jams, and jellies.

Toxicity and Safety Profile

Human Studies

High doses of *D. indica* fruit extract may cause mild stomach irritation, acid reflux, and gastritis. Excessive consumption could lead to low blood sugar levels, particularly in diabetic patients who are already on medication (42). Some individuals may experience skin rashes, itching, or oral irritation (43). Comet test results indicate minimal DNA damage ($P > 0.5$). Research on *Dillenia* species suggests that they can be safely utilized to treat various conditions, including Alzheimer's disease and related disorders, due to their high concentration of beneficial phytochemicals that do not harm healthy human cells (44). However, possible interactions with anticoagulants (increased bleeding risk) and antihypertensive drugs (excessive blood pressure reduction) may occur.

Animal Studies

In vivo evaluations of acute toxicity using male Swiss Albino mice showed no mortality following intraperitoneal administration of mucilage and polysaccharides isolated from *D. indica* fruit (45). Mice of both sexes fed the supplemented portion of *D. indica* leaves at oral dosages of 1600 mg/kg body weight (acute) and 500 mg/kg body weight (sub-acute), which may be considered the basal dose, exhibited no adverse effects (46).

Conclusion

This review article discusses the morphological characteristics, chemical constituents, pharmacological activities, therapeutic uses, pharmaceutical potential, and toxicity profile of *D. indica* (elephant apple). *D. indica* is a plant with significant promise for future development in various fields, particularly in traditional medicine and food processing. The global trend towards the use of natural products, which typically have fewer adverse effects, is driving interest in their application for disease prevention and treatment. However, there is a notable lack of comprehensive studies focused on the identification and extraction of bioactive compounds from elephant apples. Conducting robust clinical research on this medicinal plant could facilitate the development of phytopharmaceutical products, thereby enhancing the economic standing of a nation.

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Competing Interests
Nil.

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