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Review Article

# *Bauhinia variegata* Linn. (Kanchnar)

**Khemnar Sanskar*, Vishwasrao Krishna, Datir Rutik, Nirmal Aniket, Bamhane Sonali, Kakad Sakshi, Tejashri Kudnar**

*Ashvin College of Pharmacy, Manchi Hill, Sangamner, Ahilyanagar, Maharashtra 413714*

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## ABSTRACT

Bauhinia variegata Linn., commonly known as Kanchnar, Mountain Ebony, or Orchid Tree, is an important medicinal plant belonging to the family Fabaceae (Caesalpiniaceae). It has been extensively used in traditional systems of medicine such as Ayurveda, Unani, and folk medicine for the treatment of various diseases including thyroid disorders, diabetes mellitus, inflammatory conditions, skin diseases, gastrointestinal disorders, and cancer. Different parts of the plant such as bark, leaves, flowers, seeds, and roots possess significant therapeutic value.

## INTRODUCTION

Medicinal plants have served as the foundation of healthcare systems worldwide for millennia [1]. The medicinally valuable plant Bauhinia variegata Linn., often called Kanchnar or Mountain Ebony, is a member of the Fabaceae (Caesalpiniaceae) family.[2,3]. This medium-sized deciduous tree, which is found throughout Southeast Asia and the Indian subcontinent, is prized for both its numerous medicinal uses and aesthetic appeal. [4,40]. The genus Bauhinia contains over 100 species, eight of which are native to India and reach elevations of 1300 meters in the Himalayas. 5,40]. The genus Bauhinia has attracted significant attention from modern researchers and traditional practitioners due to its immense medicinal potential[6,40]. Various species of Bauhinia have been employed for centuries in Ayurveda and Unani systems to treat numerous ailments[7,8]. These herbs have been widely used by tribal people in India, and traditional medical systems like homeopathy, Ayurveda, and Unani recognize them. [9,40]. Reducing sugars, steroids, flavonoids, tannins, saponins, terpenoids, and cardiac glycosides have all been found in Bauhinia species by phytochemical screening, contributing to their varied pharmacological characteristics. [10,11]. In numerous in vitro and in vivo research, pharmacological analyses have shown that Bauhinia species have anti-inflammatory,

***Corresponding Author:** Khemnar Sanskar
**Address:** *Ashvin College of Pharmacy, Manchi Hill, Sangamner, Ahilyanagar, Maharashtra 413714*
**Email** : khemnarsanskar6@gmail.com

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antibacterial, hypolipidemic, anticancer, nephroprotective, hepatoprotective, immunomodulating, molluscicidal, and wound-healing properties. [12,13].

### 1.1 Historical Significance

The use of B. variegata in traditional medicine spans centuries. Ancient Ayurvedic texts mention the plant as Kovidara and Karbudara 6,40].Sushruta categorized it as a bitter herb (Kashaya Varga), while Acharya Charaka discussed its usage in emetic therapy (Vamana Panchakarma).[7,8,40]. The Sanskrit name Kanchana means "a glowing beautiful lady," which reflects the plant's eye-catching pink, white, or purple blooms. [9,40]. Its grey, longitudinally cracked bark is pale pink inside, and its few-flowered, lateral, sessile, or short-peduncled corymbs bear blooms of a variety of colors. The tall, rigid, flat, glabrous, dehiscent pods hold ten to fifteen seeds. [10,40].

### 1.2 Vernacular Names

| Language | Name | Reference |
|---|---|---|
| Hindi | Kachanar | [3,9] |
| Bengali | Kanchana | [2,40] |
| Marathi | Raktakanchan, Koral | [9,40] |
| Tamil | Mandare | [2,40] |
| Telugu | Devakanchanamu | [2,40] |
| Gujarati | Chapmakati | [2,40] |
| Malayalam | Koral, Kanchan | [2,40] |
| English | Mountain Ebony, Orchid Tree | [2,9] |
| Sanskrit | Kanchana, Kovidara, Karbudara | [2,7] |

### 1.3 Therapeutic Applications

Modern research has validated numerous traditional uses of B. variegata in treating[11,12]:

- Diabetes mellitus[25,26]
- Inflammatory disorders[31,32]
- Microbial infections[18,34]
- Cancer[15,30]
- Gastrointestinal disorders[2,9]
- Thyroid dysfunction[12,17]
- Skin diseases[9,18]
- Wound healing[18,44]

**Key Bioactive Constituents:** The plant's therapeutic potential is attributed to its rich phytochemical profile including flavonoids, tannins, terpenoids, saponins, cardiac glycosides, alkaloids, and phenolic compounds[13,14]. The flowers contain essential oils including myrcene, linalool, borneol, limonene and eugenol[15,40]. The bark is used as one of the ingredients of Kanchnar Guggulu for various glandular swellings and in Ayurvedic preparations used for goitre[16,17]. Crude extracts of the bark have been studied for antidiabetic, antioxidant, and anti-inflammatory activities[17,18].


**Figure 3: Graphical Illustration of pharmacological activities of Bauhinia Spp. - Kachnar (BV, BP, BA, BB, BR, BT)[40]**

## 2. BOTANICAL DESCRIPTION AND TAXONOMY

### 2.1 Taxonomic Classification

| Rank | Classification | Reference |
|---|---|---|
| Kingdom | Plantae | **[18,19]** |
| Clade | Tracheophytes, Angiosperms, Eudicots, Rosids | **[18,40]** |
| Order | Fabales | **[19,40]** |
| Family | Fabaceae (Caesalpiniaceae) | **[18,19]** |
| Tribe | Bauhinieae | **[6,40]** |
| Genus | Bauhinia | **[6,40]** |
| Species | B. variegata Linn. | **[1,2]** |
| Synonym | Phanera variegata Benth. | **[1,40]** |

### 2.2 Morphological Characteristics

#### 2.2.1 Tree Habit

- Height: 10–15 meters[1,40]
- Trunk diameter: ~0.5 meters[1,40]
- Crown: Thin, elongated, spreading[20,40]
- Bole: Straight, erect, single-stemmed[1,20]

#### 2.2.2 Bark

- Young bark: Thin, smooth, pale pink internally[5,40]
- Old bark: Brown to dark grey with longitudinal fissures, fibrous texture[1,5]
- Taste: Astringent[2,5]


**Plate 1: Bark of Bauhinia variegata showing external and internal characteristics[5]**

### 2.2.3 Leaves

The leaves exhibit a distinctive bilobed shape resembling a camel's foot[2,20]:

- Size: 7.5–15 cm long, broader than long[1,20]
- Shape: Cleft 1/4 to 1/3 down from apex[1,2]
- Base: Deeply cordate[20,40]
- Apex: Mucronate with sharp lobes[1,20]
- Texture: Leathery, smooth above, slightly hairy below[20,40]
- Venation: 11–15 nerves with straight midrib[1,20]
- Petiole: 0.8–2.5 cm, pubescent[1,40]
- Color: Bluish-green[20,40]

**Fig.1: Flower and leave of BV showing characteristic pink flowers and bilobed leaves[1,40]**

### 2.2.4 Flowers

Large, fragrant, ornamental flowers appear when the tree is leafless (January to April)[1,20]:

- Color: Purplish, pink, or white (variegated)[1,20]
- Arrangement: Short axillary racemes[1,20]
- Petals: 4–5 cm long, ovate-obovate[1,20]
- Pollination: Primarily cross-pollinated by insects (10–21.6% self-pollination)[25,40]

### 2.2.5 Fruits and Seeds

- Pods: 15–30 cm long, 1.7–2.5 cm wide, flat, firm[1,20]
- Color: Green (immature) to buff/pale brown (ripe)[1,20]
- Seeds: 10–15 per pod, round, flat, brown (1.3–1.8 cm)[1,20]
- Seed weight: 2500–3500 seeds/kg[20,40]

### Varieties of Bauhinia

Several Bauhinia species are used as Kanchnar[1,2]:

- B. variegata – White/Pink flowers (Rakta Kanchnar)[1,2]
- B. purpurea – Purple flowers (Peeta Kanchnar)[2,40]
- B. tomentosa – Yellow flowers[2,40]
- B. racemosa – White flowers (Shveta Kanchnar)[2,40]

### Flowering and Fruiting

- Flowering period: January to April[1,20]
- Fruiting period: March to July[1,20]
- Seed dispersal: By wind before monsoon[20,40]
- Germination: During rainy season[20,40]

### 2.5 Habitat and Growing Conditions

- Altitude: Up to 1800m in Himalayas (commonly 1300m)[1,5]
- Soil: Slightly acidic, well-drained, rocky/loamy/sandy loam[1,40]

- Temperature: 32–42°C (max), 7–14°C (min)[1,40]
- Rainfall: 760–1900 mm annually[1,40]

## 3. GEOGRAPHICAL DISTRIBUTION

### 3.1 Origin and Native Range

B. vriegata is native to the East Indies and Indian subcontinent, extending across Southeast Asia[4,14]:

- India: Throughout the country, especially sub-Himalayan regions[17,40]
- Southeast Asia: Myanmar, Thailand, Vietnam, Cambodia, Laos[14,16]
- Other regions: China, Pakistan[16,40]
- Introduced: United States (Texas, Louisiana)[14,40]

### 3.2 Distribution in India

Widely distributed across Indian states including Bihar, Delhi, Jammu & Kashmir, Madhya Pradesh, Karnataka, Manipur, Nagaland, Meghalaya, Odisha, Mizoram, Punjab, Rajasthan, Uttar Pradesh, Tamil Nadu, Tripura, West Bengal, and Sikkim[17,40].

The plant grows naturally in deciduous forests and mixed dry forests, and is cultivated as an ornamental plant in parks and gardens[1,40].

### 3.3 Ecological Importance

- Ornamental value: Beautiful flowers[1,40]
- Soil conservation: Root system prevents erosion[1,40]
- Wildlife habitat: Food for pollinators[1,40]
- Agroforestry: Nitrogen-fixing ability[1,40]

### 3.4 Cultivation and Propagation

Propagation methods[21,22]:

1. Seeds: Natural dispersal and germination[20,22,]
2. Direct seeding: Lines 3m apart after monsoon[21,40]
3. Stump planting: Effective for whole plants[22,40]
4. Branch cuttings: With auxin treatment[21,22]

Planting season: Seeds sown in March/April for July/August planting[22,40]

## 4. TRADITIONAL AND ETHNOBOTANICAL USES

B. variegata has been extensively used across traditional medicine systems, particularly Ayurveda, Unani, and folk medicine[2,9].

### 4.1 Ayurvedic Properties

| Property | Description | Reference |
|---|---|---|
| Rasa (Taste) | Kashaya (Astringent) | [9,40] |
| Guna (Quality) | Laghu (Light), Ruksha (Dry) | [2,9] |
| Virya (Potency) | Sheeta (Cold) | [2,40] |
| Vipaka (Post-digestive) | Katu (Pungent) | [9,40] |
| Prabhava (Special effect) | Gandamala Nashana (thyroid/ lymph disorders) | [2,12] |
| Dosha effect | Relieves Kapha & Pitta; may aggravate Vata | [2,9] |

### 4.2 Classical Ayurvedic References

**Charaka Samhita**

- Mentioned as Kovidara and Karbudara[2,7]
- Included in Vamana Upaga group (emetic therapy)[7,40]
- Flowers described as Grahi (absorbent) and Raktapitta Shamaka (bleeding disorders)[2,31]

**Sushruta Samhita**

- Placed under Urdhva Bhagahara Dravya (emetic herbs)[2,8]
- Classified in Kashaya Varga (bitter herbs)[2,8,40]
- Kovidara flower: Madhura (sweet), Raktapitta Shamaka[32,40]
- Karbudara: Madhura, Vata-Pitta Shamaka[33,40]

**Other Texts**

- Bhava Prakash Nighantu: Guduchyadi Varga[14,40]
- Kaiyyadeva Nighantu: Aushadhi Varga[15,40]
- Dhanvantari Nighantu: Guduchyadi Varga[16,40]
- Raja Nighantu: Karviradi Varga[18,40]

### 4.3 Traditional Therapeutic Uses by Plant Part

#### 4.3.1 Bark

- Anthelmintic, astringent, tonic[2,40]
- Amoebic dysentery and diarrhea[2,9]
- Wound healing: External paste for cuts, wounds, ulcers[6,7]
- Sore throat: Gargle[7,40]
- Skin diseases: Leprosy, discoloration[9,10]
- Respiratory disorders: Asthma, cough[9,40]
- Abdominal distention[10,40]

#### 4.3.2 Flowers and Buds

- Bleeding disorders (Raktapitta)[2,31,40]
- Diarrhea and dysentery[2,33]
- Heavy menstrual bleeding (Pradara)[2,40]
- Cough and asthma[2,40]
- Piles and worms: Dried buds[4,40]

#### 4.3.3 Leaves

- Vegetable use: Boiled, pickled[3,40]
- Laxative: Infusion for piles[3,40]
- Wound poultices[3,40]

#### 4.3.4 Seeds

- Aphrodisiac and tonic[34,40]
- Venomous bites: Paste with vinegar[34,40]
- Nutritional: High amino acid content, used as pulse[34,40]

#### 4.3.5 Root

- Antidote to snake poison[1,40]
- Dyspepsia: Decoction[1,40]

### 4.4 Specific Disease Indications

- Grahi: Absorbent (diarrhea)[2,31,]
- Krumighna: Worm infections[12,40]
- Kushtaghna: Skin diseases[12,40]
- Gudabhramsha: Rectal prolapse[12,40]
- Gandamala: Cervical lymphadenitis, thyroid[12,17]
- Pittasra, Raktapittashamak: Bleeding disorders[2,31]
- Pradara: Menorrhagia[2,40]
- Kasanut: Cough, cold[2,40]
- Vranaropaka: Wound healing[1,18]

## 5. PHARMACOGNOSTIC CHARACTERISTICS

Pharmacognostic studies are essential for identification, authentication, and quality control of herbal drugs[1,5].

### 5.1 Macroscopic Characteristics of Bark

- External color: Brownish to greyish-brown[1,5]
- Internal color: Light reddish-brown to cream[1,5]
- Size: 7–10 cm long, 1.5–3 cm thick[1,5]
- Surface: Rough with cracks and fissures[1,5]
- Fracture: Short (outside), fibrous (inside)[1,5]

- Odor: Characteristic[1,5]
- Taste: Mucilaginous followed by bitter[1,5]
- On drying: Becomes curved, channeled; internal surface turns brown[1,5]

### 5.2 Microscopic Characteristics

**Transverse Section of Bark**

**Periderm[5,22]:**

- Cork: 12–20 layers, radially arranged, thin-walled, elongated cells[5,23]
- Phellogen: Single layer below cork[5,23]
- Phelloderm: Wide zone with tangentially elongated cells[5,22]
- Lignified fibers and stone cells scattered[22,23]

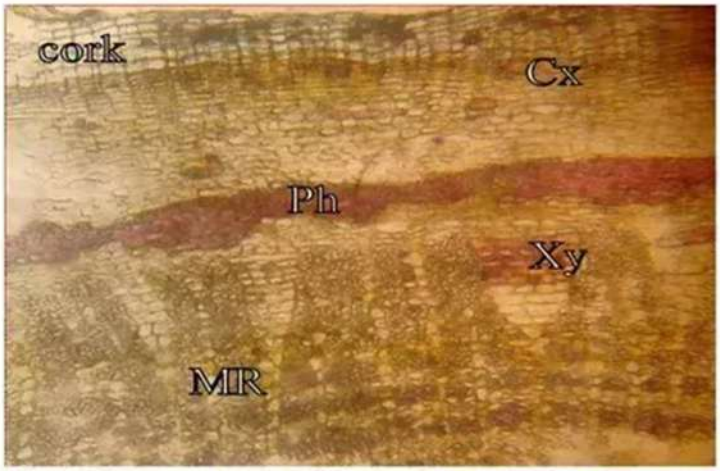


Plate 2- T.S of *Bauhinia variegata* stem bark (Abbreviations: Cx: cortex ; Ph: phloem ; Xy: xylem ; MR: medullary rays)

**Plate 2: T.S of Bauhinia variegata stem bark (Abbreviations: Cx: cortex; Ph: phloem; Xy: xylem; MR: medullary rays)[5]**

**Pericycle[5,22]:**

- Pericyclic fibers with narrow lumen, lignified, broad-walled, tapering ends[5,22]
- Bordered by sclerenchymatic cells[5,23]

**Phloem[5,22]:**

- Well-developed vascular bundle[5,22]
- Xylem (upper), Phloem (lower)[1,5]
- Contains: sieve tubes, companion cells, crystal fibers, phloem fibers, parenchyma, stone cells[23,40]
- Stone cells in radial rows and tangential bands[5,22]
- Crystal fibers (10–25 chambers) with calcium oxalate prisms[22,23,]

**Medullary Rays:**

- Uni- to biseriate rays traverse phloem[5,40]
- Stone cells present in rays[5,40]

**Calcium Oxalate Crystals:**

- Prismatically distributed[5,22,40]

**Transverse Section of Leaf**

**Mesophyll:**

- Palisade cells: 2–3 layers under upper epidermis[27,28]
- Spongy parenchyma above lower epidermis[27,28]

**Midrib:**

- Concave shape[27,28]

- Well-developed vascular bundle bordered by sclerenchymatic cells[27,28]
- Calcium oxalate crystals between epidermis[27,28]

**Trichomes:**

- Unicellular and multicellular uniseriate[29,40]
- Unicellular sessile[29,40]
- More common on lower epidermis[29,40]

### 5.3 Powder Characteristics

Microscopic examination of powdered bark reveals[5,30]:

- Cork cells: Polygonal, occasionally brownish[1,5]
- Fibers: Lignified, in groups of 3–5[30,40]
- Calcium oxalate crystals: In rows around fiber groups[5,30]
- Starch grains: Simple, 20–25 µm[30,40]
- Stone cells: Lignified walls[1,5]

### 5.4 Diagnostic Features

Key identification characteristics[1,5]:

- 10–20 layers of cork cells[1,5]
- Abundant lignified fibers and stone cells[1,5]
- Crystal fibers with calcium oxalate[1,5]
- Medullary rays in phloem[1,5]
- Starch grains, tannins[1,5]
- Presence of sterols, reducing sugars, glycosides[1,5]

## 6. PHYTOCHEMICAL PROFILE

B. variegata contains diverse bioactive phytochemicals contributing to its pharmacological activities [10,11].

### 6.1 Major Phytochemical Classes

1. Flavonoids[5,8]
2. Tannins[11,40]
3. Terpenoids[10,11]
4. Saponins[11,40]
5. Cardiac glycosides[10,11]
6. Alkaloids[11,13]
7. Phenolic compounds[13,14]
8. Steroids[10,11]
9. Amino acids[34,40]
10. Fixed oils and fatty acids[34,40]

### 6.2 Phytochemical Constituents by Plant Part

#### 6.2.1 Leaves

**Major compounds:**

- Flavonoids: Quercetin, rutin, quercetrin, kaempferol-3-glucoside, apigenin, apigenin-7-O-glucoside[5,8]
- Long-chain compounds: Heptatriacontane-12,13-diol, dotetracont-15-en-9-ol[32,40]
- Terpenoids: Lupeol[20,40]
- Steroids: β-sitosterol[6,24]
- Others: Tannins, alkaloids, cardiac glycosides, vitamin C, reducing sugars[5,10]

**Biological activities:** Antifungal, antimicrobial, antidiabetic, hypoglycemic, anticancer[15,32]

#### 6.2.2 Flowers

**Major compounds:**

- Anthocyanins: Cyanidin-3-glucoside, malvidin-3-glucoside, peonidin-3-glucoside[33,40]
- Flavonoids: Quercitroside, isoquercitroside, rutoside, taxifoline rhamnoside, kaempferol-3-glucoside[33,40]
- Acids: Ascorbic, aspartic, glutamic, octadecanoic acids[33,40]

**Biological activities:** Antidiarrheal, antidiabetic, antioxidant, antihyperlipidemic[3,35]

### 6.2.3 Seeds

**Major compounds:**

- The following are amino acids: proline, serine, threonine, tyrosine, valine, histidine, isoleucine, lysine, methionine, phenylalanine, aspartic, glutamic, arginine, glycine, alanine, and histidine. [34,40]
- Fatty acids: Oleic, linoleic, palmitic, stearic, myristic acids[34,40]
- Others: Proteins and carbohydrates[34,40]

**Biological activities:** Haemagglutinating properties[62,40]

### 6.2.4 Stem Bark

**Major compounds:**

- Steroids: Hentriacontane, octacosanol, β-sitosterol, stigmasterol[28,40]
- Flavonoids: 5,7-dihydroxyflavanone-4'-O-α-L-rhamnopyranosyl-β-D-glucopyranoside, lupeol, kaempferol-3-glucoside, naringenin-5,7-dimethyl ether[28,38]
- Phenanthrene: 2,7-dimethoxy-3-methyl-9,10-dihydrophenanthrene-1,4-dione (bauhinione)[38,40]

**Biological activities:** Antitumor, antiulcer, immunomodulatory, hepatoprotective, antibacterial [15,17]

## 6.3 Key Bioactive Markers

### 6.3.1 Quercetin

- Class: Flavonoid[5,32]
- Source: Leaves, flowers[5,8]
- Activities: Antioxidant, anti-inflammatory, anticancer, cardioprotective[24,40]
- Mechanism: Free radical scavenging, metal chelation, enzyme modulation[24,40]

### 6.3.2 β-Sitosterol

- Class: Phytosteroid[6,24]
- Source: Leaves, stem bark, seeds[6,24]
- Activities: Anticancer, antidiabetic, anti-inflammatory, immunomodulatory[6,40]
- Mechanism: Inhibits cholesterol absorption, modulates cell membrane fluidity[6,40]

### 6.3.3 Lupeol

- Class: Pentacyclic triterpenoid[20,40]
- Source: Leaves, stem bark[20,28]
- Activities: Anticancer, anti-inflammatory, antimicrobial, hepatoprotective[20,40]
- Mechanism: Induces apoptosis, inhibits NF-κB signaling[20,40]

### 6.3.4 Kaempferol

- Class: Flavonoid[5,40]
- Source: Leaves, flowers, stem bark[5,28]
- Activities: Antioxidant, anticancer, cardioprotective, neuroprotective[5,40]
- Mechanism: Free radical scavenging, signaling pathway modulation[5,40]

## 6.4 Extraction Methods

**Leaves**

- Method: Soxhlet extraction[1,40]
- Solvents: Petroleum ether (60–80°C), chloroform (50–60°C), ethanol (68–78°C), methanol, water[1,40]
- Yield: Petroleum ether (9.50% w/w), Chloroform (7.65%), Methanol (8.95%), Ethanol (8.50%), Water (0.30%)[40,41]

**Flowers**

- Defatting: Petroleum ether[42,40]

- Extraction: Hot percolation with 95% ethanol[42,40]
- Yield: 20.8% w/w[42,40]
- Fractionation: n-hexane, $CH_2Cl_2$, EtOAc, EtOH fractions[42,40]

**Stem Bark**

- Method: Percolation with 80% methanol[44,40]
- Concentration: Rotary vacuum evaporator[44,40]
- Column chromatography: Silica gel with hexane/ethyl acetate gradient[44,45]

## 7. PHARMACOLOGICAL ACTIVITIES

Extensive research has validated numerous pharmacological properties of B. variegata through in vitro and in vivo studies[12,13].

### 7.1 Antioxidant Activity

**Mechanism:**

- Free radical scavenging (DPPH, superoxide, nitric oxide, hydrogen peroxide)[19,67]
- Metal chelation[19,40]
- Lipid peroxidation inhibition[19,40]
- Enhancement of endogenous antioxidant enzymes (SOD, catalase, GPx)[19,40]

**Active compounds:** Quercetin, rutin, kaempferol, apigenin, phenolic acids, tannins[19,34,]

**Evidence:**

- Ethyl acetate, methanol, and aqueous extracts showed significant DPPH scavenging[67,69]
- Bark extracts demonstrated considerable activity in reducing power and free radical scavenging assays ($p > 0.01$, $p < 0.001$)[69,40]
- Dose-dependent activity comparable to standards (BHA, BHT, ascorbic acid, quercetin)[67,69]

**Clinical significance:** Prevention of oxidative stress-related diseases (diabetes, cardiovascular disorders, cancer, neurodegenerative diseases)[19,40]

### 7.2 Antidiabetic Activity

**Mechanism:**

- Enhancement of glucose metabolism[1,25]
- Improvement of insulin sensitivity[25,40]
- Reduction of hepatic glucose production[25,40]
- Protection of pancreatic β-cells[25,40]

**Active compounds:** Quercetin, kaempferol, glucokinin, terpenoids[25,26]

**Evidence:**

- STZ-induced diabetes: Ethanolic, aqueous, and hydro-alcoholic extracts (200–400 mg/kg) significantly reduced blood glucose in type I and II diabetes models[1,25]
- Alloxan-induced diabetes: Similar hypoglycemic effects[59,99]
- Flower extracts demonstrated antidiabetic properties[1,23]

**Clinical relevance:** Potential adjuvant therapy for diabetes management[25,26]

### 7.3 Anticancer and Antitumor Activity

**Mechanism:**

- Induction of apoptosis[15,17]
- Cell cycle arrest[15,17]
- Inhibition of angiogenesis[15,40]
- Modulation of signaling pathways (NF-κB, MAPK)[15,40]

- Enhancement of immune response[15,53,]

**Active compounds:** Quercetin, β-sitosterol, lupeol, flavonoids, lectins[14,15]

**Evidence:**

- Dalton's Ascitic Lymphoma: Ethanolic extract increased peritoneal cell count (macrophage activation, cytokine production)[53,90]
- Ehrlich Ascites Carcinoma: Cytotoxic activity in mice cell lines[90,40]
- DMBA and croton oil-induced skin carcinogenesis: Methanolic stem bark extract (500–1000 mg/kg) inhibited papilloma development, reduced tumor incidence and number, decreased tumor burden, restored glutathione levels[57,91]
- N-nitrosodiethylamine-induced liver tumors: Ethanolic stem extract showed chemoprevention[61,93]
- COLO 320 cell lines: Active fractions showed anticancer activity[23,40]
- 30-day studies: Increased life span, smaller tumors in micronucleus and chromosomal aberration tests[29,40]

**Clinical relevance:** Potential for anticancer agent development and adjuvant cancer therapy[15,30]

### 7.4 Anti-inflammatory Activity

**Mechanism:**

- Inhibition of COX and LOX[31,75]
- Suppression of pro-inflammatory cytokines (TNF-α, IL-1β, IL-6)[31,75]
- Inhibition of NF-κB activation[31,40]
- Reduction of inflammatory mediators[31,40]

**Active compounds:** Kaempferol, quercetin, apigenin, triterpene caffeate, flavanol glycosides[31,36]

**Evidence:**

- Carrageenan-induced paw edema: Isolated flavanol glycoside showed significant anti-inflammatory activity[36,64]
- CFA-induced arthritis: Ethanolic extract (250 mg/kg) for 15 days reduced paw edema volume, decreased cholesterol, triglycerides, ALP, ALT, modulated antioxidant enzymes[51,82]
- LPS and IFN-γ induced cytokine production: Six flavonoids and one triterpene caffeate suppressed cytokine production[64,75]

**Clinical relevance:** Treatment of arthritis, IBD, inflammatory conditions[31,51]

### 7.5 Antimicrobial Activity

**Mechanism:**

- Disruption of bacterial cell membrane[18,60]
- Inhibition of protein synthesis[18,60]
- Interference with DNA replication[18,40]
- Antifungal activity via cell wall disruption[74,40]

**Active compounds:** Flavonoids, tannins, alkaloids, phenolic compounds[15,58] Evidence:

**Antibacterial:**

- Gram-positive: Bacillus subtilis (highly susceptible, 14 mm inhibition zone at 22 mg/mL), Staphylococcus aureus[58,70]
- Gram-negative: Salmonella typhi, E. coli, Enterobacter aerogenes, Klebsiella pneumoniae, Pseudomonas aeruginosa, Vibrio cholerae, Shigella dysenteriae[60,70]
- Ethanolic extracts more effective against gram-positive bacteria[70,73]
- Alcoholic leaf extract showed highest activity vs. petroleum ether and chloroform[72,40]

**Antifungal:**

- Methanolic leaf extracts inhibited Aspergillus fumigatus and Aspergillus niger[74,40]

**Clinical relevance:** Treatment of infections, potential for novel antimicrobial development[18,34]

### 7.6 Hepatoprotective Activity

**Mechanism:**

- Reduction of hepatic lipid peroxidation[7,54,]
- Enhancement of antioxidant defense[7,22]
- Restoration of liver enzyme levels[54,94]
- Protection against hepatotoxins[54,94]

**Evidence:**

- $CCl_4$-induced hepatotoxicity: Ethanolic stem bark extract (100–200 mg/kg) significantly reduced AST, ALT, ALP, GGTP[7,54]
- DEN-induced liver tumors: Ethanolic stem extract showed chemoprevention, increased glutathione transferase, glutathione peroxidase[61,93,]

**Clinical relevance:** Liver disorder treatment, adjuvant in hepatotoxic drug therapy[7,22]

### 7.7 Nephroprotective Activity

**Evidence:**

- Gentamicin-induced nephrotoxicity: Ethanolic and aqueous root extracts (200–400 mg/kg) showed strong nephroprotective effect, reduced serum creatinine, serum urea, urine creatinine, BUN[77,78]
- Cisplatin-induced nephrotoxicity: Ethanolic whole stem extract (400 mg/kg) for 14 days decreased serum creatinine, serum urea, urine creatinine, albumin; weight gain, increased urine output, minimal histological damage[66,78]

### 7.8 Other Activities

| Activity | Evidence | Reference |
|---|---|---|
| Antiulcer | Pyloric ligation and aspirin-induced ulcer models: Reduced gastric output volume, total and free acidity, ulcer index | **[56,80]** |
| Immuno-modulatory | Enhanced phagocytic activity, modulated humoral and cell-mediated immunity, increased neutrophil adhesion | **[19,52]** |
| Anti-hyperlipidemic | Reduced cholesterol, triglycerides, LDL, VLDL; raised HDL in Triton WR-1339-induced hyperlipidemia | **[3,6]** |
| Wound Healing | Ethanolic and aqueous root extracts showed significant healing in excision and incision wound models | **[1,96]** |
| Anthelmintic | Crude ethanolic stem bark extract caused dose-dependent paralysis and death of Pheretima posthuma and Ascardia galli | **[63,100]** |
| Anti-goitrogenic | Alcoholic stem extract (200 mg/day) effective in normalizing goitrogenic thyroid in neomercazole-induced goitre model | **[87,88]** |

## 8. QUALITY CONTROL AND STANDARDIZATION

Standardization ensures consistent quality, safety, and efficacy of herbal drugs[26,27].

### 8.1 Physicochemical Parameters

#### Ash Values

| Parameter | Value (% w/w) | Significance | Reference |
|---|---|---|---|
| Total ash | 8.15–9.52 | Total inorganic content | [29,30,] |
| Acid-insoluble ash | 0.57–5.50 | Siliceous matter, sand contamination | [5,30] |
| Water-soluble ash | 2.25–4.7 | Water-soluble salts | [5,40] |
| Water-insoluble ash | 6.50 | Water-insoluble minerals | [1,5] |
| Sulphated ash | 3.45 | Pharmacopoeial standard | [5,40] |

**Interpretation[1,5]:** High acid-insoluble ash indicates contamination;

### 8.2 Quantitative Phytochemical Analysis

| Parameter | Value | Reference |
|---|---|---|
| Total phenolics | 88.71 ± 1.04% (gallic acid equivalents) | [19,40] |
| Total flavonoids | 132.89 ± 3.34% | [40] |
| Total tannins | 96.71 ± 6.45% (tannic acid equivalents) | [20,40] |
| Total carbohydrates | 5.06 ± 0.40% | [21,40] |
| Total alkaloids | 3.40 ± 0.45% | [40] |
| Mucilage content | 20.5 ± 0.34% | [40] |
| Crude fiber content | 58.3 ± 0.56% | [22,40] |

**Significance:** High phenolic/flavonoid content correlates with antioxidant activity; mucilage supports GI applications[19,40]

### 8.3 Chromatographic Methods

#### Thin Layer Chromatography (TLC)

**Petroleum Ether Extract:**

- Solvent system: Petroleum ether:Ethyl acetate (95:5)[30,40]
- Detection: UV 254/366 nm, Cerric ammonium sulphate spray[30,40]
- Compounds detected: 4[30,40]

**Chloroform Extract:**

- Solvent system: Chloroform: Methanol (80:20)[30,40]
- Compounds detected: 3[30,40]

#### HPTLC

- Lupeol quantification: Densitometric HPTLC, violet bands at Rf 0.65[20,40]
- Fingerprint analysis: 11 peaks detected for B. variegata leaves[22,40]
- Application: Quality control, standardization[20,22]

### 8.4 Recommended Standardization Markers

Primary markers:

1. Quercetin (HPLC/HPTLC)[24,40]
2. Lupeol (HPTLC)[20,40]
3. β-sitosterol (GC-MS)[23,40]
4. Kaempferol (HPLC)[24,40]

**Secondary markers:**

1. Total flavonoid content[40]
2. Total phenolic content[19,40]
3. Total tannin content[20,40]

### 8.5 Dosage Forms and Recommended Doses

| Form | Dose | Reference |
|---|---|---|
| Bark powder | 3–6 g | [38,40] |
| Decoction | 40–80 mL | [38,40] |
| Flower juice | 10–20 mL | [38,40] |

## 9. FORMULATIONS AND CLINICAL APPLICATIONS

### 9.1 Classical Ayurvedic Formulations

#### 9.1.1 Kanchnar Guggul

**Composition (12 ingredients):**

- Bauhinia variegata stem bark (Kanchnar) – 480 g[7,11]
- Commiphora wightii oleo-resins purified (Guggulu-Shuddha) – 996 g[11,40]
- Terminalia chebula pericarp (Haritaki) – 96 g[7,40]
- Terminalia bellerica pericarp (Bibhitaka) – 96 g[7,40]
- Phyllanthus emblica pericarp (Amalaki) – 96 g[11,40]
- Zingiber officinale rhizome (Sunthi) – 48 g[7,11]
- Piper nigrum fruits (Marica) – 48 g[7,11]
- Piper longum fruits (Pippali) – 48 g[11,40]
- Crataeva nurvala stem bark (Varuna) – 48 g[7,11]
- Elettaria cardamomum seeds (Ela) – 12 g[7,40]
- Cinnamomum zeylanicum stem bark (Tvak) – 12 g[11,40]
- Cinnamomum tamala leaves (Tejpatra) – 12 g[7,11]

**Properties:**

- Kanchnar and Guggulu possess Deepan, Pachan, Vatta-Kaphashamak, Shoth-har, Lekhan, Bhedi properties[7,11]
- Guggulu oleo-resins have potent anti-inflammatory (shothhara) effect[11,40]

**Indications:**

- Gandamala (cervical lymphadenitis)[11,12]
- Apachi (chronic lymphadenopathy/scrofula)[7,40]
- Granthi (cyst)[7,40]
- Gulma (abdominal lump)[11,40]
- Vrana (ulcer)[7,11]
- Kustha (skin diseases)[7,40]
- Bhagandara (fistula-in-ano)[11,40]
- Slipada (filariasis)[7,11]
- Benign and malignant tumors[7,11]

**Dosage:** 2–4 tablets twice daily with warm water (as per physician's advice)[7,40]

**Listed in:** Indian Ayurvedic Pharmacopoeia, Ayurvedic Formulary[7,40]

#### 9.1.2 Other Classical Formulations

1. Kanchan Gutika – Glandular swellings, tumors[36,40]
2. Gandamala Kundan Rasa – Goitre, cervical lymphadenitis[36,40]
3. Gulkand Kanchnar – Constipation, digestive disorders[36,40]
4. Kanchanaradi Kwatha – Thyroid disorders, glandular swellings[36,37]
5. Ushirasava – Heavy menstrual bleeding, skin diseases[37,40]
6. Chandanasava – Cardiac and digestive tonic[37,40]
7. Vidangarishta – Worm infestations, digestive disorders[37,40]

### 9.2 Clinical Applications

#### 9.2.1 Thyroid Disorders

- Traditional use: Gandamala nashaka (thyroid problems), goitre[2,12]
- Clinical evidence: Experimental anti-goitrogenic activity; Kanchnar Guggul widely prescribed for hypothyroidism[87,88]

#### 9.2.2 Cervical Lymphadenitis

- Traditional use: Gandamala (cervical lymphadenitis/scrofula)[2,12]
- Clinical evidence: Increases efficacy of anti-tubercular medications; anti-inflammatory and immunomodulatory effects[86,40]

#### 9.2.3 Diabetes Mellitus

- Traditional use: Antidiabetic in traditional texts[25,26]
- Clinical evidence: Multiple animal studies demonstrate hypoglycemic effects; human trials needed[1,25]

#### 9.2.4 Skin Diseases

- Traditional use: Kushtaghna (skin diseases), leprosy, discoloration[9,12]
- Clinical evidence: Antimicrobial, anti-inflammatory, wound healing documented[18,72]

#### 9.2.5 Gastrointestinal Disorders

- Traditional use: Diarrhea, dysentery, ulcers[2,9]
- Clinical evidence: Antiulcer, antidiarrheal effects in animal models[56,80]

#### 9.2.6 Cancer

- Emerging application: Several studies demonstrate anticancer potential; Kanchnar Guggul used as adjuvant therapy[15,30]
- Status: Requires extensive clinical validation[15,30]

### 9.3 Traditional Preparation Methods

**Bark Decoction (Kwatha)**

1. Take 10–20 g dried bark powder[38,40]
2. Add 8 parts water (80–160 mL)[38,40]
3. Boil until reduced to 1/4 volume[38,40]
4. Filter and consume warm[38,40]

**Bark Paste**

1. Take dried bark powder[6,7,40]
2. Mix with water, honey, or ghee to form paste[6,7,40]
3. Apply externally to wounds, ulcers, swellings[6,7,40]

### 9.4 Dosage and Administration

**General guidelines:**

- Powder: 3–6 g daily with water or honey[38,40]
- Decoction: 40–80 mL twice daily[38,40]
- Juice: 10–20 mL twice daily[38,40]
- Tablets (Kanchnar Guggul): 2–4 tablets twice daily with warm water[7,40]

**Duration:** Typically 1–3 months or as directed[40]

**Precautions:**

- Take under medical supervision[40]
- Inform healthcare provider about concurrent medications[40]
- Monitor for adverse effects[40]

## 10. RESEARCH GAPS AND FUTURE DIRECTIONS

Despite extensive traditional use and growing scientific evidence, several research gaps remain[1,40].

### 10.1 Phytochemistry

**Current status:** Many compounds identified; structures elucidated[13,14]

**Gaps:**

- Complete phytochemical profiling using metabolomics[1,40]

- Minor bioactive compound identification[1,40]
- Structure-activity relationship studies[1,40]
- Bioavailability and pharmacokinetic studies[1,40]

**Future directions:**

- Comprehensive metabolomic analysis[1,40]
- Novel compound isolation[1,40]
- Synergistic effects of compound mixtures[1,40]
- Standardized extracts with defined composition[1,40]

**10.2 Pharmacology**

**Current status:** Numerous in vitro/in vivo studies; mechanisms partially understood[12,13]

**Gaps:**

- Detailed mechanism of action for many effects[1,40]
- Dose-response relationships[1,40]
- Long-term efficacy studies[1,40]
- Comparative studies with standard drugs[1,40]
- Bioavailability and pharmacokinetics[1,40]

**Future directions:**

- Molecular-level mechanistic studies[1,40]
- Molecular target identification[1,40]
- Genomic and proteomic studies[1,40]
- Animal models mimicking human conditions[1,40]
- Combination therapy investigation[1,40]

**10.3 Clinical Studies**

**Current status:** Traditional use documented; animal studies supportive; limited human trials[1,40]

**Gaps:**

- Lack of randomized controlled trials (RCTs)[1,40]
- No Phase I, II, III clinical trials for most indications[1,40]
- Human safety and efficacy data lacking[1,40]
- Optimal dosage regimens not established[1,40]
- Long-term safety data absent[1,40]

**Future directions:**

- Well-designed RCTs for key indications (diabetes, thyroid disorders, cancer adjuvant, inflammation)[1,40]
- Phase I safety studies in healthy volunteers[1,40]
- Dose-finding studies[1,40]
- Long-term follow-up studies[1,40]
- Post-marketing surveillance[1,40]
- Pharmacovigilance systems[1,40]

**10.4 Standardization and Quality Control**

**Current status:** Some parameters established; TLC/HPTLC methods developed[20,22]

**Gaps:**

- Lack of universally accepted protocols[1,40]
- Validated biomarkers needed[1,40]
- Batch-to-batch variability not characterized[1,40]
- Geographical/seasonal variation influence unclear[1,40]

**Future directions:**

- Validated analytical methods (HPLC, GC-MS, LC-MS)[1,23]
- Reference standards for major compounds[1,40]
- DNA barcoding for authentication[1,40]

- Good Agricultural and Collection Practices (GACP)[1,40]
- Pharmacopeial monograph development [1,26]
- Quality by Design (QbD) approaches[1,40]

### 10.5 Toxicology

**Current status:** Generally considered safe; limited acute toxicity data[1,40]

**Gaps:**

- Comprehensive toxicity studies lacking (sub-acute, chronic, reproductive, genotoxicity, carcinogenicity)[1,40]
- Drug interaction studies[1,40]
- Safety in special populations (pregnant, children, elderly)[1,40]

**Future directions:**

- Systematic toxicity studies (OECD guidelines)[1,40]
- Drug-drug and drug-herb interaction studies[1,40]
- Toxicokinetic studies[1,40]
- Vulnerable population safety studies[1,40]
- Post-marketing adverse event monitoring[1,40]

### 10.6 Formulation Development

**Current status:** Traditional formulations established; some modern products available[7,11]

**Gaps:**

- Extraction method optimization[1,40]
- Novel drug delivery systems unexplored [1,40]
- Bioavailability enhancement strategies needed [1,40]
- Formulation stability studies lacking[1,40]

**Future directions:**

- Standardized extract development[1,40]
- Novel delivery systems (nanoparticles, liposomes, phytosomes, sustained-release) [1,40]
- Bioavailability enhancement (bioenhancers, self-emulsifying systems)[1,40]
- Stability studies and shelf-life determination [1,40]

### 10.7 Other Research Needs

**Agricultural and conservation:**

- Sustainable harvesting practices[1,40]
- Cultivation optimization[21,22,40]
- GACP implementation[1,40]
- Conservation strategies[1,40]

**Regulatory aspects:**

- Comprehensive monographs[1,40]
- International standard harmonization[1,40]
- Evidence for regulatory approvals[1,40]
- Intellectual property protection[1,40]

**Integration with modern medicine:**

- Evidence-based integrative guidelines[1,40]
- Healthcare provider education[1,40]
- Drug interaction studies[1,40]
- Adjuvant use protocols[1,40]

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