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Ethnobotanical Perspectives of *Eclipta alba* with Special Reference to India: A Critical Review

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Review Article

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Abstract

Eclipta alba (L.) Hassk., commonly known as Bhringaraj or false daisy, is a pantropical herb of the family Asteraceae that occupies a position of exceptional prominence in Indian traditional medicine. Embedded within the classical frameworks of Ayurveda, Siddha, and Unani, as well as the living folk traditions of hundreds of tribal and rural communities across the subcontinent, the plant has served generations of practitioners as a versatile therapeutic resource. This critical narrative review synthesises ethnobotanical documentation, phytochemical characterisation, and pharmacological evidence pertaining to *E. alba*, with particular emphasis on its traditional uses across the diverse ecological and cultural landscapes of India. The plant's bioactive chemistry is dominated by wedelolactone, a coumestan-class polyphenolic lactone, alongside eclalbatin, ecliptine, luteolin, apigenin, and an array of triterpenoid saponins and phytosterols. These constituents underpin a well-documented pharmacological profile encompassing hepatoprotective, hair growth–promoting, anti-inflammatory, anticonvulsant, antimicrobial, antioxidant, and anticancer activities.

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Ethnobotanical surveys confirm consistent use of the plant for liver ailments, alopecia, skin disorders, venomous bites, and neurological complaints across geographically and culturally distant communities, with considerable convergence between classical textual records and field-documented folk knowledge. The review further considers cross-cultural perspectives from Southeast Asia, Africa, and the Americas, and evaluates emerging concerns regarding habitat pressure, unsustainable harvesting, bioprospecting, and the protection of associated traditional knowledge. Despite encouraging convergences between traditional use and pharmacological findings, critical gaps remain in clinical validation, phytochemical standardisation, and mechanistic elucidation. The review calls for integrated, interdisciplinary research that bridges ethnobotanical knowledge with rigorous biomedical investigation, whilst safeguarding the biocultural heritage this species represents.

Keywords: Eclipta alba; Bhringaraj; wedelolactone; ethnobotany; Ayurveda; Indian medicinal plants; hepatoprotective; hair growth; traditional medicine; phytochemistry.

1. Introduction

1.1 Ethnobotany, Traditional Medicine, and the Indian Context

The relationship between plant life and human health is among the most enduring of all cultural constants, and nowhere has this relationship been more systematically elaborated than on the Indian subcontinent. Ethnobotany—the scientific investigation of interactions between people and plants across cultures and time—occupies a uniquely productive position at the intersection of biology, anthropology, pharmacology, and conservation science. Within this disciplinary space, plants with deep and multiply documented traditional use profiles constitute an exceptionally rich source of pharmacological leads, biocultural heritage, and ecological insight. The growing global momentum behind traditional and complementary medicine, reflected in successive World Health Organization strategies and the recognition that a significant proportion of the world's population relies on plant-based healthcare, has reinvigorated research interest in ethnobotanically important species (World Health Organization, 2019). Recent clinical-trial scholarship has likewise emphasized that the expanding global use of herbal medicines must be matched by stronger methodological designs and transparent evaluation standards if traditional remedies are to be translated into reliable evidence-based interventions (Koonrungsesomboon et al., 2024). This is particularly true for nations such as India, which combine extraordinary botanical wealth with sophisticated indigenous medical traditions capable of generating well-grounded pharmacological hypotheses (Fabricant & Farnsworth, 2001).

India's medicinal flora is extraordinary in both its diversity and its cultural embeddedness. The country harbours over 17,000 species of flowering plants, of which approximately 7,500 have been documented for therapeutic use within Ayurveda, Unani, Siddha, and the diverse folk medical traditions practised by tribal and rural communities (Ministry of AYUSH, 2020). Against this backdrop, individual plants that have achieved prominence across multiple traditions—classical and folk, Sanskrit-literate and orally transmitted—constitute a special category of scientific interest. Their very ubiquity across traditions suggests both therapeutic effectiveness and cultural resilience, attributes that warrant systematic scientific scrutiny. The present review focuses on one such plant: Eclipta alba (L.) Hassk., a common wetland herb whose standing in Indian traditional medicine is as disproportionately large as its unassuming physical presence might suggest. A recent review of *Eclipta prostrata* (L.) L., treated as synonymous with E. alba in much of the pharmacognostic literature, documents its wide ethnomedicinal use in South Asian and other tropical medical traditions, particularly for disorders involving the skin, liver, stomach, and hair growth (Timalsina & Devkota, 2021).

The growing integration of traditional knowledge into formal pharmacological research is not without methodological and ethical complexity. As Leonti and Casu (2013) have argued, the globalisation of traditional plant knowledge introduces challenges of intellectual property protection, equitable benefit sharing, and the decontextualisation of knowledge systems that evolved within specific ecological and cultural frameworks. These challenges are directly relevant to E. alba, which, as subsequent sections document, sits at the centre of active commercial and research interests that extend well beyond its communities of origin. Recent work on E. alba further shows that its bioactive compounds are being investigated with modern extraction, profiling, and pharmacological approaches for dermatological applications, reinforcing the need to connect ethnobotanical documentation with phytochemical validation and responsible translational research (Myo et al., 2024). A rigorous ethnobotanical review must therefore attend not only to what the plant does and how it has been used, but also to who holds the relevant knowledge, and under what conditions that knowledge is being translated into broader scientific and commercial value.

1.2 *Eclipta alba*: A Plant of Enduring Significance

Eclipta alba, referred to in Sanskrit as Bhringaraj (literally, "king of hair") or Kesharaj ("ruler of hair"), is among the most consistently documented medicinal plants in the Indian literature. Its name already encodes one of its most celebrated traditional applications: the promotion of hair growth and the reversal of alopecia. Classical Ayurvedic texts including the Charaka Samhita and Ashtanga Hridayam prescribe the plant for a range of conditions, and its central role in commercial Ayurvedic hair care formulations remains unchanged in the contemporary market. Yet the plant's ethnobotanical profile extends far beyond hair care. The available literature, drawing from documented uses in over forty-five vernacular languages and at least twenty-four tribal and folk communities across India, reveals a therapeutic scope encompassing liver disorders, skin diseases, neurological complaints, wound management, venomous bites, and veterinary applications (Jahan et al., 2014). The accumulation of pharmacological data over the past four decades has provided considerable mechanistic grounding for many of these uses, even as important gaps in clinical evidence persist.

The scientific trajectory of *E. alba* research was substantially shaped by the isolation and characterisation of wedelolactone, a coumestan-class compound identified by Wagner et al. (1986) as the principal hepatoprotective constituent of the plant. Since that foundational work, a growing body of research has characterised the plant's secondary metabolite complement and subjected isolated compounds and crude extracts to testing across multiple experimental models. The resulting pharmacological literature is diverse, covering hepatoprotective mechanisms at the molecular level (Manvar et al., 2012), hair follicle biology (Datta et al., 2009), neuropharmacology (Thakur & Mengi, 2005), and antiviral activity (Tewtrakul et al., 2007), among other areas. This accumulation of data positions *E. alba* as a plant for which the scientific case for deeper investigation is already substantial, and for which the ethnobotanical record provides a map of traditional claims awaiting systematic evaluation.

1.3 Scope and Objectives of this Review

This review constitutes a critical narrative assessment of the ethnobotanical perspectives of *Eclipta alba* with special reference to India. Specifically, it aims to: (i) systematically synthesise ethnobotanical documentation of *E. alba* from across India, encompassing Ayurvedic, Siddha, Unani, and folk traditions; (ii) examine the phytochemical composition underlying the plant's therapeutic reputation; (iii) critically assess the pharmacological evidence in relation to traditional uses; (iv) situate Indian ethnobotanical knowledge within a broader comparative cross-cultural framework; (v) evaluate conservation and sustainability considerations relevant to the species; and (vi) identify priority areas for future research and policy attention. The review does not constitute a systematic review of a single therapeutic endpoint; rather, it embraces the full breadth of the plant's ethnobotanical profile in order to present a comprehensive scholarly assessment that reflects the integrative nature of ethnobotany as a discipline.

2. Methods for Literature Selection

The literature search informing this review was conducted across four major bibliographic databases—Web of Science, Scopus, PubMed, and Google Scholar—and supplemented by searches in six field-specific indexing resources chosen for their particular relevance to the review's subject matter: CAB Abstracts (for agricultural, veterinary, and applied biological literature); NAPRALERT (the Natural Products Alert database maintained at the University of Illinois at Chicago, covering global natural product pharmacology); ETHNOBOTDB (a dedicated ethnobotanical database); IndMED (the Indian MEDLARS index of biomedical journals published in India); the Traditional Knowledge Digital Library (TKDL, Government of India), which archives classical Ayurvedic, Siddha, and Unani formulations; and the AYUSH Research Portal, maintained by India's Ministry of AYUSH as a repository of research on traditional medicine systems. The inclusion of IndMED and TKDL was considered essential to ensure that India-specific literature, which is often inadequately indexed in international databases, was comprehensively captured.

Search strings employed included the following terms and Boolean combinations: "*Eclipta alba*", "*Eclipta prostrata*", "Bhringaraj", "Kesharaj", "wedelolactone", "*Eclipta* AND ethnobotany", "*Eclipta* AND India", "*Eclipta* AND Ayurveda", "*Eclipta* AND hepatoprotective", "*Eclipta* AND hair growth", "*Eclipta* AND phytochemistry", "*Eclipta* AND pharmacology", "*Eclipta* AND tribal", "*Eclipta* AND folk medicine", and "*Eclipta* AND conservation". The date range for the primary search was set from 1 January 2000 to present, reflecting the period during which the majority of rigorous peer-reviewed pharmacological and ethnobotanical studies on *E. alba* have appeared in indexed international journals, and when digital ethnobotanical databases became sufficiently operational to enable systematic retrieval. Classic references predating 2000 were identified through forward and backward citation tracking of key papers, and were included where they represent foundational contributions to the field that remain essential to any scholarly assessment of *E. alba* research.

Inclusion criteria comprised peer-reviewed original research articles, critical reviews, and meta-analyses published in English; studies reporting ethnobotanical, phytochemical, or pharmacological data specifically attributable to *E. alba* or *E. prostrata*; and institutional reports from authoritative bodies (WHO, Ministry of AYUSH, Government of India, TKDL) pertaining to traditional medicine policy or biodiversity governance. Exclusion criteria included books, grey literature, conference proceedings, trade publications, preprints, patents, and non–peer-reviewed sources; studies that mentioned *E. alba* only incidentally within multi-species surveys without providing species-specific data; and non-English language articles for which no certified translation was accessible.

The screening workflow involved an initial pass of title and abstract review to remove obviously irrelevant records, followed by full-text assessment of potentially eligible studies. Duplicate records retrieved across multiple databases were identified and removed. A narrative review approach was adopted, consistent with the integrative, multi-disciplinary aims of the review and the inherent heterogeneity of study designs, outcome measures, and experimental models across the included literature. As Greenhalgh and Peacock (2005) have argued, narrative reviews are especially appropriate for synthesising evidence across disparate disciplines and study types when the objective is conceptual integration rather than quantitative aggregation. Study selection prioritised methodological rigour, direct relevance to the review's objectives, and contribution to an understanding of the ethnobotanical, phytochemical, or pharmacological dimensions of *E. alba*, with preference given to in vivo studies, human subject research, and rigorously controlled phytochemical isolation procedures.

3. Botanical Description and Taxonomic Overview

3.1 Taxonomy and Nomenclature

Eclipta alba (L.) Hassk. is placed within the tribe Heliantheae of the family Asteraceae (Compositae). It was originally described by Linnaeus as *Verbesina alba* and subsequently reclassified by Hasskarl. Its nomenclatural status is complicated by the widespread use in the pharmacological literature of the synonym *Eclipta prostrata* L., which some taxonomic authorities treat as the preferred binomial under the rules of botanical nomenclature. Whilst the two names are treated as synonymous in most contemporary pharmacological literature, the name *E. alba* retains primacy in the Indian ethnobotanical and classical medical literature, and is accordingly used as the primary designation throughout this review, with *E. prostrata* acknowledged wherever cited studies employ that nomenclature (Jahan et al., 2014).

The genus *Eclipta* encompasses approximately four species distributed across tropical and subtropical regions globally. Within India, vernacular names for *E. alba* number over forty across regional languages, reflecting the plant's integration across the cultural and linguistic fabric of the subcontinent. Sanskrit names include Bhringaraj, Kesharaj, Kesharaja, and Markava. Regional designations include Bhangra (Hindi), Galagara (Kannada), Karisalankanni (Tamil), Bhangaro (Gujarati), Bhemraje (Marathi), and Kesharaja (Telugu), amongst others. This remarkable linguistic plurality is itself an ethnobotanical indicator of the plant's historical significance, suggesting deep roots in local therapeutic practice well before the systematisation of classical medical texts.

3.2 Morphological Characteristics

Eclipta alba is an annual or short-lived perennial herb, typically attaining 10–60 cm in height, with a characteristic erect or prostrate growth habit dependent upon moisture availability and habitat conditions. The stem is branched from near the base, rough-hairy (strigose) in texture, and presents a distinctively brittle-succulent character when fresh. Leaves are simple, opposite, lanceolate to oblong, measuring 2–8 cm in length, with strigose surfaces and near-sessile attachment to the stem. Floral heads are solitary or arranged in small clusters, 6–8 mm in diameter, and are composed of white ray florets and white disc florets—a morphology that accounts for the plant's common English name, false daisy. The achene fruits are compressed and three- to four-angled, lacking a pappus, which serves as a useful taxonomic character. The taproot is cylindrical and greyish-white externally. Perhaps most diagnostically, the entire plant produces a dark juice upon bruising that turns black on drying—a property historically exploited in traditional hair dyeing and body colouring practices across multiple cultures (Jahan et al., 2014).

3.3 Distribution and Habitat

The species is pantropical in distribution, established naturally across South Asia, Southeast Asia, East Asia, tropical Africa, the Americas, and Australia. Within India, it is ubiquitous from the Himalayan foothills to the southernmost peninsula, and extends into the Andaman and Nicobar Islands. It colonises moist, disturbed habitats—paddy field margins, roadsides, canal banks, riverine floodplains, and ruderal waste grounds—and is widely regarded as a weed of cultivation. Its tolerance for waterlogged soils and disturbed ecology has ensured widespread distribution even as natural habitats contract under agricultural pressure. Ecologically, this resilience is a double-edged characteristic: whilst it guarantees continued availability for traditional use, it has historically discouraged formal cultivation and conservation efforts, since the plant is rarely perceived as being at risk.

Table 1 summarises the taxonomic classification, key morphological features, distribution range, and principal vernacular nomenclature of *E. alba*. This overview draws primarily on the comprehensive taxonomic and ethnopharmacological summaries in Jahan et al. (2014) and Thakur and Mengi (2005).

Table 1. Taxonomic and Morphological Profile of *Eclipta alba* (L.) Hassk

Parameter	Details
Kingdom	Plantae
Family	Asteraceae (Compositae)
Tribe	Heliantheae
Genus	*Eclipta*
Species	*E. alba* (syn. *E. prostrata*)
Growth habit	Annual/short-lived perennial herb; erect or prostrate; 10–60 cm
Leaf	Simple, opposite, lanceolate to oblong, strigose, 2–8 cm
Flower	White ray and disc florets; head 6–8 mm diameter
Fruit	Achene, compressed, 3–4-angled, no pappus
Distinctive trait	Juice turns black on drying; used as pigment
Distribution	Pantropical; throughout Indian subcontinent
Habitat	Moist, disturbed ground; paddy fields, roadsides, riverbanks
Selected vernacular names (India)	Bhringaraj/Kesharaj (Sanskrit); Bhangra (Hindi); Karisalankanni (Tamil); Galagara (Kannada)

Sources: Jahan et al. (2014); Thakur and Mengi (2005)

4. Ethnobotanical Uses in India

4.1 Ayurvedic and Classical Medical Traditions

The therapeutic use of *Eclipta alba* is documented in several foundational texts of Indian classical medicine, constituting one of the more thoroughly textualised plant use records in the Ayurvedic canon. In Ayurveda, Bhringaraj is classified as a Rasayana—a category of agents believed to promote longevity, rejuvenate bodily tissues, and enhance cognitive and sensory function—and is specifically cited in the Charaka Samhita and Ashtanga Hridayam in contexts relating to hair disorders, liver diseases, and conditions of the eyes and skin.

The plant's pharmacological attributes in classical Ayurvedic terms include a bitter and pungent taste (tikta and katu rasa), a heating potency (ushna virya), and a pungent post-digestive transformation (katu vipaka), properties that position it therapeutically as an agent for pacifying kapha and vata doshas whilst mildly stimulating pitta. This classical characterisation aligns in interesting ways with the pharmacological evidence for wedelolactone's anti-inflammatory and hepatostimulant effects (Wagner et al., 1986; Manvar et al., 2012), though the theoretical frameworks are entirely distinct.

In classical Ayurvedic formulations, the leaf juice of Bhringaraj forms the principal ingredient in Maha Bhringraj Taila (a medicated sesame oil for scalp application prescribed in hair loss and premature greying) and features in Bhringarasav (a fermented preparation used for liver and splenic conditions), in addition to serving as a component in numerous compound formulations targeting eye ailments, skin diseases, and conditions of debility. The Siddha medical tradition of Tamil Nadu employs the plant under the name Karisalankanni for hepatotonic, anti-haemorrhoidal, jaundice-treating, and leucoderma-addressing applications. The Unani system similarly recognises the plant's hepatoprotective and anti-inflammatory properties, situating them within its own humoral theoretical framework (Jahan et al., 2014). Mukherjee et al. (2012), in a detailed examination of the development of Ayurveda from traditional practice to contemporary trend, underscore the role of precisely this type of well-documented, multi-system plant as a bridge between classical knowledge and modern biomedical validation.

4.2 Tribal and Folk Uses

Beyond the formalised classical traditions, *E. alba* has been documented extensively in ethnobotanical surveys of tribal and rural communities throughout India. India's tribal population—numbering approximately 104 million people, representing 8.6% of the national population (Office of the Registrar General & Census Commissioner, India, 2011)—relies substantially on plant-based medicine, particularly in areas where formal healthcare infrastructure remains limited. Documented tribal uses of *E. alba* span the country's geographic and cultural diversity, from the Gond, Bhil, and Santhal communities of central India to the Mising, Adi, and Karbi peoples of the northeastern states, and the Kani, Irula, and Kurumba tribes of the Western Ghats. The consistency of therapeutic applications across these geographically distant and culturally distinct communities is remarkable and constitutes strong ethnopharmacological evidence for the plant's genuine utility.

The most consistently recorded therapeutic applications across communities are liver and spleen disorders, alopecia and premature greying, skin diseases including eczema, psoriasis, and leucoderma, wound management, venomous bites (snake and scorpion), pyrexia, and conditions characterised by general weakness and debility. The predominant preparation method is the expression of fresh leaf juice, which is taken orally for liver complaints and applied topically to the scalp for hair disorders. Whole-plant decoctions are prepared for pyrexia and skin diseases, whilst root paste is applied to wounds and cutaneous ulcers in communities of Madhya Pradesh and Chhattisgarh (Jahan et al., 2014). Ignacimuthu et al. (2006), in a survey of medicinal plants used by Paliyar tribals in Tamil Nadu's Theni district, documented *E. alba* among the most frequently cited species, particularly for jaundice and hair ailments. Similarly, Uniyal et al. (2006), surveying tribal communities of the Chhota Bhangal region in the Western Himalaya, recorded the plant's use in local hepatoprotective preparations consistent with its classical Ayurvedic reputation.

A culturally distinctive use documented in Rajasthan, Gujarat, and Maharashtra involves the application of fresh *E. alba* juice to the skin as a tattoo pigment and ritual colourant, exploiting the blackening reaction of the plant's oxidising juice. This application extends the plant's cultural relevance beyond strictly medicinal dimensions, situating it within broader practices of bodily adornment and identity marking. In Assam and other northeastern states, the plant is employed in ethnoveterinary medicine for the treatment of liver fluke infestation and digestive disorders in cattle—an application that mirrors its human hepatotherapeutic use and, as Gopiesh Khanna and Kannabiran (2007) have suggested through their work on the bioactivity of related plant species, may reflect a community-level recognition of the plant's antiparasitic potential that predates formal scientific investigation.

The diversity of preparation methods—fresh juice, dried powder, oil infusion, decoction, whole-plant paste—across Indian communities carries significant implications for the bioavailability and relative potency of active constituents. Different extraction procedures mobilise different compound classes; in particular, wedelolactone and related coumarins are better extracted by alcoholic solvents than by water, suggesting that aqueous traditional preparations may deliver a different phytochemical profile from laboratory hydroalcoholic extracts. This methodological gap between traditional and experimental preparations has been underappreciated in the pharmacological literature and may partly explain discrepancies between experimental findings and observed traditional efficacy.

4.3 Regional Variation and Documentation

Systematic documentation of *E. alba*'s folk uses has been an ongoing scholarly endeavour in India since the nineteenth century, with contributions from multiple generations of ethnobotanists, botanists, and physicians. Important contemporary contributions have come from the Foundation for Revitalisation of Local Health Traditions (FRLHT) in Bengaluru, the AICRPE (All India Coordinated Research Project on Ethnobiology), and individual researchers contributing to the TKDL and IndMED databases (TKDL, 2021). Sharma et al. (2012) conducted an extensive survey of jaundice treatment practices in indigenous communities of the Sub-Himalayan Uttarakhand region, finding *E. alba* among the most frequently prescribed plants—a finding that cross-validates classical Ayurvedic prescriptions in a living folk context and underscores the continuity between textual and oral traditions.

Regional disparities in documentation depth remain significant. Northeastern India—a region of extraordinary biodiversity and remarkable cultural diversity—has seen intensive ethnobotanical survey activity in recent decades, and *E. alba* features prominently in published survey data from Assam, Arunachal Pradesh, Manipur, and Meghalaya. By contrast, some ecologically and culturally rich states including Mizoram, Nagaland, and parts of Jharkhand and Odisha remain comparatively poorly documented. The risk of irreversible knowledge loss in under-documented regions is real: as Benz et al. (2000) demonstrated in a comparable context in Mexico, plant knowledge can erode precipitously within a single generation when traditional healer communities age without trained successors and when economic modernisation reduces reliance on wild-plant therapies.

Table 2 presents a consolidated summary of documented ethnobotanical uses of *E. alba* across major tribal and cultural regions of India, drawing on field survey data from across the subcontinent.

Table 2. Summary of Documented Ethnobotanical Uses of *Eclipta alba* in India

Region/Community	Condition Treated	Plant Part(s) Used	Preparation Method
Tamil Nadu (Paliyar, Irula)	Jaundice, alopecia, skin disease	Leaves, whole plant	Fresh juice, decoction
Western Himalaya (tribal communities)	Liver disorders, pyrexia	Leaves, root	Decoction, paste
Madhya Pradesh / Chhattisgarh (Gond)	Wounds, ulcers, liver complaints	Leaves, root	Paste, fresh juice
Rajasthan / Gujarat (Bhil)	Hair disorders, skin pigmentation, snakebite	Whole plant	Juice (topical/oral)
Assam / Northeast India (Mising, Adi)	Liver conditions, hair disorders, cattle parasite	Leaves, whole plant	Fresh juice, decoction
Western Ghats (Kani, Kurumba, Paniyan)	Liver disease, alopecia, leucoderma	Leaves	Fresh juice, oil infusion
Uttarakhand (sub-Himalayan communities)	Jaundice, spleen disorders	Leaves	Decoction, fresh juice

Sources: Jahan et al. (2014); Ignacimuthu et al. (2006); Uniyal et al. (2006); Sharma et al. (2012)

5. Phytochemical Constituents

5.1 Primary Bioactive Compounds

The phytochemistry of *Eclipta alba* has been investigated in some depth across multiple research groups, and the plant is now known to contain a diverse array of secondary metabolites spanning several structural classes (Feng et al., 2019). The most pharmacologically significant of these is wedelolactone (7-methoxy-5,11,12-trihydroxycoumestan), a polyphenolic lactone belonging to the coumestan class of isoflavonoid-related compounds. The identification of wedelolactone—alongside its des-methylated congener demethylwedelolactone—as the principal hepatoprotective constituent of *E. alba* by Wagner et al. (1986) established a chemical basis for the plant's most prominent traditional application and remains the cornerstone of the plant's pharmacological identity. Wedelolactone has since been characterised as a multi-target bioactive molecule with anti-inflammatory, hepatoprotective, oestrogenic, anti-haemorrhagic, and antiviral activities (Wagner et al., 1986; Barua et al., 2023; Ma-Ma et al., 1978; Manvar et al., 2012; Jahan et al., 2014).

A second chemically important compound is eclalbatin, a polyacetylene glycoside considered to contribute to the plant's antifungal and antibacterial activity. The alkaloids ecliptine and verazine have been isolated from the plant and attributed preliminary pharmacological significance. The flavonoids luteolin and apigenin, both of which have well-established anti-inflammatory and antioxidant profiles in the broader literature, are present in *E. alba* at pharmacologically relevant concentrations and likely contribute synergistically to the plant's anti-inflammatory properties (Barua et al., 2023; Ma-Ma et al., 1978; Jahan et al., 2014). Triterpenoid saponins including oleanolic acid and ursolic acid have been isolated and subjected to testing in antiproliferative assay systems (Manvar et al., 2012). Phytosterols, principally stigmasterol and β-sitosterol, are also present and may contribute to the plant's reputed anti-inflammatory and antilipidemic effects through mechanisms shared with other phytosterol-containing plants (Timalsina & Devkota, 2021).

5.2 Compounds Relevant to Hair Biology

Given the plant's pre-eminent traditional reputation as a hair growth promoter, its phytochemical composition has been interrogated specifically for constituents capable of influencing hair follicle biology. Early work by Datta et al. (2009) attributed hair growth-promoting activity in mice partly to extractable sterol-containing fractions, and subsequent investigations have implicated multiple constituents including wedelolactone, eclalbatin, and certain polyphenolic compounds in the modulation of follicular proliferation and melanocyte activity. The blackening juice of the plant—widely exploited traditionally as a hair dye—reflects the presence of polyacetylenic compounds that undergo rapid oxidative polymerisation and colour development upon exposure to atmospheric oxygen. The hair-dyeing property is thus chemically distinct from the hair growth–promoting activity, though both are subsumed within the traditional concept of Bhringaraj as a hair tonic.

Table 3. Principal Phytochemical Constituents of *Eclipta alba* and Their Pharmacological Significance

Compound	Structural Class	Major Pharmacological Activity	Key Reference(s)
Wedelolactone	Coumestan	Hepatoprotective, anti-inflammatory, antiviral	Wagner et al. (1986); Manvar et al. (2012)
Demethylwedelolactone	Coumestan	Hepatoprotective, oestrogen-like effects	Wagner et al. (1986)
Eclalbatin	Polyacetylene glycoside	Antifungal, antibacterial	Jahan et al. (2014)
Ecliptine	Alkaloid	CNS activity (preliminary)	Jahan et al. (2014)
Luteolin	Flavone	Anti-inflammatory, antioxidant	Barua et al. (2023); Ma-Ma et al. (1978); Jahan et al. (2014)
Apigenin	Flavone	Anti-inflammatory, antioxidant	Barua et al. (2023); Ma-Ma et al. (1978); Jahan et al. (2014)
Oleanolic acid	Pentacyclic triterpenoid	Antiproliferative, anti-inflammatory	Manvar et al. (2012)
Ursolic acid	Pentacyclic triterpenoid	Antiproliferative, hepatoprotective	Manvar et al. (2012)
β-Sitosterol	Phytosterol	Anti-inflammatory, antilipidemic	Jahan et al. (2014)
Stigmasterol	Phytosterol	Anti-inflammatory	Jahan et al. (2014)

Sources: Wagner et al. (1986); Jahan et al. (2014); Manvar et al. (2012); Barua et al. (2023); Ma-Ma et al. (1978)

5.3 Variation in Chemical Composition

Chemical composition in *E. alba* is subject to variation with geographical origin, phenological stage, plant part harvested, drying and storage methodology, and extraction procedure. Kumar et al. (2022), in a quantitative phytochemical comparison of populations from three agroclimatic zones in India, demonstrated statistically significant differences in wedelolactone content depending on collection site, with populations from humid subtropical environments yielding higher concentrations than those from arid or semi-arid zones. This finding is directly relevant to the standardisation of medicinal preparations and the reproducibility of pharmacological studies, yet remains underappreciated in much of the secondary literature. The reliance on commercial plant materials in pharmacological studies, without rigorous botanical authentication and chemical standardisation, constitutes a recurring methodological limitation across the field. Han et al. (2015), applying high-performance liquid chromatography (HPLC) profiling to geographically diverse Indian accessions, confirmed substantial inter-accession variation in both coumestan and flavonoid content.

Table 3 summarises the principal phytochemical constituents of *E. alba*, their structural class, major pharmacological activities, and key references. The diversity of compound classes evident in Table 3 helps explain the breadth of therapeutic applications recorded across classical and folk traditions, and underscores the value of multi-constituent phytochemical analysis in interpreting traditional use data.

6. Pharmacological Evidence and Ethnopharmacological Validation

6.1 Hepatoprotective Activity

The hepatoprotective activity of *Eclipta alba* is arguably the single most thoroughly investigated pharmacological property of the plant, and it stands as perhaps the strongest case of direct convergence between a traditional therapeutic claim and experimental evidence. Wedelolactone has been shown in multiple in vitro and in vivo studies to protect hepatocytes against chemically induced injury, principally through suppression of oxidative stress, inhibition of NF-κB-dependent inflammatory signalling, and modulation of apoptotic pathways in liver cells (Manvar et al., 2012; Thakur & Mengi, 2005). In rodent models employing carbon tetrachloride (CCl_4)- and paracetamol-induced hepatotoxicity, hydroalcoholic extracts of *E. alba* have consistently demonstrated significant reductions in serum transaminase levels—including alanine aminotransferase (ALT) and aspartate aminotransferase (AST), which serve as biomarkers of hepatocellular injury—alongside histopathological improvements and restoration of hepatic antioxidant enzyme activity, notably catalase and superoxide dismutase (SOD), offering mechanistic plausibility for the plant's traditional prescription in liver disease and jaundice (Thakur & Mengi, 2005; Manvar et al., 2012).

Manvar et al. (2012) went a step further in demonstrating antiviral hepatoprotective activity, showing that wedelolactone possesses inhibitory activity against hepatitis C virus (HCV) NS3 protease, a mechanistically significant finding given that chronic HCV infection is a leading cause of hepatic fibrosis globally. Similarly, Tewtrakul et al. (2007) reported significant HIV-1 protease inhibitory activity of wedelolactone, adding a broader antiviral dimension to the compound's pharmacological profile. These observations reinforce the plant's potential as a source of anti-infective hepatoprotective agents, though translation into clinically applicable interventions requires further investigation in terms of pharmacokinetics, bioavailability, and safety in human subjects.

6.2 Hair Growth–Promoting Activity

The traditional identification of *E. alba* as a pre-eminent promoter of hair growth—captured in its very Sanskrit name—has attracted experimental investigation, most prominently in the work of Datta et al. (2009), who demonstrated that topical application of an alcoholic extract of *E. alba* root to mice promoted hair growth in a shaving-induced model, with histological evidence of earlier transition from telogen to anagen phase in treated follicles compared to controls. The mechanism is partially understood through the proposed inhibition of 5α-reductase, the enzyme responsible for converting testosterone to the more potent dihydrotestosterone (DHT), which mediates androgen-dependent alopecia; this hypothesis is consistent with the phytosterol and polyphenolic composition of the root extract and has been discussed in the context of the extract's overall bioactive profile (Datta et al., 2009). Whilst the murine in vivo evidence for anagen promotion is compelling at a histological level, the specific molecular pathways governing follicular cell proliferation and growth factor signalling in response to *E. alba* constituents remain to be fully elucidated in future mechanistic studies using appropriate human cell models.

These experimental findings are consistent with the traditional claim that the plant promotes hair growth rather than merely conditioning existing hair, and provide a preliminary biological rationale for the plant's celebrated use in classical and folk medicine. Critically, however, clinical trials in human patients with androgenetic alopecia or alopecia areata remain sparse and methodologically limited, representing one of the most significant translational gaps in the entire *E. alba* pharmacological literature.

6.3 Anti-inflammatory and Antioxidant Activities

The anti-inflammatory activity of *E. alba* preparations has been documented across multiple experimental models employing carrageenan-induced paw oedema, cotton pellet granuloma, and acute peritonitis assays in rodents. Wedelolactone's inhibition of NF-κB signalling—a master regulatory pathway of inflammation—constitutes the principal identified molecular mechanism, though inhibitory effects on cyclooxygenase (COX) enzyme activity have also been reported (Barua et al., 2023; Ma-Ma et al., 1978). The substantial phenolic content of the plant, encompassing wedelolactone, luteolin, apigenin, and caffeic acid derivatives, provides multiple lines of antioxidant activity through free radical scavenging and transition metal chelation.

Kumar et al., (2022) conducted a comparative antioxidant analysis across multiple *E. alba* accessions using DPPH (2,2-diphenyl-1-picrylhydrazyl), FRAP (ferric reducing antioxidant power), and ABTS assays, demonstrating robust antioxidant capacity broadly correlated with total phenolic and flavonoid content. The pharmacological coherence of the anti-inflammatory findings with the folk use of the plant for inflammatory skin conditions, arthritis, and fever is readily interpretable, though most evidence remains at the in vitro or animal level with limited extrapolation to clinical settings.

6.4 Antimicrobial and Antiparasitic Activities

Antimicrobial assays of *E. alba* extracts have yielded consistently positive results against a broad panel of bacterial pathogens including *Staphylococcus aureus*, *Escherichia coli*, *Pseudomonas aeruginosa*, *Klebsiella pneumoniae*, and *Salmonella typhimurium*, as well as against dermatophytic fungi including *Trichophyton mentagrophytes* and *Candida albicans*. Wedelolactone and eclalbatin fractions have been implicated in the antimicrobial bioactivity of the plant across multiple assay systems. The broader antiparasitic properties of *E. prostrata*—including larvicidal effects against *Culex quinquefasciatus*—have been documented by Gopiesh Khanna and Kannabiran (2007), illustrating the plant's capacity for bioactivity against arthropod vectors as well as microbial pathogens. The ethnobotanical uses of *E. alba* in wound management, skin infections, and venomous bite treatment—all contexts involving a risk of secondary infection—are coherently aligned with these findings.

Antiparasitic activity against *Plasmodium falciparum* (antimalarial), *Leishmania* spp. (anti-leishmanial), and various helminth organisms has been reported in preliminary studies, though the therapeutic concentrations required are substantially higher than those demonstrating antibacterial activity, and significant translational hurdles remain. The ethnoveterinary use of the plant for managing helminthic infestation in cattle, as recorded in northeastern India, is partially supported by these antiparasitic data, though the species and dose parameters differ from human applications.

6.5 Anticancer and Antiproliferative Activities

The antiproliferative activity of *E. alba* extracts and isolated compounds against human cancer cell lines has been investigated by several research groups, with particular interest in the activity of wedelolactone and the triterpenoids oleanolic acid and ursolic acid. Wedelolactone has been shown to exert cytotoxic effects in human hepatocellular carcinoma (HepG2) cells in the context of anti-HCV mechanistic studies (Manvar et al., 2012). The proposed mechanisms include inhibition of androgen receptor signalling in prostate cancer models, induction of apoptosis via the intrinsic mitochondrial pathway, and disruption of topoisomerase II activity. Whilst these findings are pharmacologically promising, they are based predominantly on in vitro data, and the gap between cytotoxic concentration in cell culture and achievable plasma concentrations in vivo is substantial. No clinical trials of *E. alba* or wedelolactone in cancer patients have been published in the peer-reviewed literature, and the anticancer evidence must therefore be treated as hypothesis-generating rather than therapeutic (Yadav et al., 2017; Nelson et al., 2020; Arya et al., 2015).

Table 4 presents a consolidated comparison of documented traditional uses and corresponding pharmacological evidence for *E. alba*, organised by therapeutic category. The table reveals both the considerable breadth of in vitro and in vivo support for many traditional claims, and the persistent absence of clinical-level evidence that must inform any responsible assessment of the plant's therapeutic potential.

Table 4. Convergence Between Traditional Uses and Pharmacological Evidence for *Eclipta alba*

Traditional Use (India)	Experimental Model(s)	Evidence Level	Key Reference(s)
Liver disease / jaundice	CCl_4/paracetamol hepatotoxicity models (rodent); HCV protease assay	In vivo + in vitro; strong	Wagner et al. (1986); Manvar et al. (2012); Thakur & Mengi (2005)
Alopecia / hair promotion	Murine shaving/testosterone models; histological evaluation	In vivo; moderate	Datta et al. (2009)
Skin inflammation / eczema	Carrageenan oedema model; macrophage cytokine assay	In vivo + in vitro; moderate	Barua et al.(2023); Ma-Ma et al., (1978); Kumar et al., (2022)
Epilepsy / convulsions	MES and PTZ seizure models (rat)	In vivo; preliminary	Thakur & Mengi (2005)
Wound infection / snakebite	Larvicidal and bioactivity assays; MIC assays	In vitro; moderate	Gopiesh Khanna & Kannabiran (2007)
Cancer / tumour	HepG2, MCF-7, HeLa cell lines	In vitro only; preliminary	Manvar et al. (2012); Barua et al. (2023); Ma-Ma et al., (1978)
General tonic / debility	Adaptogenic and cognitive models	In vivo; limited	Thakur & Mengi (2005)

Sources: Wagner et al. (1986); Manvar et al. (2012); Datta et al. (2009); Barua et al.(2023); Ma-Ma et al., (1978); Kumar et al., (2022); Gopiesh Khanna and Kannabiran (2007); Thakur and Mengi (2005)

7. Cross-Cultural Ethnobotanical Perspectives

7.1 *Eclipta alba* Beyond India: Southeast Asia and East Asia

Whilst the present review's primary focus is India, the cross-cultural documentation of *E. alba* use provides important external validation of therapeutic claims that might otherwise be interpreted as culturally specific artefacts. The species is extensively used in traditional medicine systems across Southeast Asia—most notably in Chinese traditional medicine (as 墨旱莲, *Mò Hàn Lián*), Vietnamese folk medicine, Thai traditional medicine, and Brazilian traditional medicine—and across tropical Africa and the Americas. In Chinese traditional medicine, *E. alba* (referred to as *Herba Ecliptae*) has official pharmacopoeial recognition and is prescribed for conditions including liver disease, haematuria, premature greying, and tinnitus, with a pharmacopoeia entry specifying wedelolactone as a quality marker for standardisation purposes (Chinese Pharmacopoeia Commission, 2020). The convergence of Indian and Chinese traditional medical systems on the hepatoprotective and hair-promoting uses of the plant is particularly striking, given the independence of these traditions, and constitutes what ethnopharmacologists term trans-cultural validation—arguably one of the strongest forms of evidence for the genuineness of a traditionally described therapeutic effect (Fabricant & Farnsworth, 2001).

Maneenoon et al. (2015), working with rural communities in northeastern Thailand, documented consistent use of *E. alba* for jaundice and hair loss in terms closely paralleling Indian records. Tewtrakul et al. (2007), in a systematic screening study of southern Thai traditional medicine plants, identified *E. alba* extracts among those with the highest anti-HIV activity, attributing the activity to wedelolactone—a finding that, though conducted in a Thai context, directly reinforces Indian ethnobotanical records of the plant's use in viral hepatitis.

7.2 Comparative Analysis and the Concept of Cultural Consensus

The theoretical framework of cultural consensus analysis, widely employed in ethnopharmacological research and elaborated for ethnobotanical methodology by Farnsworth and colleagues, proposes that the degree of agreement across independent cultural groups regarding the therapeutic utility of a plant constitutes a form of empirical evidence for its pharmacological relevance. By this framework, *E. alba* occupies an exceptionally well-supported position: liver protection and hair growth promotion are documented across Indian Ayurveda, Chinese traditional medicine, Thai folk medicine, Vietnamese traditional medicine, and Brazilian popular medicine, and this convergence is unlikely to reflect cultural diffusion alone given the botanical and geographic distances involved. The weight of this cross-cultural consensus should inform research prioritisation in pharmacological and clinical investigation (Leonti & Casu, 2013). Whilst consensus alone cannot substitute for clinical evidence, it provides a principled basis for investment in translational research and arguably represents a more efficient signal of therapeutic promise than high-throughput screening of synthetic compound libraries.

8. Conservation, Sustainability, and Bioprospecting

8.1 Ecological Status and Harvesting Pressures

As noted above, *E. alba* is widely considered a weed of disturbed habitats and is rarely formally cultivated or classified as threatened under the International Union for Conservation of Nature (IUCN) Red List criteria. This classification—or more precisely, the absence of a formal threat classification—has historically led to the assumption that conservation attention is unnecessary and that wild harvesting can proceed without ecological consequence. This assumption warrants critical reexamination. Whilst the species is genuinely common across its range in many locations, the emergence of large-scale commercial herbal markets—driven by both Ayurvedic pharmaceutical manufacturers and export demand—has intensified wild harvesting pressure in areas where the plant was previously collected only for local use. Sharma et al. (2012) reported localised depletion of *E. alba* populations in Uttarakhand as a function of unregulated commercial collection, and similar trends are observable in ethnobotanical survey reports from Maharashtra and Andhra Pradesh.

The species' strong association with paddy field margins also renders its populations vulnerable to agricultural change. The widespread adoption of herbicide-based weed management in commercial rice production—accelerated by the promotion of clean agriculture practices under various government schemes—has reduced the density of *E. alba* and associated wetland flora in prime agricultural landscapes. Whilst the plant is not at risk of global extinction, regional population depletion can significantly undermine the accessibility of the plant to the rural and tribal communities who depend upon it for primary healthcare. Conservation attention is therefore warranted not necessarily from the perspective of species survival but from that of equitable access and biocultural sustainability.

8.2 Cultivation and Agronomic Research

Formal cultivation of *E. alba* remains underdeveloped relative to its commercial and therapeutic importance. Kumar et al., (2022) and Han et al., (2015) both called for the development of standardised cultivation protocols, including selection of high-wedelolactone accessions, optimisation of harvest timing relative to phenological stage, and development of postharvest processing procedures that preserve chemical integrity. The plant's essentially weedy ecology means that it can be grown with relatively minimal agricultural input—an advantage in the context of smallholder agroforestry systems—but the absence of improved variety selection, agronomic guidelines, or market linkage mechanisms has limited farmer uptake. The Ministry of AYUSH's National Medicinal Plants Board (NMPB) has included *E. alba* in its priority cultivation programme, providing limited subsidies for commercial cultivation, but implementation at scale remains modest (Ministry of AYUSH, 2020).

8.3 Intellectual Property and Traditional Knowledge Protection

The commercialisation of *E. alba*-based products raises significant questions relating to intellectual property, the rights of traditional knowledge holders, and access and benefit sharing under the Nagoya Protocol of the Convention on Biological Diversity (CBD). The Traditional Knowledge Digital Library (TKDL) of India has documented numerous Ayurvedic formulations containing Bhringaraj, providing a publicly accessible record intended to prevent biopiracy by establishing prior art (TKDL, 2021). TKDL's success in challenging patent applications that sought to claim novelty for formulations already present in classical Indian medical texts illustrates both the value and the limitations of this approach: whilst it can prevent the most egregious forms of biopiracy, it does not ensure that the communities whose ancestral knowledge underpins commercial products receive equitable benefit.

Leonti and Casu (2013) have critically examined the tension between global pharmaceutical bioprospecting and local traditional knowledge rights, arguing that ethnobotanical data too readily functions as a free informational resource for external researchers without reciprocal benefit to knowledge-holding communities. This critique applies with particular force to *E. alba*, where the pharmacological leads derived from Indian ethnobotanical knowledge have generated considerable commercial value in Ayurvedic hair care and hepatoprotective formulations, whilst the communities whose traditional knowledge provided the foundational research hypothesis receive no formal recognition or benefit sharing. International frameworks including the Nagoya Protocol (formally entered into force in October 2014) establish the right of source country governments to require prior informed consent and mutually agreed terms for access to genetic resources and associated traditional knowledge, but implementation at the community level remains inconsistent across Indian states (Convention on Biological Diversity, 2011).

8.4 Safety, Toxicology, and Quality Control

The safety profile of *E. alba* in traditional use contexts is generally regarded as favourable, with adverse effects rarely reported in the ethnobotanical literature. In animal toxicological studies, acute and sub-chronic oral administration of standardised extracts has shown no significant toxicity at doses commonly employed in pharmacological experiments, and lethal dose (LD_{50}) values are consistently high (Datta et al., 2009; Thakur & Mengi, 2005). However, as Mukherjee et al. (2012) have cautioned, the absence of formally conducted chronic toxicology studies, reproductive toxicology data, and drug–herb interaction assessments in peer-reviewed literature means that safety claims must be qualified. Wedelolactone's demonstrated oestrogenic activity at higher concentrations raises particular concerns for chronic use in pregnant women and children—patient categories for whom *E. alba* preparations are sometimes traditionally prescribed for purposes such as lactation promotion and tonic use in infants. Standardised quality control across commercial Ayurvedic preparations, encompassing botanical identity, chemical profiling, heavy metal analysis, and microbial testing, remains inconsistent in the Indian marketplace, with the Bureau of Indian Standards and AYUSH quality guidelines providing frameworks that are not uniformly enforced (Ministry of AYUSH, 2020).

The potential for pharmacokinetic interactions between *E. alba* preparations and conventional pharmaceuticals is a safety dimension that has been largely neglected in the published literature. Given that patients with chronic liver disease—the principal target population for the plant's hepatoprotective use—are often managing their conditions with multiple pharmaceutical agents, the possibility of interactions with hepatically metabolised drugs is a genuine concern. Mechanistic studies specifically addressing cytochrome P450 inhibition or induction by wedelolactone remain very limited, and this area warrants prioritised investigation before clinical studies involving co-administration with pharmaceutical agents are expanded.

9. Critical Assessment and Research Gaps

9.1 Strengths of the Evidence Base

The ethnobotanical and pharmacological literature on *Eclipta alba* presents several genuinely substantive strengths. The consistency of therapeutic claims across geographically and culturally distinct traditional systems—spanning Indian classical medicine, tribal folk practices, and Southeast Asian and East Asian medical traditions—represents a form of multicultural empirical validation that is not easily dismissed. The identification of wedelolactone as the primary hepatoprotective principle has provided a structurally characterised and mechanistically interpretable lead compound with well-established pharmacological activity in multiple experimental models. The pharmacological literature is extensive relative to that of many ethnobotanically important plants, with over four decades of data accumulation addressing multiple biological endpoints at biochemical, cellular, and whole-organism levels.

9.2 Critical Gaps and Methodological Limitations

Notwithstanding these strengths, several categories of critical limitation constrain the translational value of the existing literature and must be addressed in future research. The most fundamental gap concerns clinical evidence. With very few exceptions, the pharmacological evidence base for *E. alba* consists of in vitro cell culture studies and rodent model experiments. Whilst these are essential early-stage tools, they are poor predictors of clinical efficacy in humans, and their value in guiding therapeutic decisions is limited without confirmatory clinical trial data. No adequately powered, blinded, placebo-controlled clinical trials of *E. alba*-based preparations have been published for any major therapeutic indication—not hepatoprotection, not alopecia, not epilepsy. This represents a formidable gap between the richness of the ethnobotanical record and the thinness of the clinical evidence base.

A second category of limitation relates to phytochemical standardisation. As noted above, the chemical composition of *E. alba* varies substantially with geographical origin, season, plant part, and processing methodology. The majority of pharmacological studies do not provide adequate chemical characterisation of the test materials, making it difficult to compare findings across studies or to attribute observed activities reliably to identified compounds. The lack of pharmacokinetic data for wedelolactone in humans—including oral bioavailability, plasma half-life, tissue distribution, and metabolic fate—constitutes a further gap that prevents any meaningful dose-response relationship from being established for therapeutic purposes.

9.3 Documentation and Ethical Research Priorities

The ethical dimensions of ethnobotanical research involving traditional communities deserve sustained critical attention. As Gadgil et al. (1993) argued in an early and still relevant framework, biodiversity knowledge held by local communities represents a form of cultural capital that has historically been extracted without acknowledgement or recompense. Contemporary ethnobotanical research practice has evolved substantially in terms of ethical protocols—free, prior, and informed consent (FPIC) is now a standard requirement, and community benefit agreements are increasingly formalised—but implementation disparities remain significant, particularly in remote areas with limited access to legal support. The documentation of *E. alba*'s traditional knowledge cannot be separated from the question of who controls that documentation and for whose benefit it is undertaken.

The ongoing erosion of plant knowledge within traditional communities—driven by urbanisation, economic modernisation, formal educational systems that assign low prestige to traditional knowledge, and the decline of intergenerational knowledge transmission—poses a direct threat to the long-term vitality of the ethnobotanical record. For *E. alba* specifically, this is less immediately acute than for many lesser-known species, given the plant's prominent position in commercial Ayurvedic practice. Nevertheless, the nuanced community-specific knowledge of dosage, preparation, seasonal collection, and associated ritual or dietary prescriptions that gives traditional therapeutic use its contextual validity cannot be assumed to persist as long as the plant's name recognition. Targeted biocultural documentation programmes, ideally conducted by community-based researchers and supported by national institutions such as the FRLHT and AICRPE, are needed to capture this knowledge before it dissolves.

10. Future Research Directions

The foregoing critical assessment suggests a set of research priorities that, if pursued with appropriate methodological rigour and ethical grounding, could substantially advance the evidence base for *E. alba* as a therapeutic plant and contribute meaningfully to the broader agenda of integrative medicine in India.

Clinical trials are the most pressing priority. Randomised, double-blind, placebo-controlled trials addressing the hepatoprotective activity of standardised *E. alba* preparations in patients with non-alcoholic fatty liver disease, viral hepatitis, or drug-induced hepatotoxicity are feasible with existing pharmacological foundations and are needed to move the evidence base from promising to actionable. Similar trial designs are needed for androgenetic alopecia, a therapeutic area where patient populations are large, outcome measures are well-validated, and the ethnobotanical rationale is unusually well-supported by experimental data. Mukherjee et al. (2012) have specifically advocated for an integrated translational research model in Ayurveda that connects ethnobotanical documentation, chemical standardisation, mechanistic pharmacology, and clinical evaluation—a model that *E. alba* is particularly well-positioned to exemplify.

Pharmacokinetic and formulation research should constitute a second parallel priority. The oral bioavailability of wedelolactone and other key constituents in standardised human doses must be characterised, and delivery strategies that optimise absorption—including nanoparticle encapsulation, solid lipid formulations, and nanoemulsion systems—should be evaluated systematically (Barua et al., 2023; Ma-Ma et al., 1978). Transcriptomic and proteomic approaches to elucidating the molecular mechanisms of wedelolactone's pleiotropic activities—particularly its concurrent influence on NF-κB, androgen receptor, and apoptotic signalling pathways—would provide a richer mechanistic map than current biochemical endpoint measurements afford.

For ethnobotanical and conservation research, priority should be given to completing systematic surveys in under-documented regions, formalising community benefit agreements in published field studies, and integrating population-genetic characterisation of *E. alba* accessions with phytochemical profiling to identify the genetic basis of chemical variation. The development and validation of DNA barcoding approaches for quality authentication of commercial *E. alba* materials would address a significant gap in pharmacovigilance for the Ayurvedic pharmaceutical sector (Han et al., 2015). Finally, the development of community-based cultivation protocols that both enable standardised herbal supply and provide economic benefit to traditional knowledge communities would represent a meaningful step towards equitable integration of *E. alba*'s biocultural heritage into contemporary healthcare.

Table 5 summarises key research priority areas identified in this review, together with associated methodological recommendations. The seven domains presented in Table 5 represent not a hierarchical ranking of importance but a complementary set of research investments that would collectively move the field from its current preclinical foundations towards the clinical and regulatory validation that the plant's ethnobotanical standing warrants.

Table 5. Priority Research Areas and Methodological Recommendations for *Eclipta alba*

Research Domain	Priority Gap	Recommended Approach
Clinical evidence	No RCTs for any therapeutic indication	Placebo-controlled trials: hepatoprotection, alopecia
Pharmacokinetics	Wedelolactone oral bioavailability in humans unknown	PK studies in human volunteers; bioequivalence assessment
Phytochemical standardisation	Inter-accession chemical variability undercharacterised	HPLC profiling of geographically diverse accessions; marker validation
Formulation	Optimised delivery systems absent	Nanoemulsion, solid lipid nanoparticle, and encapsulation studies
Conservation	Regional depletion unmonitored; cultivation underscaled	Population monitoring; NMPB-backed cultivation programme
Traditional knowledge	Under-documented tribal uses; erosion risk	FRLHT-supported community documentation; biocultural inventories
Drug–herb interactions	CYP450 interaction potential uncharacterised	In vitro CYP inhibition/induction studies; clinical interaction trials

Sources: Manvar et al. (2012); Barua et al., (2023); Ma-Ma et al.,(1978); Han et al., (2015); Mukherjee et al. (2012); Ministry of AYUSH (2020)

11. Conclusions

Eclipta alba occupies a singular position in the ethnobotanical heritage of India: few medicinal plants can claim so consistent a therapeutic identity—from the Sanskrit of classical Ayurvedic texts to the living oral traditions of geographically remote tribal communities—sustained across millennia of practice across the breadth of the subcontinent. This review has demonstrated that the ethnobotanical record for *E. alba* is not merely historically interesting but carries meaningful implications for pharmacological research and integrative medicine. The convergence of classical textual prescriptions, diversely documented folk uses, cross-cultural validation from independent medical traditions, and an expanding pharmacological evidence base constitutes a coherent and mutually reinforcing argument for the plant's genuine therapeutic utility—most persuasively for hepatoprotective and hair growth–promoting applications.

At the same time, this review has identified the profound translational gap that separates an impressive ethnobotanical and preclinical evidence base from the clinical validation that modern evidence-based medicine requires. The absence of randomised clinical trials for any therapeutic indication is, quite simply, the most critical limitation in the field and one that no amount of preclinical excellence can compensate for. Equally, the lack of standardised chemical characterisation across much of the pharmacological literature, the near-total absence of pharmacokinetic data in humans, and the paucity of long-term safety assessment data collectively constrain the confidence with which therapeutic recommendations can be made.

Beyond the strictly pharmacological dimensions, this review underscores the necessity of approaching *E. alba*'s ethnobotanical heritage with ethical care. The communities whose traditional knowledge provides the foundational research hypotheses and the ecological contexts within which the plant thrives deserve formal recognition, equitable benefit sharing, and active participation in research governance. The existing Indian framework of the TKDL, NMPB, and AYUSH provides institutional architecture for this engagement, but its realisation in practice requires sustained political will, academic commitment, and community empowerment that extends well beyond the publication of survey data. *Eclipta alba* is, ultimately, more than a pharmacological resource: it is a living expression of India's biocultural heritage, and its continued relevance to both traditional and contemporary medicine depends on attending to that heritage with as much seriousness as to its chemistry and its cells.

12. Limitations

This review carries several limitations that should be acknowledged. First, the language restriction to English-language publications, applied for reasons of practicality, means that a body of literature published in Hindi, Tamil, Malayalam, Kannada, and other Indian regional languages—as well as Chinese, Japanese, and Portuguese—was not accessible for direct synthesis. Some ethnobotanical knowledge specific to communities documented primarily in regional-language publications may therefore be underrepresented. Second, as a narrative review rather than a systematic meta-analysis, the synthesis presented here is inherently subject to the selectivity and interpretive judgements of the authors in study inclusion and weighting. Although systematic criteria were applied in the literature search, the integrative and interpretive aspects of the review involve scholarly judgements that other researchers might exercise differently. Third, the rapidly evolving nature of the primary literature means that pharmacological studies appearing in journals with a modest lag between acceptance and indexing may not have been captured within the search window. Fourth, quality and methodological heterogeneity across the included pharmacological studies—varying in model systems, extract preparations, and outcome measures—limits the degree to which findings can be directly compared or synthesised quantitatively. Finally, the review's primary geographic focus on India, whilst explicitly stated as an objective, means that important contributions from Southeast Asian, African, and South American ethnobotanical traditions are addressed only in comparative rather than exhaustive terms. Dedicated regional reviews from these traditions would complement the present work and contribute further to the global cross-cultural validation of *E. alba* as a therapeutic plant.

Declaration of AI Use

This manuscript was prepared through the combined contributions of all author(s), including contributions to the study design, data, content development, results, interpretation, and related scholarly work. The author(s) acknowledge the use of Grammarly and ChatGPT to assist with grammar checking, language refinement, reference formatting. These AI-assisted tools were not used as authors and did not replace the intellectual contributions or scholarly judgment of the author(s). All AI-assisted outputs, including content, references, and interpretations, were carefully reviewed, revised, verified, and approved by the author(s). The author(s) accept full responsibility for the accuracy, integrity, and final content of the manuscript.

Competing Interests

Authors have declared that no competing interests exist.

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