

# A Comprehensive Review on *Eclipta alba* (L.) Hassk.: Phytochemistry, Pharmacology, and Therapeutic Potential

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## Abstract

*Eclipta alba* (L.) Hassk., widely referred to as Bhringraj, is a well-documented herb traditionally used in various traditional healing systems such as Ayurveda, Unani, Siddha, and Traditional Chinese medicine. Belonging to the *Asteraceae* family, this plant is distributed all over the world. It has been used ethnomedicinally to treat liver disorders, skin infections, respiratory ailments, and promote hair growth. In recent years, *E. alba* has garnered increasing scientific attention due to its diverse pharmacological actions and the presence of a rich spectrum of bioactive phytoconstituents. This review comprehensively compiles existing knowledge on the botanical characteristics, traditional uses, phytochemistry, and pharmacological activities of *E. alba*. It highlights key constituents such as wedelolactone, eclalbasaponins, apigenin, luteolin, and stigmaterol, which have shown potential in antioxidant, hepatoprotective, anti-inflammatory, antimicrobial, neuroprotective, and anticancer models. The review further discusses recent developments, clinical investigations, and applications of *E. alba* in dermatology and neurodegenerative conditions. In addition, the article emphasizes gaps in clinical validation, dosage standardization, and toxicity profiling that need to be addressed to enhance its integration into evidence-based medicine. Overall, this review reaffirms *E. alba* as a promising herb with considerable therapeutic potential and encourages continued pharmacological and phytochemical exploration.

**Key words:** Bhringraj, bioactive compounds, *Eclipta alba*, ethnopharmacology, herbal therapeutics, medicinal plants, pharmacological activities, phytochemistry, systematic review, traditional medicine

## INTRODUCTION TO *ECLIPTA ALBA* (L.) HASSK

*E. alba* (L.) Hassk., also popularly known as Bhringraj, the king of hair, is a herbaceous species classified under the *Asteraceae* family, which is one of the largest families of flowering plants. Native to tropical and subtropical regions, *E. alba* has garnered significant attention for its extensive medicinal properties, making it a vital component in traditional systems of medicine. It is widely distributed across regions such as India, Southeast Asia, South America, and parts of Africa.<sup>[1]</sup> The plant is not only revered for its therapeutic uses but also for its potential in modern pharmacology as a rich source of phytoactive compounds with significant medicinal value.

## Taxonomy and classification

The botanical hierarchy of *E. alba* is structured as below:

- Kingdom: Plantae
- Phylum: Angiospermae
- Division: Angiosperms
- Class: Dicotyledonae
- Order: Asterales
- Family: *Asteraceae*

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- Genus: *Eclipta*
- Species: *E. alba* (L.) Hassk.

The plant is known for its small size, typically growing between 30 and 60 cm in height. It produces white to purple flowers arranged in spherical clusters, characteristic of its family. Its fruits are achenes, which disperse through the wind. Although several species exist within the genus *Eclipta*, *E. alba* is the most commonly used for its medicinal properties.<sup>[2]</sup>

### Geographical distribution and habitat

*E. alba* thrives in tropical and subtropical climates and is widely distributed across Asia, Africa, and South America. In India, it is typically found in moist, well-drained soils, growing in riverbanks, fields, disturbed soils, and open areas.<sup>[2]</sup> It has an adaptive ability to grow in diverse climatic conditions and can be found at altitudes ranging from sea level to 1500 m. The plant is found in areas that experience moderate rainfall and prefer warm temperatures. This resilience to varied environmental conditions makes it easy to cultivate and harvest, increasing its availability for traditional and modern use.

### Historical and cultural relevance

In traditional medicine systems, *E. alba* has been used for centuries due to its therapeutic efficacy. In Ayurveda, it is known as Bhringraj or the “King of Hair,” often utilized for promoting hair growth and improving scalp health.<sup>[1]</sup> It is also considered a potent liver tonic, believed to have a significant role in rejuvenating the liver and improving overall liver function. In addition to its role in treating liver disorders, *E. alba* has been used in treating conditions such as jaundice, respiratory diseases, skin ailments, and digestive issues.<sup>[3]</sup>

The plant is also integral in Unani medicine, where it is used to treat conditions such as fever, inflammation, and skin diseases. In Traditional Chinese medicine (TCM), it is believed to clear heat from the liver and eyes, supporting vision and detoxification. Various other cultures worldwide have utilized *E. alba* for a wide range of ailments, further emphasizing its broad ethnomedicinal significance.<sup>[1]</sup>

## BOTANICAL AND ETHNOMEDICINAL RELEVANCE OF *E. ALBA* (L.) HASSK

*E. alba* (L.) Hassk., commonly known as Bhringraj, king of hair, is a herbaceous plant that belongs to the family of *Asteraceae*, one of the largest families of flowering plants. With a long history of use in traditional medicine, this plant is revered in various cultures, especially in Ayurvedic, Unani, and TCM systems. In this section, we will explore the botanical characteristics and ethnomedicinal relevance of

*E. alba*, highlighting its significance in traditional medicine and its integration into modern pharmacological research.

### Botanical characteristics

*E. alba* is a small, annual herb that typically grows up to 30–60 cm in height. The plant is characterized by slender, branched stems, opposite leaves, and white to purple flowers that are arranged in spherical clusters known as heads. The flowers are small, with a tubular shape, and they bloom during the rainy season, attracting pollinators such as bees and butterflies.<sup>[2]</sup> The leaves are ovate-lanceolate, with serrated margins, and possess a slightly smooth texture. The plant produces achene-type fruits, which are easily dispersed by the wind due to the presence of a tuft of fine hairs at one end.<sup>[1]</sup>

In terms of habitat, *E. alba* thrives in moist, well-drained soils in tropical and subtropical regions. It is commonly found in fields, riverbanks, and disturbed soils.<sup>[2]</sup> This plant is particularly adaptable and can grow in a wide range of environmental conditions, from sea level up to an altitude of 1500 m. The plant flourishes in regions that experience moderate rainfall and temperatures suitable for tropical and subtropical growth.<sup>[3]</sup>

### Ethnomedicinal importance

The ethnomedicinal relevance of *E. alba* is vast, as it has been utilized for centuries in various traditional healing systems, most notably in Ayurveda. In Ayurvedic medicine, *E. alba* is known as Bhringraj. It is a key herb used to promote hair health, often referred to as the “King of Hair” because of its reputed ability to stimulate hair growth and prevent hair loss.<sup>[1]</sup> The plant’s extract is commonly used in hair oils and other topical formulations aimed at treating scalp conditions, dandruff, and premature graying. This reputation is backed by traditional knowledge, where Bhringraj is considered a tonic that improves hair strength and texture, promoting overall hair health.

Beyond its use for hair health, *E. alba* is regarded as a potent liver tonic in Ayurveda. It is used to treat liver ailments such as jaundice, hepatitis, and liver cirrhosis. The plant is believed to detoxify the liver and aid in liver regeneration by supporting liver cell repair and reducing the effects of toxins on liver function.<sup>[3]</sup> This hepatoprotective property is attributed to various phytoactive compounds present in the plant, such as wedelolactone, which is known for its ability to promote liver health and restore liver function.<sup>[4]</sup>

In Unani medicine, *E. alba* is used to treat fever, inflammation, and conditions affecting the skin and respiratory system. The herb is applied topically for treating wounds, burns, and infections, often in the form of poultices or extracts.<sup>[1]</sup> Its antibacterial and anti-inflammatory properties

make it valuable in managing a wide range of infections and inflammatory disorders.

In TCM, *E. alba* is believed to clear heat from the liver and eyes, supporting detoxification and improving vision. The plant's action is also thought to address conditions such as vertigo, headaches, and poor eyesight.<sup>[2]</sup> The herb is used in a variety of formulations designed to improve overall health and vitality.

Apart from these, the plant has been used in folk medicine for the treatment of respiratory issues, digestive disorders, diabetes, and skin diseases such as eczema and psoriasis.<sup>[1]</sup> Its adaptogenic properties, ability to balance doshas (in Ayurvedic medicine), and wide range of therapeutic effects have contributed to its continued use in diverse cultures and health systems.

## PHYTOCHEMICAL PROFILE AND BIOACTIVE CONSTITUENTS OF *E. ALBA* (L) HASSK

*E. alba* (L.) Hassk., widely referred to as Bhiringraj, is renowned for its diverse bioactive compounds that contribute to its wide array of pharmacological activities. The plant contains several classes of phytochemicals, including coumestans, flavonoids, triterpenoids, alkaloids, sterols, and others. These constituents are responsible for the plant's therapeutic applications in Ayurvedic and traditional medicine.

### Coumestans

The major bioactive coumestan in *E. alba* is wedelolactone. Wedelolactone has been thoroughly investigated for its liver-protective, anti-inflammatory, and antioxidant properties. It acts by suppressing Nuclear factor kappa (NF- $\kappa$ B) signaling, thereby lowering the levels of pro-inflammatory cytokines, which highlights its potential in managing inflammatory disorders.<sup>[5]</sup> Other coumestans, such as demethylwedelolactone, also contribute to the anti-inflammatory and antioxidant effects.<sup>[6]</sup>

### Flavonoids

*E. alba* contains various flavonoids, which exhibit significant antioxidant, anti-inflammatory, and anticancer activities. Luteolin and its glycoside luteolin-7-O-glucoside are particularly abundant in the plant and play a key role in reducing oxidative stress.<sup>[7]</sup> Apigenin is another prominent flavonoid with anti-inflammatory and anticancer properties.<sup>[8]</sup> In addition, cinnaroside, a flavonoid glycoside, further enhances the antioxidant capacity of the plant.<sup>[9]</sup>

### Triterpenoids and saponins

Triterpenoids, particularly ursolic acid and oleanolic acid, are abundant in *E. alba*. These compounds exhibit anti-inflammatory, hepatoprotective, and anticancer properties.<sup>[10]</sup> Eclalbasaponins I-VI, oleanane-type triterpene glycosides, also contribute to the plant's hepatoprotective and immunomodulatory activities.<sup>[12]</sup>

### Alkaloids

Alkaloids such as ecliptine and ecliptalbine found in *E. alba* have been shown to possess antimicrobial and anti-inflammatory properties.<sup>[11]</sup> Nicotine and nicotinic acid, though present in smaller amounts, also contribute to the bioactive profile of the plant, particularly for their effects on the nervous system.<sup>[12]</sup>

### Sterols and phytosterols

Sterols such as stigmasterol,  $\beta$ -sitosterol, and spinasterol are present in *E. alba* and are known for their cholesterol-lowering and anti-inflammatory effects.<sup>[13]</sup> These phytosterols contribute to the plant's cardiovascular benefits.

### Other bioactive constituents

Apart from the major classes of compounds, *E. alba* also contains polyacetylenes, thiophenes, resins, and sulfur compounds, all of which contribute to its therapeutic properties, particularly for antimicrobial and cytotoxic activities.<sup>[14]</sup> Polypeptides such as cystine, glutamic acid, phenylalanine, and tyrosine further add to the plant's nutritional and therapeutic value.<sup>[15]</sup>

### Phytochemical distribution in plant parts

Phytochemicals in *E. alba* are distributed across various plant parts, with the leaves containing the highest concentration of wedelolactone, flavonoids, and sterols.<sup>[9]</sup> The roots are rich in hentriacontanol, and the aerial parts, including stems, contain compounds like  $\beta$ -amyrin and ursolic acid.<sup>[10]</sup>

### Extraction methods

Advanced extraction techniques like supercritical carbon dioxide extraction, ultrasound-assisted extraction, and microwave-assisted extraction have been employed to obtain bioactive constituents from *E. alba*. These techniques optimize yield and preserve the bioactive compounds such as wedelolactone, flavonoids, and saponins.<sup>[11]</sup>

## PHARMACOLOGICAL SIGNIFICANCE OF *E. ALBA* (L.) HASSK.

*E. alba*, widely referred to as Bhringraj, has gained significant attention in traditional medicine for its broad range of therapeutic effects. Modern pharmacological studies have validated many of the ancient claims surrounding its medicinal properties. This plant contains several bioactive constituents, such as wedelolactone, flavonoids, and alkaloids, which contribute to its wide array of pharmacological activities, including hepatoprotective, anti-inflammatory, antioxidant, antimicrobial, anticancer, and neuroprotective effects.

### Hepatoprotective effects

One of the most prominent pharmacological properties of *E. alba* is its hepatoprotective activity. Several studies have demonstrated that extracts from *E. alba*, particularly its leaves, possess the ability to protect the liver from various toxins and diseases. The primary bioactive compound responsible for this activity is wedelolactone, a coumestan derivative. Wedelolactone has been shown to promote liver cell regeneration and reduce liver damage induced by hepatotoxic agents such as carbon tetrachloride (CCl<sub>4</sub>).<sup>[10]</sup> It also inhibits oxidative stress and inflammation in the liver, which are key mechanisms involved in liver damage. In a study by Palanisamy and Ranjith, administration of *E. alba* extract significantly reduced liver enzymes (serum glutamic-oxaloacetic transaminase, serum glutamic-pyruvic transaminase), indicating its protective effects on liver function.<sup>[5]</sup>

Moreover, *E. alba* has been traditionally used in Ayurvedic medicine to treat liver disorders such as jaundice, cirrhosis, and hepatitis. Its hepatoprotective action has been confirmed by experimental animal models, which show a reduction in liver inflammation, fibrosis, and necrosis when treated with *E. alba* extracts.<sup>[9]</sup>

### Anti-inflammatory activity

*E. alba* is used for its anti-inflammatory effects, which are crucial in the management of arthritis, asthma, and inflammatory bowel disease. The plant's anti-inflammatory action is due to the flavonoids such as luteolin and apigenin, both of which are known to inhibit the pro-inflammatory cytokines production and reduce the activity of key inflammatory mediators like NF- $\kappa$ B and cyclooxygenase-2.<sup>[7]</sup> In addition, wedelolactone also plays a role in reducing inflammation by downregulating the expression of inflammatory markers.<sup>[6]</sup>

In a study, *E. alba* exhibited significant anti-inflammatory effects in animal models of induced inflammation.<sup>[7]</sup> The extract demonstrated a reduction in paw edema and joint swelling, further corroborating its traditional use in inflammatory

conditions. Furthermore, *E. alba* has also been shown to possess antiallergic properties, making it a useful remedy for allergic rhinitis and asthma.<sup>[3]</sup>

### Antioxidant properties

The antioxidant activity of *E. alba* has been extensively studied due to its potential to combat oxidative stress, which is linked to various chronic diseases, including cancer, cardiovascular disease, and neurodegenerative disorders. Flavonoids like luteolin and apigenin, as well as wedelolactone, contribute significantly to the antioxidant activity of the plant.<sup>[8]</sup> These constituents neutralize free radicals, prevent lipid peroxidation, and boost the function of natural antioxidant enzymes such as superoxide dismutase and catalase.<sup>[9]</sup>

In addition to these compounds, *E. alba* has been shown to increase the levels of glutathione, a crucial antioxidant in the body that protects cells from oxidative damage. The antioxidant capabilities of the plant suggest its potential as a therapeutic candidate for managing disorders linked to oxidative stress, such as Alzheimer's disease, Parkinson's disease, and various cardiovascular conditions.<sup>[16]</sup>

### Antimicrobial and antifungal activity

*E. alba* has demonstrated significant antimicrobial and antifungal properties. Bioactive constituents such as wedelolactone, luteolin, and apigenin demonstrate strong antibacterial activity against a range of pathogens, including *Staphylococcus aureus*, *Escherichia coli*, and *Pseudomonas aeruginosa*. Their antimicrobial action is primarily due to the disruption of bacterial cell wall formation, compromise of membrane integrity, and inhibition of protein synthesis.<sup>[10,12]</sup>

The plant also possesses antifungal properties, particularly against *Candida albicans* and *Aspergillus niger*, due to its ability to inhibit fungal cell membrane growth and metabolic pathways.<sup>[5]</sup> These antimicrobial and antifungal activities make *E. alba* an important agent for treating skin infections, wounds, and other microbial diseases.

### Anticancer potential

The anticancer properties of *E. alba* have garnered considerable attention in recent years. Wedelolactone, a major bioactive compound of *E. alba*, has shown significant promise in inhibiting the growth of cancer cells in various *in vitro* and *in vivo* models. It induces apoptosis in cancer cells by activating the caspase pathway and modulating the expression of pro-apoptotic proteins.<sup>[8]</sup> Wedelolactone suppresses tumor cell growth by disrupting the cell cycle, specifically by hindering the transition from the G1 phase to the S phase.<sup>[6]</sup>



*E. alba* has demonstrated anticancer activity against breast, liver, and lung cancers. In a study by Sharma *et al.*, *E. alba* extract exhibited significant cytotoxic effects on human breast cancer cells (Michigan Cancer Foundation-7) and induced apoptosis through mitochondrial pathway activation.<sup>[11]</sup> These findings suggest that *E. alba* could be developed as an adjunct therapy in cancer treatment.

### Neuroprotective effects

Neurodegenerative diseases, such as Alzheimer's and Parkinson's, involve the deterioration of neuronal function and increased oxidative stress. *E. alba* has been shown to exhibit neuroprotective effects through its antioxidant and anti-inflammatory activities. Wedelolactone plays an important role in protecting neurons from stress-induced damage.<sup>[5]</sup> The plant is used to improve memory and cognitive function, and this has been supported by modern studies that show enhanced memory retention and learning abilities in animal models after administration of *E. alba* extracts.<sup>[11]</sup>

### Other pharmacological activities

Apart from the primary therapeutic effects mentioned above, *E. alba* also demonstrates various other pharmacological properties, including:

- Anti-diabetic activity: Studies have demonstrated that *E. alba* can reduce blood sugar levels and enhance insulin sensitivity in diabetic animal models.<sup>[3]</sup>
- Wound healing: The plant is used topically for wound healing due to its antimicrobial and anti-inflammatory properties.<sup>[12]</sup>
- Hair growth stimulation: *E. alba* is a popular ingredient in hair oils and shampoos for promoting hair growth and preventing hair loss.<sup>[8]</sup>

## TRADITIONAL AND ETHNOMEDICINAL USE OF *E. ALBA* (L.) HASSK

*E. alba*, widely referred to as Bhringraj, has been widely utilized in traditional medicine systems across various cultures for centuries. This herb is predominantly used in Ayurvedic, Unani, and TCM to treat a broad spectrum of ailments. Its therapeutic uses are based on its ability to promote overall health, particularly in liver function, hair care, and skin health. The plant's medicinal properties have been passed down through generations, and its continued relevance in modern times underscores its value in ethnomedicine.

### Ayurvedic medicine

In Ayurvedic medicine, *E. alba* is regarded as a powerful herb with multiple health benefits. It is most commonly referred to as "Bhringraj," a name derived from the Sanskrit

word *Bhringa*, meaning "bee," which refers to the plant's attractiveness to bees, and *Raj*, meaning "king," symbolizing its revered status in traditional medicine. Bhringraj is considered a *rasayana* (rejuvenating herb) and is used to promote longevity and vitality.

The primary use of *E. alba* in Ayurveda is for its hepatoprotective properties. It is commonly used to treat liver-related ailments, including jaundice, hepatitis, cirrhosis, and other liver disorders. Ayurvedic texts describe the use of the plant in treating disorders associated with the liver's ability to detoxify the body, restore bile secretion, and prevent liver damage. The leaves of the plant are frequently used in the form of juice or decoctions, sometimes mixed with other herbs like *Phyllanthus amarus* to treat jaundice.<sup>[9]</sup>

Moreover, *E. alba* is highly valued in Ayurveda for promoting hair growth. The plant is believed to strengthen hair follicles, reduce hair fall, and stimulate hair regrowth. The oil extracted from its leaves is commonly used in hair care formulations to treat conditions like dandruff and premature graying.<sup>[17]</sup> The plant's application is not only limited to hair but also to skin health, where it is used in poultices and topical treatments for wounds, burns, and skin infections.

### Unani medicine

In Unani medicine, *E. alba* is known as "Karisma" and is used for its medicinal benefits, particularly in treating liver and hair-related issues. The Unani system places significant emphasis on balancing the four humors of the body: Blood, phlegm, yellow bile, and black bile. *E. alba* is believed to have a cooling effect and is commonly used to treat conditions related to excess heat or bile, such as inflammation, jaundice, and fever.

Similar to Ayurvedic practices, *E. alba* is utilized in Unani medicine for hair care. The leaves and oil of the plant are employed to strengthen hair, prevent hair fall, and treat dandruff and scalp infections. The Unani practitioners also use *E. alba* as a remedy for digestive disorders, particularly those involving excessive bile production, such as gastritis and indigestion.<sup>[18]</sup>

### TCM

In TCM, *E. alba* is called "Mo Han Lian" and is used primarily for its effects on the liver and kidneys. It is considered a cooling herb that detoxifies the liver and promotes the flow of vital energy, or *Qi*. The herb is also used to nourish the liver and kidneys, which are thought to be critical organs in maintaining vitality, energy, and longevity in TCM.

In TCM, the plant is utilized to treat various ailments, such as liver disorders, jaundice, and vertigo. It is also employed in managing kidney weakness, urinary tract infections, and dizziness linked to liver dysfunction. Typically, the plant is

prepared as a decoction or powdered form, and it is occasionally combined with other herbs to boost its therapeutic benefits.<sup>[19]</sup>

### Ethnomedicinal uses in other regions

*E. alba* has been utilized in traditional medicine across different regions of Southeast Asia, Africa, and South America to address a variety of health conditions. In Sri Lanka and India, it is used for hair growth and to treat alopecia. The application of its juice to the scalp is considered an effective remedy for baldness. Similarly, in parts of West Africa, *E. alba* is used to treat malaria, fever, and jaundice.<sup>[20]</sup>

The plant's use extends to the treatment of skin diseases in several African and Asian communities. The leaves are crushed and applied to wounds, cuts, and boils to promote healing and prevent infection. In addition, the juice or poultices of *E. alba* are used to treat conditions such as eczema, psoriasis, and other inflammatory skin disorders.<sup>[5]</sup>

### Contemporary ethnopharmacology

The contemporary use of *E. alba* is supported by a growing body of ethnopharmacological research that validates many of the traditional claims associated with the plant. Modern studies have confirmed its hepatoprotective, anti-inflammatory, and antioxidant properties, which validate its widespread use in treating liver disorders, inflammation, and oxidative stress-related conditions. The plant has also shown promise in modern pharmacological research as an antimicrobial and anticancer agent.<sup>[1]</sup>

In India, the juice of *E. alba* is often used as a natural remedy for hair care and skin health, aligning with its traditional use in Ayurvedic practices. The plant is increasingly being incorporated into herbal formulations and cosmetics for promoting hair growth and improving scalp health.<sup>[21]</sup>

## RECENT DEVELOPMENTS AND APPLICATIONS OF *E. ALBA* (L.) HASSK

*E. alba* (L.) Hassk., commonly known as Bhringraj, continues to garner significant attention in both traditional medicine and modern scientific research. Over the past few years, substantial advancements have been made regarding the phytochemistry, pharmacology, and potential applications of this versatile plant. These developments are providing insights into the mechanisms behind its therapeutic properties and opening new avenues for its application in the healthcare and cosmetic industries.

### Advances in phytochemical research

Recent studies have focused on identifying and characterizing the active phytochemical constituents of *E. alba*. The primary

bioactive compounds in *E. alba* include wedelolactone, luteolin, apigenin, flavonoids, alkaloids, and saponins, which contribute to its hepatoprotective, anti-inflammatory, and antimicrobial properties.<sup>[1]</sup> Recent studies have introduced innovative extraction techniques, such as supercritical fluid extraction and microwave-assisted extraction, to enhance the yield and purity of bioactive compounds from the plant.<sup>[22]</sup> These modern extraction techniques have the potential to enhance the quality and efficacy of plant-based therapeutic formulations.

In addition, molecular docking studies have been used to understand the mechanisms of action of active compounds such as wedelolactone, which interact with enzymes involved in liver detoxification pathways. This research is paving the way for the development of more targeted therapeutic agents derived from *E. alba*.

### Pharmacological applications

Recent pharmacological research has highlighted the wide-ranging potential of *E. alba* in treating several modern ailments. One of the key areas of focus has been its hepatoprotective properties. Studies showed that *E. alba* extracts show significant protective effects against liver toxicity induced by alcohol, chemicals, and viral infections.<sup>[23]</sup> The plant's active compounds, particularly wedelolactone, play a crucial role in modulating oxidative stress and inflammation in liver cells, thereby improving liver function. These findings support the traditional use of *E. alba* as a remedy for liver disorders such as jaundice, cirrhosis, and hepatitis.

Moreover, *E. alba* has shown promise in neuroprotective research. Recent studies suggest that the plant's bioactive compounds can help in mitigating neurodegenerative diseases, including Alzheimer's and Parkinson's diseases. The antioxidant and anti-inflammatory properties of *E. alba* help protect neurons from oxidative damage and promote cognitive function.<sup>[24]</sup> These findings are particularly important for developing natural alternatives for managing age-related cognitive decline.

In addition to its liver and neuroprotective effects, *E. alba* has demonstrated significant anticancer properties. Studies have shown that wedelolactone, a major constituent of *E. alba*, inhibits the growth of cancer cell lines, such as breast, lung, and liver cancers.<sup>[22]</sup> Wedelolactone has been shown to induce cell cycle arrest and apoptosis in cancer cells, making it a promising lead compound for future cancer therapies.

### Applications in cosmeceuticals and hair care

*E. alba* has long been a part of traditional hair care formulations, particularly in Ayurvedic medicine, where it is used to promote hair growth. Recent developments in cosmeceutical research have further validated these uses. *E. alba* extracts have been incorporated into a variety of hair

care products to strengthen hair follicles, reduce dandruff, and prevent premature graying.<sup>[25]</sup> Modern clinical studies have confirmed the effectiveness of *E. alba* in promoting hair growth in individuals suffering from alopecia.

The topical application of *E. alba* oil significantly increased hair density and reduced hair fall, further cementing its role as a valuable ingredient in hair care formulations.<sup>[26]</sup> In addition, because of its anti-inflammatory and wound-healing benefits, *E. alba* is gaining popularity in cosmetic dermatology for the treatment of skin conditions such as acne, eczema, and psoriasis. Its effectiveness in promoting wound healing and minimizing scar formation has made it a favored ingredient in creams and lotions designed to treat skin blemishes and scars.<sup>[27]</sup>

### Regulatory and commercialization efforts

As the medicinal and cosmetic uses of *E. alba* gain recognition, regulatory bodies have begun to assess the safety and efficacy of products containing this herb. In countries like India and China, where the plant has been used for centuries, *E. alba* is gaining acceptance in the form of herbal supplements and cosmetics. However, global regulatory bodies, including the U.S. Food and Drug Administration and the European Medicines Agency, are still in the process of reviewing the plant's safety profile for broader use in pharmaceutical products.

Pharmaceutical companies are increasingly investing in the commercialization of *E. alba* extracts for liver protection and hair growth applications. As research continues to uncover the plant's therapeutic potential, it is expected that *E. alba* will find a more prominent place in the global market for herbal medicines and cosmetics.

## CONCLUSION

Recent developments in the study of *E. alba* have reinforced its significance in traditional and modern medicine. Phytochemical research has provided a deeper understanding of its bioactive constituents, while pharmacological studies have validated its hepatoprotective, neuroprotective, and anticancer properties. Furthermore, the plant's applications in the cosmetic industry, particularly for hair care and skin health, are gaining widespread attention. As research on *E. alba* progresses, it shows promise in becoming a significant contributor to the development of natural therapeutic agents and cosmetics, further reinforcing its role in both traditional and contemporary healthcare systems.

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