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BOERHAVIA DIFFUSA L. (PUNARNAVA): A COMPREHENSIVE REVIEW ON ETHNOBOTANY, PHYTOCHEMISTRY, PHARMACOLOGY, AND THERAPEUTIC APPLICATIONS

Anshuman Yadav*, Vivek Gupta, Yogesh Kumar, Gyan Singh

Research Scholar, Faculty of Pharmacy, PK University, Thanra - 473665, Madhya Pradesh, India.

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Correspondence should be addressed to
Anshuman Yadav,
Research Scholar,
Faculty of Pharmacy, PK University,
Thanra - 473665, Madhya Pradesh,
India.

Email- ay949041@gmail.com

ABSTRACT: In a world pivoting toward integrative and personalized medicine, *Boerhavia diffusa* L. (Punarnava) emerges as a phytopharmacological gem bridging ancestral knowledge with 21st -century drug discovery. Celebrated in Ayurveda for revitalizing organs and restoring systemic balance, this resilient herb holds untapped potential for treating complex disorders like inflammation, diabetes, and renal dysfunction. This review offers a multidimensional exploration of its traditional wisdom, biochemical depth, and modern translational relevance. A transdisciplinary approach was employed, analyzing peer-reviewed databases for ethnomedical documentation, bioactive profiling *via* advanced spectroscopy (LC-MS/MS, FTIR, NMR), and pharmacological insights from *in vitro*, *in vivo*, and emerging *in silico* models. Novel formulation strategies—including nanocarriers, phytosomes, and hybrid herbal scaffolds-were examined for enhancing bioavailability, targeting, and therapeutic index. *Boerhavia diffusa* hosts a dynamic phytochemical matrix-punarnavine, boeravinones, ursolic acid, and flavonoids that act as polypharmacological agents. These modulate redox signaling, immune checkpoints, and metabolic enzymes, offering renoprotective, hepatoprotective, antidiabetic, and cytoprotective effects. Smart delivery systems-nanogels, biopolymer conjugates, and green-synthesized nanoparticles-amplify its efficacy and reduce toxicity. Bioinformatics tools and molecular docking studies further reveal promising interactions with key therapeutic targets, inviting new drug leads from this traditional herb. *Boerhavia diffusa* is more than a medicinal plant-it's a biointelligent system with vast therapeutic implications. To harness its full potential, the roadmap ahead must integrate omics-driven validation, AI-assisted drug design, and eco-sustainable cultivation practices to elevate this ancient remedy into a global therapeutic asset.

Keywords: *Boerhavia diffusa*, Ethnomedicine, Phytochemistry, Pharmacological activities, Therapeutic applications

1. INTRODUCTION

The path of tradition meets the direction of technology creates a new path toward natural medical compounds. Medical plants are now leading today's drug discovery efforts because of their complex benefits that correspond to human medical needs which they originally provided through traditional healing systems [1]. The fields of molecular pharmacology and high-throughput screening and systems biology conduct modern evaluations about plants that traditional healing systems like Ayurveda, Unani, Siddha and Chinese medicine have used. Research methods have discovered previously unknown bioactive molecules and validated older frameworks for actions simultaneously [2].

The plant genus *Boerhavia diffusa* L. functions under its common name Punarnava as it represents one of the numerous rediscovered botanicals that occupy specific areas of medical use. Punarnava derives its naming origin from Sanskrit where its ancient meaning translates to "the one that rejuvenates" showing its traditional medical application for revitalization of the body's core systems particularly liver and kidneys [3]. *B. diffusa* is a plant species that exists from tropical to subtropical climates spread throughout the world. Tradition has been used Punarnava as medical practitioners have used it chronologically to treat disorders pertaining to fluid drainage, swelling, respiratory distress, liver protection, *etc*. Probably because of its ability to survive in the most severe conditions, this plant has a wide medical potential [4].

Boerhavia diffusa is a well-known plant on phytochemical and pharmacological ground; therefore, its role as a nano medical, bioinformatics and green pharmacological issues explores today. Bioactive composition of alkaloids, rotenoids and flavonoids and lignans, in addition to pharmacological effects of immunomodulation, nephroprotective and hepatoprotective and metabolic control by the multiple effects make this the drug [5]. This herb is propelled to the medical advances for *B. diffusa* by detailed findings on how these bioactives fit disease related targets and how drug delivery methods are developed [6]. This review will briefly introduce *Boerhavia diffusa* from all of the aspects that is known to date, especially its ethnobotanical history, its chemical profile, recent pharmacological uses and its translational research promise [7]. This paper attempts to review comprehensively *B. diffusa* a plant of higher historical significance and future possible utilization in world healthcare through a combination of modern scientific concepts and traditional literature [8].

2. Botanical Description

2.1 Taxonomical Classification

Boerhavia diffusa L. is classified under the family Nyctaginaceae, which comprises numerous herbaceous plants valued for their adaptability and medicinal uses. The complete taxonomical classification is as follows:

- **Kingdom**: Plantae
- **Division**: Magnoliophyta (Angiosperms)
- **Class**: Magnoliopsida (Dicotyledons)
- **Order**: Caryophyllales
- **Family**: Nyctaginaceae
- **Genus**: *Boerhavia*
- **Species**: *Boerhavia diffusa* L. This taxonomic position reflects its evolutionary significance and its association with various bioactive phytoconstituents [9].

2.2 Morphological Characteristics

Boerhavia diffusa, is prostrate or ascending, perennial, and trailing. The thick, meaty, and tapering roots (in some cases brown, reddish in color) are widely used in traditional medicine due to their phytochemical richness. The cylindrical, striped, verdant, and inflated stems sprawl over the floor and are purplish green. Smooth or slightly wavy borders, oval to oblong in shape, simple, opposite, paired. There could be either a smooth or somewhat rough surface. The tiny, tuberous blossoms are pink to purple, clumping at the plant's terminal or axillary nodes with the group defined by an involucre surrounding each one (Fig. 1) [10].

Fig. 1: Morphological illustration of *Boerhavia diffusa* [14]

2.3 Vernacular Names

Boerhavia diffusa is such a long established and widely used (especially in many countries and civilizations) common name that it has many different common names. It is known as Mookirattai in Tamil, Atikamamidi in Telugu, Thazhuthama in Malayalam and Komme Beru in Kannada in India. In Sanskrit and Hindi, punarnava is known (Table 1). The English name of spreading hogweed is Atifa internationally, spread the hog weed is the Arabic name. This name usually means that it solves the anti-aging and swelling issues [11].

Table 1: Taxonomical Classification and Vernacular Names of *Boerhavia diffusa* L. [13]

S. No.	*Parameter*	*Details*
1	Kingdom	Plantae
2	Division	Magnoliophyta (Angiosperms)
3	Class	Magnoliopsida (Dicotyledons)
4	Order	Caryophyllales
5	Family	Nyctaginaceae
6	Genus	*Boerhavia*
7	Species	*Boerhavia diffusa* L.
8	Common Name (English)	Spreading Hogweed
9	Hindi	Punarnava
10	Sanskrit	Shothaghni, Punarnava
11	Tamil	Mookirattai
12	Telugu	Atikamamidi

2.4 Geographical Distribution and Ecological Presence

Boerhavia diffusa is now pantropical plant species which originally found in India subcontinent. It is native to tropical and subtropical climates, although it is found in abundance in sandy loamy soils, along roadsides, in pastures, and on wastelands. Despite their low number worldwide, they're an important species for conservation and medicine because of their ecological versatility tolerance of damaged habitats, nutrient poor soils, dry or semi-arid climates [12].

3. Ethnobotanical Relevance

3.1 Traditional Uses in Ayurveda, Siddha, and Other Indian Systems

Boerhavia diffusa L., the Punarnava widely heard of, has a conspicuous position in the traditional medical systems of India. It is known as "Punarnavi" in Ayurveda that is a renewer of tissues. It is herb, rejuvenating and is used for treating kidney, edema and liver disease and inflammatory conditions [15]. This plant is classical example of inclusion in Ayurvedic formulation *viz*. Punarnavadi Kwath, Punarnavarishta and Punarnavadi Mandura for its diuretic, hepatoprotective and anti-inflammatory properties. It is also similarly used for the management of dropsy, anemia, asthma, and chronic fevers in Siddha and Unani systems, either as a polyherbal decoction or with other medicinal agents [16].

3.2 Folk Medicine Practices and Local Uses

Previous experience of *Boerhavia diffusa* in traditional medicine in India as well as in South American, African and Southeast Asian popular and tribal systems. Indigenous people also turn to root paste or decoction for many medical issues such as UTIs, dysmenorrhea, stomach-aches and even bites from animals [17]. The crushed leaves are used topically to treat skin diseases, wounds and insect bites. It is believed that drinking the plant infusion as a tea or as a plant infusion 3 times throughout the seasons will increase the plants vigor and vitality and it is used as a natural eye drop for conjunctivitis and night blindness in rural India [18].

3.3 Parts Used and Route of Administration

The medicinal effects of the plant are best found in the roots which, together, make the whole of the plant useful for medicine. Usually, their most common oral administration forms include decoctions, powders, and fermented concoction. It is used to internal cleaning or externally, infusions made from the leaves and aerial parts [19]. Some people inhale smoke from dried plant material and others take apple cider vinegar nasally to ward off respiratory issues or headaches or sinus congestion. The variety of parts used, and the way in which plant is used as medicine, illustrates its versatility and diversity in the ethnomedical uses [20].

4. Phytochemical Constituents

4.1 Major Classes of Constituents

Scientific evidence shows *Boerhavia diffusa* demonstrates multiple therapeutic effects because of its phytoconstituents that occur throughout the plant. These constituents possess multiple chemical compounds. The plant produces numerous bioactive compounds that include alkaloids as well as flavonoids while also containing phenolics and steroids and two types of glycosides. In addition to saponins and triterpenoids it contains lignans. The various plant components in *Boerhavia diffusa* demonstrate multiple healing properties that include protection of the liver along with immune regulation as well as anti-inflammatory effects alongside antioxidant actions. Research has focused intensively on using punarnavine and boeravinones as therapeutic agents because these two compounds stand out among Mandukaraya's chemical compounds (Table 2, Fig. 2) [21].

4.2 Key Bioactive Compounds and Their Structures

Punarnavine, an alkaloid with immunomodulatory and anticancer properties and rotenoids boeravinone B, C, E, and F, hepatoprotective and antifibrinolytic effects and liriodendrin, a calcium channel blocker with favorable effects on the heart are among the most thoroughly researched active compounds. Flavonoids such quercetin, eupalitin and kaempferol add to the antioxidant profile of the plant. We know that these substances actually are biological activity thanks to detailed chemical structures analysis [22].

4.3 Isolation and Analytical Techniques

Products made from *Boerhavia diffusa* are carefully adhered to quality control by modern techniques using the modern techniques of analysis to identify and define its phytoconstituents. Profile of substances such as punarnavine and boeravinones is carried out before using High Performance Liquid Chromatography (HPLC) to quantify these substances using Thin Layer Chromatography (TLC) [23]. It also permits non-volatile and volatile compounds to be identified as well as complete structural analysis using newer, more sophisticated methods such as gas chromatography–mass spectrometry (GC–MS) and liquid chromatography–mass spectrometry (LC–MS). Functional groups and chemical identities can be confirmed as well, as they are also utilized in UVVis and IR spectroscopy [24].

4.4 Distribution of Phytochemicals in Different Plant Parts

Physical variety in *Boerhavia diffusa* has a great difference in its phytochemical composition. The high concentration of alkaloids, mainly punarnavine, boeravinones, and steroids, are the reason for which the most of its therapeutic use are obtained from the roots [25]. They are used to protect wounds and heal infection since the stems and leaves have high concentrations of tannins, flavonoids and saponins. Even though they are not used often, the sterols and lipids in the seeds are noteworthy. So we can use this distribution to understand in what order we want to formulate it, or what outcome we want to target for a specific therapeutic outcome [26].

Table 2: Identified Phytochemicals from Roots, Leaves, and Seeds of *Boerhavia diffusa* [27]

S. No.	*Phytochemical Name*	*Class*	*Plant Part*	*Pharmacological Activity*
1	Punarnavine	Alkaloid	Root	Immunomodulatory, Antitumor
2	Boeravinone B	Rotenoid	Root	Hepatoprotective, Antioxidant
3	Boeravinone C	Rotenoid	Root	Antifibrinolytic, Antiviral
4	Eupalitin	Flavonoid	Leaf	Anti-inflammatory, Antioxidant
5	Kaempferol	Flavonoid	Leaf	Antioxidant, Antibacterial
6	Quercetin	Flavonoid	Leaf	Anti-inflammatory, Cardioprotective
7	Liriodendrin	Lignan Glycoside	Root	Calcium channel blocker
8	Sitosterol	Phytosterol	Seed	Antilipidemic, Anti-inflammatory
9	Saponins	Triterpenoid Glycosides	Leaf	Diuretic, Immunomodulatory
10	Alkaloids (unspecified)	Alkaloids	Seed	Antimicrobial, Adaptogenic
11	Phenolic compounds	Polyphenols	Leaf	Antioxidant, Anti-aging
12	Triterpenes	Terpenoids	Root	Anti-inflammatory, Diuretic

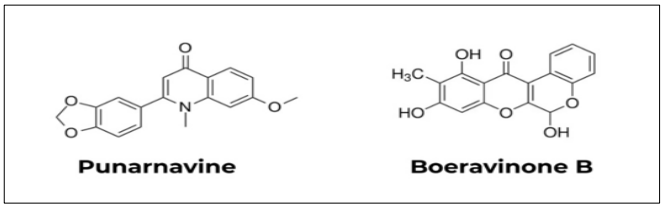

Fig. 2: Structures of major phytoconstituents like punarnavine, boeravinone B [28]

5. Pharmacological Activities

5.1 Nephroprotective and Diuretic Activity

Boerhavia diffusa has also received high status in traditional medicine, which attributed the properties to its diuretic and kidney protecting affairs. The root extract of Punarnava is used in the Ayurvedic formula 'Punarnavadi Kwatha' to aid in the treatment of Kidney Swelling, Nephritis and other UTIs. Preclinical research has demonstrated that there is an increase

in urine flow and elimination of nitrogenous waste. Alkaloids (flavonoids, punarnavine) affect the renal function and balance of electrolyte as well as lowering oxidative stress [29].

5.2 Hepatoprotective and Antioxidant Effects

This great plant is to treat jaundice, hepatitis, liver failure because of its amazing hepatoprotective properties. Compounds such as eupalitin and boeravinones affect cellular protection by exclusive inhibitions of lipid peroxidation and boosts in hepatic glutathione and activity of antioxidant enzyme. CCl_4 induced liver injury models have in done extensive research which postulates behind CCl_4 as a natural hepatotonic as it significantly enhances the liver enzyme levels and histological configuration [30].

5.3 Anti-inflammatory and Analgesic Effects

Mainly, *B. diffusa's* flavonoids and triterpenoids have analgesic and anti-inflammatory properties. As per experimental research, it could block the expression of COX-2 and downregulate pro-inflammatory cytokines like IL-6 and TNF α. Extracts from the roots and leaves of this plant, which have demonstrated their efficaciousness in the models of carrageenan induced paw edema and acetic acid induced writhing pain, model pain both centrally and peripherally like traditional nonsteroidal anti-inflammatory drugs (NSAIDs) [31].

5.4 Antimicrobial and Immunomodulatory Effects

B. diffusa extracts inhibited both methanolic and water-based extracts of *B. diffusa*, as bacteria, fungi and other micro-organisms. Alkaloid punarnavine has a positive effect on the immunological response, stimulating the activity of macrophages, cell multiplication lymphocytes, the production of cytokines. As a result, there is great promise that this plant can be used as an immunomodulatory drug particularly the long-term infections and diseases that weaken the immune system [32].

5.5 Antidiabetic and Anticancer Potential

The belief in *B. diffusa's* ability to regulate glucose homeostasis is increasing. It prevents the working of α-glucosidase, which is a carbohydrate digesting enzyme or helps improve insulin sensitivity. In diabetic rat models, there has been notable decrease of glycosylated hemoglobin and blood glucose. Boeravinones have also been shown to have potential for treatment of metabolic and oncological illness, and potential in antiproliferative effects with breast and colon cell lines. It is suggested that these effects are due to induction of apoptosis and cell cycle arrest [33].

5.6 Underlying Mechanisms of Pharmacological Action

B. diffusa's pharmacological effectiveness is due to the fact that it targets many, many targets simultaneously. It has bioactive components which are known to influence cellular signaling pathways through activation of AMPK, NF-κB inhibition, control of MAPK pathway. In part, these processes account for its impact against inflammation, diabetes and cancer. As an antioxidant with free radical neutralizing profile and immunomodulatory substances (which control T cell activity and cytokines release), it is a viable option of integrative medicine [34].

Table 3: Summary of pharmacological studies with models and outcomes [35]

S. No.	*Activity Studied*	*Extract/Compound Used*	*Experimental Model*	*Key Outcome*
1	Nephroprotective	Root extract	Gentamicin-induced nephrotoxicity in rats	Reduced urea, creatinine; improved renal histology
2	Diuretic	Aqueous root extract	Saline-loaded rats	Increased urine output and electrolyte excretion
3	Hepatoprotective	Methanolic root extract	CCl_4-induced liver injury in rats	Decreased SGOT, SGPT, ALP, and improved liver tissue
4	Antioxidant	Ethanolic leaf extract	DPPH & ABTS assays	Strong free radical scavenging activity
5	Anti-inflammatory	Hydroalcoholic root extract	Carrageenan-induced paw edema	Significant inhibition of inflammation
6	Analgesic	Aqueous root extract	Acetic acid-induced writhing in mice	Reduced writhing response
7	Antimicrobial	Methanolic leaf extract	*S. aureus*, *E. coli*, *C. albicans*	Broad-spectrum inhibition zone observed
8	Immunomodulatory	Punarnavine (alkaloid)	Macrophage activation & lymphocyte proliferation	Enhanced immune response parameters
9	Antidiabetic	Whole plant extract	Streptozotocin-induced diabetic rats	Decreased blood glucose and HbA1c
10	Anticancer	Boeravinone B	MCF-7 & HT-29 cell lines	Induced apoptosis and cell cycle arrest

6. Therapeutic Applications

6.1 Role in Kidney, Liver, and Inflammatory Disorders

Much attention has been raised on *Boerhavia diffusa* in the alleviation of hepatic and renal diseases. Very commonly used in Ayurvedic formulations for the treatment of kidney stone, edema, and chronic nephritis due to its strong nephroprotective effect [36]. The main bioactive components of the plant, punarnavine and boeravinones, are diuretic and possess anti-inflammatory properties and are useful in excretion of waste products from the kidneys reducing the inflammation and other forms of toxic effects in the kidneys. It is traditionally used to treat jaundice and liver failure because it has hepatoprotective properties [37].

6.2 Use in Metabolic Diseases and Infections

Several preclinical investigations have confirmed the potential antidiabetic activity of *Boerhavia diffusa* in multiple studies. It has number of antioxidants to control the oxidative stress associated with overweight, diabetes or any other form of disease. Not only is the plant used for treating respiratory and infectious problems as well as immune related problems, but the plant possesses broad spectrum antibacterial activity against bacteria, fungus, and certain virus strains [38].

6.3 Marketed Formulations and Patent Information

Commercially available formulations of *Boerhavia diffusa* are available, in particular in the markets of South-East Asia and

India. products made of its medicinal properties are Punarnavadi Kwath and Punarnava Mandur, and these are Herbal diuretic pills [39]. On a world scale there have been patent applications for its potential applications in diuretic formulations, liver protection and in the management of metabolic syndrome. To meet the demand of standardization of herbal medicine, *B. diffusa* containing polyherbal combinations and proprietary nanoformulations have evolved [40].

6.4 Clinical Studies and Therapeutic Evaluation

Although extensively documented in terms of traditional use, this is still at the infancy stages of scientific confirmation through clinical research. So far, the most promising human trials have been with edema, ascites and liver cirrhosis. Treatment with *Boerhavia diffusa* has been associated with better renal parameters and lower liver enzymes resulting in general improvement of the quality of life. To be confirmed as effective, and establish that its dosage forms are equal, there has to be a larger randomized clinical trial [41].

7. Future Perspectives and Research Gaps

7.1 Need for Clinical Validation and Pharmacokinetic Studies

Boerhavia diffusa still needs strong clinical confirmation, even though there is a lot of conventional and preclinical evidence for it. Only a small amount of data from human trials supports the majority of pharmacological claims, which are based on in vitro or animal models [42]. Randomized controlled studies that include several centers and are well-designed are essential for determining its safety, effectiveness, and recommended dose. To back up its clinical translation, pharmacokinetic profiling—which includes ADME, or absorption, distribution, metabolism, and excretion—of important components is crucial [43].

7.2 Quality Control and Standardization Challenges

B. diffusa is notoriously difficult to standardize because to its chemical complexity as well as differences in plant sections, geographical sources, and extraction processes. There is a lack of consistency in the active substance of many current formulations. In order to create quality control techniques that have been validated, it is necessary to use advanced analytical technologies such as HPTLC, LC-MS, and DNA barcoding. Fingerprint profiling and bioactives measurement should also be mandated by regulatory frameworks for herbal goods [44].

7.3 Scope for Nanoformulations and Combinational Herbal Therapies

Using nanotechnology-based carriers, like liposomes, nanoparticles, and phytosomes, can greatly improve the bioavailability and targeted delivery of *B. diffusa*, according to growing studies. Possible negative effects and dosage reductions are also possible with these systems. Also, in the treatment of long-term diseases like cancer, inflammation, or diabetes, there is untapped promise in merging *B. diffusa* with additional herbal extracts that exert complementary effects [45].

7.4 Potential for Drug Development and Molecular Targeting

As a potential source for new medicines, *Boerhavia diffusa* contains a wide variety of bioactive chemicals. There have been interactions with many therapeutic targets, such as COX-2, TNF-α, α-glucosidase, and VEFG, as demonstrated by molecular docking and in silico investigations. Research in the future should center on identifying and evaluating the therapeutic potential of molecules that have a strong affinity for these targets. This can serve as a starting point for the creation of semi-synthetic derivatives or NCEs [46].

CONCLUSION

Boerhavia diffusa (Punarnava) has an illustrious ethnopharmacological legacy in the tradition of the Indian medicine. This is just a few of the many systems which have recognized long ago the vast spread and therapeutic usefulness of the plant. Phytochemical spectrum of orchid is analyzed in depth and many bioactive compounds constituted the varied pharmacological profile. They are alkaloids, flavonoids, steroids and glycosides.

This plant has been subjected to various scientific studies and a plethora of beneficial effects have been demonstrated in particular, they protect and improve the liver and kidneys, reduce inflammation and killing of bacteria, and even cause the blood sugar to reduce and battle cancer. It continues to be of relevance in current therapeutic paradigms and its long-standing use is given credence by these results. New clinical trials and commercial formulations have confirmed its safety and effectiveness in treating metabolic, inflammatory, renal and hepatic diseases.

However, the potential is nonetheless incredibly huge, and there is still a gaping hole in translational research. Areas that need utmost attention are therapeutic trials, pharmacokinetics, uniformity, innovative administration system. If we do research across disciplines, we can fill these gaps and validate the traditional claims as well as the possibility that *Boerhavia diffusa* can be used in the modern evidence-based medicine.

In conclusion, *B. diffusa* represents both a legacy and a future in medicinal plant research-an ethnomedicinal treasure with untapped potential waiting to be fully explored and harnessed for global healthcare solutions.

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