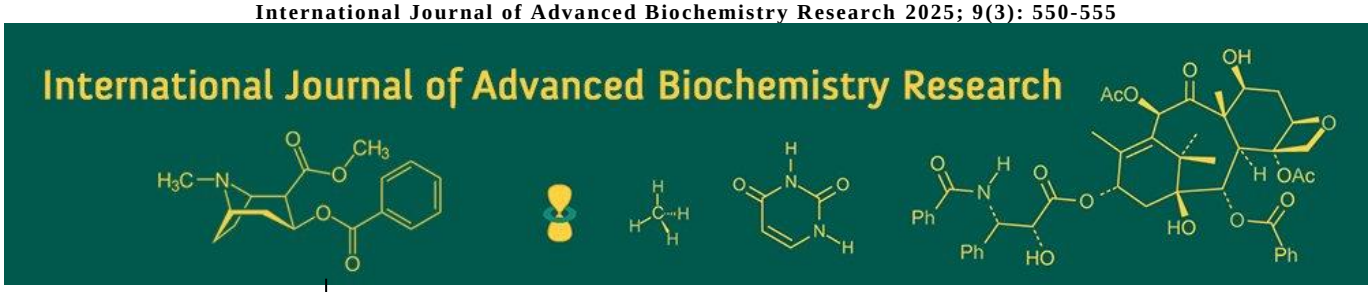

ISSN Print: 2617-4693
ISSN Online: 2617-4707
NAAS Rating: 5.29
IJABR 2025; 9(3): 550-555
www.biochemjournal.com
Received: 25-12-2024
Accepted: 29-01-2025

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A review: Phytochemistry and medicinal activities of *Bacopa monnieri*

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DOI: https://www.doi.org/10.33545/26174693.2025.v9.i3g.3996

Abstract
Bacopa monnieri, a traditionally used medicinal herb, has garnered significant attention for its diverse phytochemistry and purported therapeutic benefits. This mini-review synthesizes current knowledge on the phytoconstituents of *B. monnieri*, focusing on the major bioactive compounds, including saponins (bacosides), and their chemical structures. We explore the established and emerging pharmacological activities of *B. monnieri* extracts and isolated compounds, emphasizing their neuroprotective, anxiolytic, nootropic, and anti-inflammatory properties. The review critically examines the evidence supporting these claims, highlighting gaps in the current research, such as inconsistencies across studies and the need for more rigorous clinical trials to determine optimal dosages and efficacy. Furthermore, we discuss the potential for developing standardized *B. monnieri* extracts with consistent bioactive compound profiles to ensure therapeutic reproducibility and efficacy. The review also concludes by summarizing the current understanding of *B. monnieri's* phytochemistry and medicinal potential, emphasizing the need for further research to fully elucidate its mechanisms of action and optimize its therapeutic applications.

Keywords: *Bacopa monnieri*, phytochemistry, pharmacology, traditional uses

1. Introduction
Significantly, this vast majority of medicines developed today has come from less than 15% of those botanical species that have been assessed pharmacologically. While it is estimated that there exist half a million species of higher plants on Earth, over 20,000 have been discovered to be medicinal plants. Phytotherapy has been a traditional practice aimed at the relief of various ailments, echoing the practices of ancient civilizations. The extensive acceptance of herbal medicine in the world could be attributed to its cost-effectiveness as well as minimal side effects when considered against synthetic alternatives [1]. These herbal substances are vital in neurology as therapeutic agents in neuropsychiatric diseases, making them very crucial in modern medicine. One of the best examples is of Brahmi (Botanical name: *Bacopa monnieri*), a perennial creeping aquatic plant with 146 unique species, with all the species being accounted for as having flowers and leaves at every node, which also sprout roots along branching stems. This extraordinary medicinal plant has a bitter-sweet taste and is used traditionally to treat people with colds, with the quality of being virtually odourless. In the world of Ayurvedic medicine, the plant is locally revered as the Brahmi plant, or the creation plant, named after Brahma, who created everything. There, it has been vigorously used over three thousand years with the traditional Ayurvedic system as a nootropic aimed to enhance cognitive capabilities, repair brain damage, and combat diverse kinds of psychological disorders [2]. It is also a nootropic herb because it is used for the improvement of memory and other aspects of cognition through the regulation of critical hormones, neurotransmitters, enzymes, and especially acetylcholine [3]. Some of the cognitive benefits that are attributed to this botanical species are attributed to some of the phytochemical constituents in it, including Bacoside A, which has received much attention in some scientific studies. Though Brahmi possesses numerous advantages, it falls under the category of critically endangered species primarily because of large-scale harvesting. Still, the herb is wholly and completely good for medicinal usage and demonstrates the need to preserve such plants. In general, botanical medicine made from plants is relatively inexpensive and not significantly toxic compared with synthetic pharmaceutical agents, and

the significance of such natural remedies appears in today's care.

2. Distribution

Bacopa monnieri is distributed to include India, Nepal, Sri Lanka, Taiwan, Vietnam, Pakistan and China. It covers areas in the whole tropical and subtropical belts world over. The major chemical constituents of *Bacopa monnieri* are series of alkaloids such as herpestine, nicotine, and brahmin; saponins such as bacoside, betulinic acid, and hersaponin; and additional components such as stigmastanol, beta-sitosterol, stigmasterol [4].

3. Taxonomical Classification

Kingdom-Plantae
Class-Dicotyledones
Clade-Asterids
Order-Lamiales
Family-Scrophularaciae
Genus-*Bacopa*
Species-*monnieri*

4. Phytochemistry

The *Bacopa monnier*i phytochemical composition covers a very wide range of compounds such as alkaloids, flavonoids, glycosides, bacosides A and B, triterpenoids, saponins, beta-sitosterol, stigmasterol, D-mannitol, alpha-alanine, aspartic acid, betulinic acid, glutamic acid, serineand so many [5 & 6]. Phytochemical studies show that, in terms of content, leaves of this plant are rich in nicotine, bacoside A, bacoside B, betulinic acid, beta-sitosterol, D-mannitol, herpestine, and tannins. The stem contains lignified fibers, alkaloids, tannins, saponins, and calcium oxalate as indicated by the phytochemical screening [7 & 8]. In addition, the roots contain anthocyanins, isoflavonoids, and flavonoids that form the biosynthesis pathway of the phenylpropanoid pathway [9].

The first alkaloid extracted from *Bacopa monnieri* was brahmine [10] and thereafter followed by the nicotine and herpestine [11]. Bacoside A is a complex compound, chemically named as 3-(α-L-arabinopyranosyl)-O-β-D-glucopyranoside-10,20-dihydroxy-16-keto-dammar-24-eneI. It exhibits neuropharmacological and nootropic properties. Aglycones of Bacoside A are jujubogenin [12]. For instance, Bacoside A is predominantly purified as an artefact mixture of its optically active isomer, Bacoside B. They are classified into the general category of dammarane-type triterpenoid saponins because they contain jujubogenin and pseudojujubogenin as their glycone moieties. Bacoside A consists of a complex formed by four triglycosidic saponins, which includes bacoside A3, bacopasaponin C, bacopaside II, and bacopaside X; hence, it is the richest fraction in this regard [13, 14 & 15]. Bacoside B has constituents of bacopasides IV, V, N1 and N2compounds.

5. Pharmacological Activity

5.1 Anti-cancer activity

It has cytotoxic activity against proliferation and expansion of cancerous cell lines. The potential of this extract as an anti-cancer agent is said to be through various mechanisms such as the induction of apoptosis, alteration of signalling pathways linked with cancer, inhibition of angiogenesis and cell proliferation and intensification of the immune system's anti-cancer activity [50]. The ethanolic extract is the strongest anti-cancer activity [40].

5.2 Anti-asthmatic activity

In Ayurveda, *Bacopa monnieri* is used to treat diseases involving respiratory systems and it has alleviated coughs and other related respiratory diseases like bronchitis and asthma. It helps in the relaxation of the smooth muscles in the airway that reduces the inflammation in the airways and maintains airflow. Additionally, it may help manage the respiratory diseases [50].

5.3 Anti-inflammatory activity

It also diminishes oedema and inflammation as it inhibits the prostaglandin synthesis [51]. This is achieved by inhibiting the functions of immune cells, inhibiting inflammatory enzymes, restricting the formation of inflammatory cytokines, and reducing oxidative stress [52].

5.4 Anti-oxidant activity

Alcoholic and hexane extract of *Bacopa monnieri* exhibits anti-oxidant activity owing to its ability to neutralize free radicals and inhibit lipid peroxidation. This prevents cell from oxidative stress-induced damage [41, 53 & 54].

5.5 Anti-microbial activity

The bioactive compounds in *Bacopa monnieri* exhibit inhibitory activity against both gram-positive and gram-negative bacteria as well as some fungal strains. It is being thought that the principle by which *Bacopa monnieri* shows antimicrobial activity through the damage of microbial cell membranes, interference of critical microbial metabolism and inhibition of enzymatic activity in microbes, hence showing suppressive activity against a wide range of bacterial and fungal pathogens [53 & 55].

5.6 Anti-depressant activity

Besides its major antidepressive properties, the methanolic extract of Bacopa corresponds to regulation and transformation of significant neurotransmitters including dopamine, serotonin, and gamma-aminobutyric acid and its potential in promoting neurogenesis in the hippocampal area and reducing oxidative stress, that may provide for improvement in mood and decrease of the clinical manifestations of depression. Several of the bioactive constituents of *Bacopa monnieri* are also claimed to play a role as promoters of mood balance [55-58].

5.7 Anti-convulsive activity

Bacopa is found to be an antiepileptic drug in the midst of Ayurvedic medicine. This herbal medication, through modulation of neurotransmitter release, oxidative stress reduction, neuroinflammation inhibition, and neuronal hyperexcitability inhibition, prevents seizure occurrence and protects from side effects of the disease [38 & 52].

5.8 Hepatoprotective activity

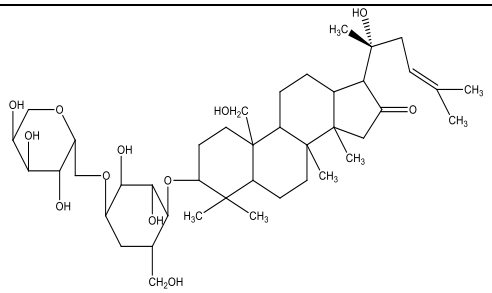
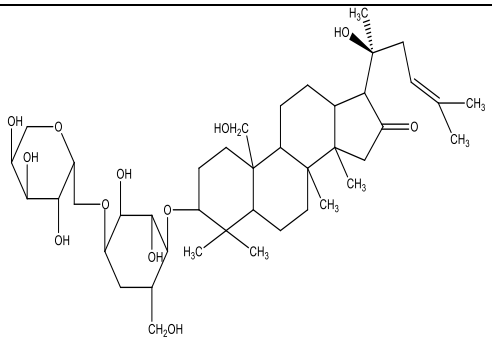
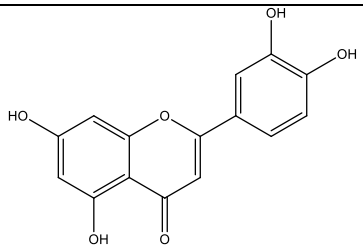
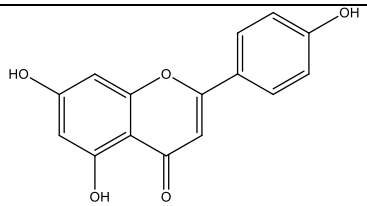
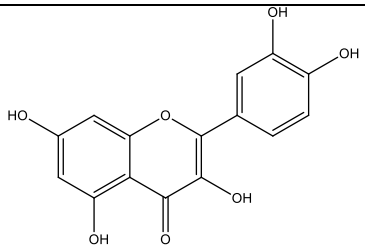
This extract retains liver structure and enzyme activity, making it hepatoprotective. Its properties of depressing lipid peroxidation, enhancing antioxidant defense systems, as well as preventing inflammation and fibrosis in the liver aligns with its hepatoprotective benefit [35 & 53].

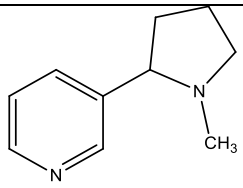
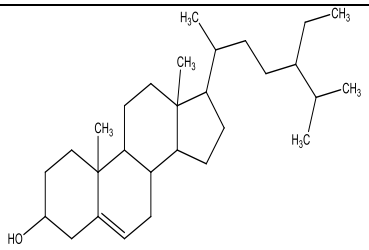
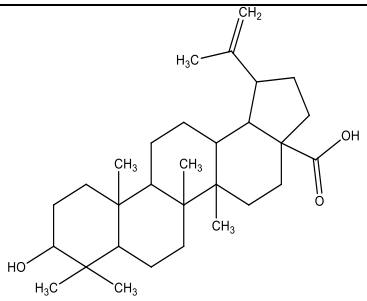
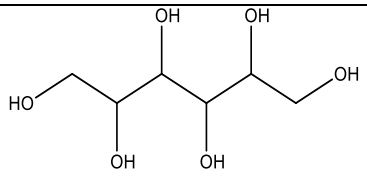
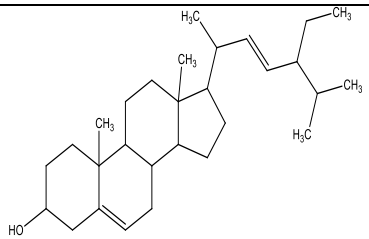
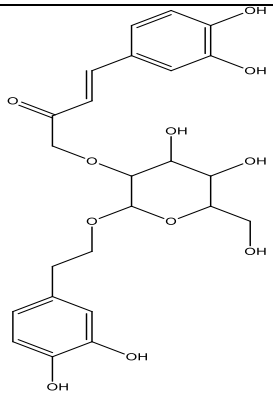
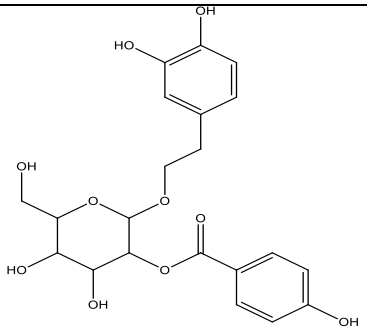
5.9 Analgesic activity
Bacopa monnieri's analgesia is seen through the interference with the opioidergic system, anti-inflammatory actions, inhibition of different pain mediators, and reduction of pain perception. It works to dampen the pain signals, thus relieving pain [54].

5.10 Sedative activity
Bacopa monnieri supresses the central nervous system via regulation of GABA receptors. In addition to its modulatory effects on the GABA receptors, *Bacopa monnieri's* sedating action which is partly due to its encouragement of rest and sleep. Further research has to be done to completely understand its specific sedation mechanisms and to establish the most appropriate therapeutic dosages [53].

5.11 Nootropic (memory boosting) activity
The "bacosides" are bioactive constituents of the herb *Bacopa monnieri* which have been well-documented in improving synaptic communication and in inducing nerve cell regeneration, the latter particularly in the hippocampus. This process is essential to the augmenting of memory formation, recall, and retention among other cognitive tasks [54-58]. Therefore, those individuals who incorporate *Bacopa monnieri* into their wellness programs are likely to have highly enhanced overall cognitive ability and memory.

Table 1: Phytoconstituents of *B. monnieri* with their structure and pharmacological activity.

Phytoconstuent	Structure	Pharmacological activity	Reference
Bacoside A		Improves memory Enhances cognitive function Anti-inflammatory Anti-hypertensive Anti-tumour	[16, 17 & 18]
Bacoside B		Neuro-protective Anti-inflammatory Maintains neurotransmitter balance	[16, 17 & 18]
Luteolin		Anti-inflammatory Analgesic	[19]
Apigenin		Antioxidant Neuro-protective Anti-inflammatory Anti-microbial	[20 & 21]
Quercetin		Anti-inflammatory Anti-hypertensive	[22 & 23]

Nicotine		Reduces stress and anxiety Increases heart rate	[24]
β-Sitosterol		Reduces cholesterol levels Anti-inflammatory	[25]
Betulinic acid		Cytotoxic (Anti-cancer) Anti-inflammatory Anti-malarial Anti-diabetic Anti-oxidant	[26]
D-mannitol		Diuretic (increases urine production) Reduces intraocular pressure	[27]
Stigmasterol		Anti-tumor Anti-inflammatory Anti-allergic Reduces cholesterol levels	[28 & 29]
Plantainoside B		Improves memory Neuro-protective	[30]
Monnieraside III		Anti-oxidant Neuro-protective Improves memory Improves cognitive function	[31]

6. Conclusion

Bacopa monnieri, or Brahmi as it is widely referred to, is a well-researched medicinal herb that boasts a rich history in traditional Ayurvedic medicine. The exceptional herb has been used for centuries due to its restorative properties and is greatly prized for its numerous health advantages. Its phytochemical composition has an impressive mixture of compounds consisting of saponins, alkaloids, flavonoids, and many other bioactive constituents that contribute largely to its varied therapeutic activities. Various studies have strongly confirmed its neuroprotective, cognition-enhancing, antioxidant, anti-inflammatory, and adaptogenic activities, and therefore, it is a potent drug candidate for the therapy of many neurological diseases like Alzheimer's disease, anxiety, and epilepsy. In addition, *Bacopa monnieri* has hepatoprotective, cardioprotective, antimicrobial, and even anticancer action, further broadening its medicinal significance in various areas of well-being. In spite of the extensive exploration of its drug-like potential, major challenges like standardization, bioavailability, and clinical authentication are still obstacles that must be overcome. Further studies must aim at enhancing its formulations, increasing its bioavailability, and carrying out large-scale clinical trials to adequately establish its efficacy and safety across different populations. In summary, Bacopa monnieri emerges as a powerful herbal drug with broad therapeutic potential. Further research in this field will aid in unlocking its complete medicinal potential, thereby leading to its use in today's pharmaceutical and nutraceutical products, ultimately serving a wider population in need of natural health alternatives.

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