Systematic Analysis of the Therapeutic Potential of *Bacopa monnieri*: A Wonder Therapeutic Plant

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Abstract

Bacopa monnieri (L.) Wettst., a well-known perennial creeping herb, native to parts of America, the African subcontinent, and South Asia, had been a well-known nootropic plant, documented in ancient Indian systems of medicine, *Ayurveda*. The dynamic variations in the phytocompounds consortia, regulated by abiotic cultivation conditions and germplasm, provided a paradigm shift towards the exploring profound therapeutic effect of the plant along with advancements in scalable cultivation strategies. Tailoring the cultivation conditions for modulating the phytocompound yield, was the biggest challenge, bringing agricultural scientists and enthnopharmacologists to synchronize the research quest for exploring and developing a novel cultivation scalable strategy. The current systematic review is a compilation of the systematic analysis as per PRISMA guidelines for exploring the therapeutic potential of *Bacopa monnieri*.. The ScienceDirect, PubMed and Elicit (AI) tool was used to collect more than 3000 search results which after screening every individual paper based on selection, exclusion and inclusion criteria, left the article count (n) of 17 studies. The systematic analysis was done after inclusion randomized control trails(RCT) human subject studies and exclusion of duplicates, unlinked or incomplete studies not related to *Bacopa monnieri*. Based on the in-depth analyses of selected research studies it can be proposed that existing randomized control trails (RCT) and pre-existing systematic and meta-analysis had shown the dose dependent efficacy of *Bacopa monnieri* extracts on neurological improvements such as improvement in word recall, working memory and attention, among elderly along with secondary health benefits including cholinergic enhancement via AChE suppression and anti-inflammatory activities, along with others. The systematic analysis paved the way for the development of phytocompound consortia rich cultivar of Bacopa monnieri for enhancing the efficacy and therapeutic properties.

Keywords: Systematic, Nootropic, *Bacopa monnieri*, dose, inflammatory,

1. Introduction

The changing lifestyle over the decades, concomitant with globalization and urbanization, has directly affected human life in multiple ways, including a growing disease burden, as evidenced by the increasing prevalence of non-communicable diseases across society. According to the World Health Organization (WHO), lifestyle diseases or non-communicable diseases (NCDs) are responsible for 74% of the global deaths, killing around 43 million people in 2021 (WHO Data source). Amongst various NCD, affecting different age specific cohorts throughout the world, neurological disorders are a major societal concern, due to associated symptom affecting quality of life (Steinmetz et al., 2024a). The existing systematic studies have reported the disease burden in the year 2021 due to neurological disorders are the leading public health concern, with DALY of 443 million, affecting 3.4 billion people worldwide (Steinmetz et al., 2024b). Various existing treatments have failed to provide cure to neurological disease conditions, however symptomatic relief had been observed (Passeri et al., 2022)

Bacopa monnieri, a small, creeping perennial herb native to wetlands across India and Southeast Asia (Choudhary et al., 2021). Ayurveda has termed it a *Rasayana* —a chemical classified as a *Medhya Rasayana*—a rejuvenating herb for the intellect and memory. The utility of the herb had extended beyond ethnopharmacological assessment to modern drug development attributed to the pivotal role in brain health, particularly given the rising prevalence of age-related cognitive decline and neurodegenerative diseases (Vijayababu, 2023). The therapeutic efficacy of *B. monnieri* is primarily attributed to its diverse phytochemical profile, notably the triterpenoid saponins, including bacoside A and bacoside B. Furthermore, different types of Bacoside A have been also show varied efficacies, as analysed using cell based assay with neuronal cell lines (P. Bhardwaj, Jain, et al., 2018). The diversity of habitats, for cultivation of *Bacopa monnieri*, concomitant with variability from regional practices persists not only in the metabolome but also in the concentration of bioactive compounds in the commercially available formulations(P. , Bhardwaj et al., 2016). The therapeutic evaluation, performed using *Bacopa monnieri* had been categorized to three broad categories, *viz.* in-silico analysis, in-vitro and randomized control studies using animal models or human subjects, as enlisted in Table 1.

Table 1: In-silico, In-vitro and animal studies on therapeutic potential of the bioactive compounds of *Bacopa monnieri*

S.No	Study	In-silico analysis	In-vitro / Animal study model	Outcomes of the study	References
1.	Neuroprotection (Alzheimer's)	Bacosides docking to AChE & β-amyloid targets (binding energy -8.5 to -10.2 kcal/mol)	Rat Alzheimer's model ($AlCl_3$-induced); Wistar rats (40-80 mg/kg extract)	Reduced escape latency, increased cholinergic neuron density in hippocampus; β-amyloid reduction	(Brimson et al., 2021; Gupta et al., 2024; Uabundit et al., 2010)
2.	Anti-inflammatory		Plant extract induces release of inflammatory cytokines from microglial cells and inhibits enzymes associated with inflammation in the brain.		(Nemetchek et al., 2017)
3.	Cognitive enhancement		Transgenic PS-1/AβPP mice; ethylcholine aziridinium rat model	↓ β-amyloid in brain regions; reversed learning/memory deficits	(Brimson et al., 2021)
4	Antioxidant		In-vitro antioxidant activities were compared for field acclimatized and in-vitro propagated *Bacopa monnieri*	Impact of cultivation conditions on phytocompounds and their associated bioactivities were compared	(P. Bhardwaj et al., 2019)

2. Methodology for Systematic Analysis

The systematic analysis was performed using ScienceDirect, PubMed Central and Elicit tools as a resource base, as per PRISMA guidelines on 1 April, 2026 (Fig. 1). Elicit is a free AI tool, that has been developed and used by researchers due to its accuracy and reliability in data extraction and systematic analysis (Bernard et al., 2025; Kung, 2023)

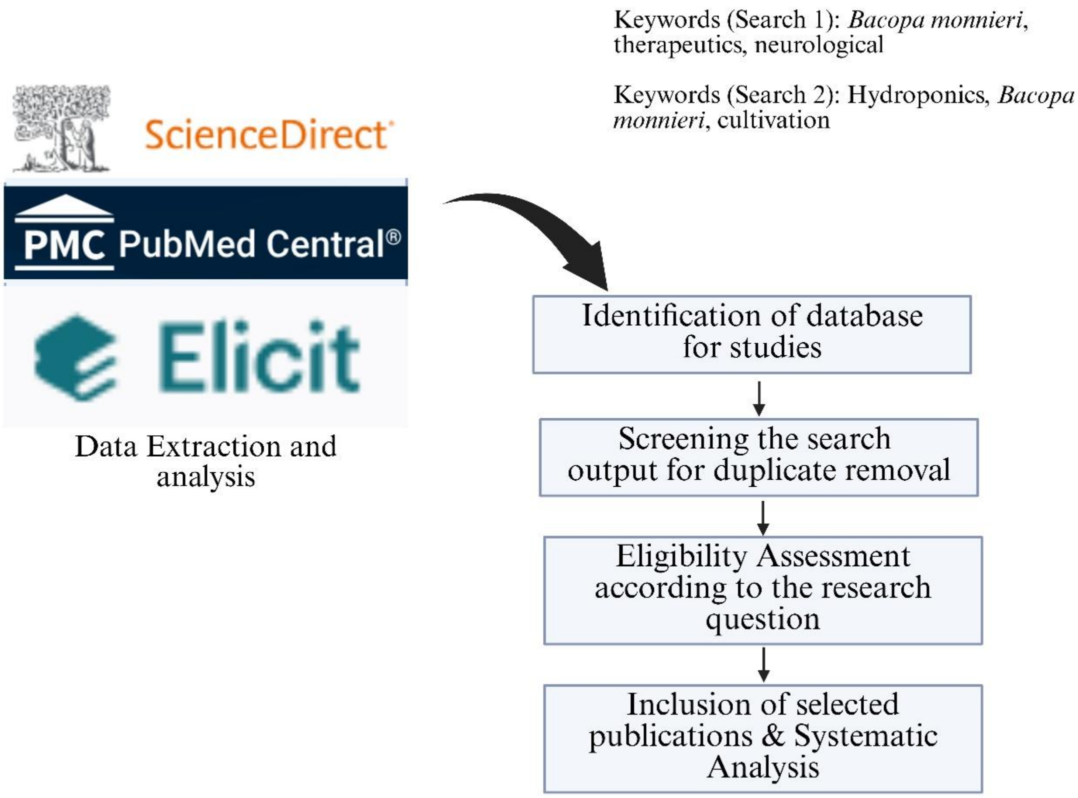

Fig. 1: Schematic for data extraction, screening and analysis using key databases

Based on the screening analysis through the leading databases, more than 3000 articles were obtained cumulatively through ScienceDirect, PubMed Central® and Elicit. The screening of data had shown publications with duplicate data, absence of full-length papers, articles not focused on the research studies and were excluded from the study. Only 17 research articles were left for systematic analysis (Fig. 2).

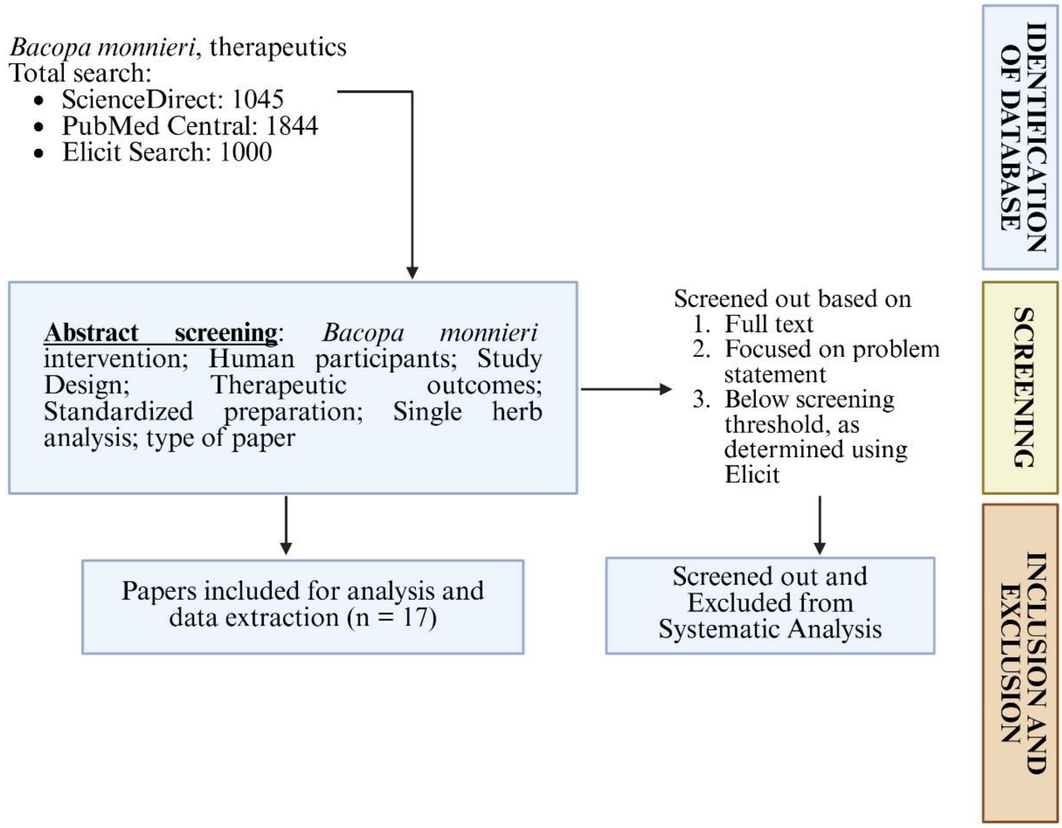

Fig.2: Systematic analysis steps for exploration of the therapeutic properties of *Bacopa monnieri*, including randomized case control (RCT) studies, human trials and studies exploring the mechanism of therapeutics conferred by the plant

The abstract screening was primarily performed with the quest to explore the information and intervention related to human participation, study design, therapeutic outcomes and type of papers which enabled the screening out of the search results, as shown in Fig 2.

Recent experimental research, spanning controlled human clinical trials and advanced in silico and in vivo mechanistic studies, confirms its diverse pharmacological activity, supporting its utility as an adaptogen and cognitive enhancer, alongside its non-neurological benefits (Gościniak et al., 2025; Pase et al., 2012).

2. Advances in Cognitive Enhancement and Memory

The most well-researched and reported therapeutic advancement of *B. monnieri* is its proven efficacy in modulating specific domains of human cognition, moving beyond the anecdotal support of *Charaka* and *Sushruta* to evidence-based memory and cognitive enhancement.

2.1. Memory Acquisition and Recall

Multiple randomized, double-blind, placebo-controlled trials (RCTs) over the last decade have consistently demonstrated the herb's ability to improve memory function, particularly tasks related to delayed word recall and memory free recall (Pase et al., 2012). Unlike traditional stimulants, the mammalian studies have reported that on administration, the *B. monnieri* based formulations require 6 to 12 weeks of consistent supplementation (often 300 to 450 mg/day of standardized extract) before significant improvements are observed (Calabrese et al., 2008; Gościniak et al., 2025). This delayed onset suggests the mechanism involves structural and adaptive changes in the neural system rather than acute modulation. While the evidence for memory is robust, recent clinical data suggests a positive effect on the speed of attention and information processing. Studies have shown improvements in tasks requiring rapid decision-making and reduced distractibility (Derbyshire, 2019), potentially through its adaptogenic action on the hypothalamic-pituitary-adrenal (HPA) axis and modulation of the GABAergic system (Gościniak et al., 2025).

3. Secondary Therapeutic Applications: Anxiety and Mood

Apart from cognition, contemporary clinical trials have reaffirmed and quantified *B. monnieri*'s traditional use as an anxiolytic (anti-anxiety) agent.

3.1. Anxiolytic and Stress-Reducing Effects

Systematic reviews and meta-analyses have well-documented that standardized *B. monnieri* extracts can significantly reduce feelings of anxiety (Derbyshire, 2019; Vijayababu, 2023). This effect is often connected to the adaptogenic properties of the herb, which help to normalize monoamine levels and corticosterone in experimental models of chronic stress. This calming effect supports its classification as a cognitive enhancer, providing an exquisite elixir for students or professionals seeking enhanced focus without the apprehension associated with caffeine or certain synthetic nootropics.

3.2. Role in Depression

Preclinical studies indicate potential antidepressant activity, demonstrated by decreased escape failures and increased avoidance responses in animal models of depression (Gościniak et al., 2025). This is hypothesized to be linked to its ability to modulate neurotransmitters (serotonin and dopamine), suggesting its potential role as a complementary therapeutic in mild depression. Though, well designed and expansive human clinical trials are highly required in this area (Pase et al., 2012).

4. Other Systemic Therapeutic Roles

In addition to its well-known central nervous system effects, *B. monnieri* enthrals significant properties that provide systemic protection, primarily due to its potent antioxidant and anti-inflammatory mechanisms.

4.1. Hepatoprotective Activity

Numerous preclinical studies have demonstrated the protective effect of *B. monnieri* extracts against various chemical-induced liver toxicities. Explicitly stating that the alcohol extract has shown a significant capacity to prevent alterations in liver antioxidant enzyme levels and reduce lipid peroxidation induced by toxins like morphine and nitrobenzene (Menon et al., 2010; Sumathy et al., 2001). This hepatoprotective activity is considered to stabilize cellular integrity and normalize serum biomarkers like Aspartate Aminotransferase (AST) and Alanine Aminotransferase (ALT) (Menon et al., 2010). Furthermore, its components exhibit potential for treating liver damage and may induce, trigger apoptosis in hepatocellular carcinoma (HCC) cells in vitro conditions (Jeyasri et al., 2020).

4.2. Cardioprotective Effects

B. monnieri has been objectively dealt as a cardiotonic in Ayurveda. Current scientific research and theories supports this, explaining that the herb's extracts exert cardioprotective efficacy, particularly in models of Diabetes mellitus. Also,the pre-treatment with the extract has been shown to preserve the histopathological architecture of the heart, reduce elevated fasting blood sugar, and normalize myocardial enzyme activity Creatine Phosphokinase (CPK), and CPK-Myocardinal Band, demonstrating a myocardial salvaging effect against damage caused by conditions associated with heightened oxidative stress (Ghatage et al., 2014; Sumathy et al., 2001).

5. Emerging Role in Neurodegenerative Disorders

A significant area of recent advancement is the investigation of *B. monnieri* components for the treatment of complex neurodegenerative disorders (NDs), where its anti-inflammatory and neuroprotective mechanisms are most significant [2].

5.1. Alzheimer's Disease (AD) and Parkinson's Disease (PD)

Preclinical and early-stage clinical work strongly suggests *that B. monnieri* secondary metabolites (bacosides) entail protective mechanisms relevant to AD and PD (Shailja Choudhary et al., 2021; Valotto Neto et al., 2024).

- **Anti-Amyloidogenic Effect:** Bacosides have shown the ability to inhibit the aggregation and limit the deposition of beta-amyloid plaques in the brain, a hallmark of AD (Gościniak et al., 2025).
- **Neuroprotection:** In PD models, extracts have been shown to delay motor impairment, reduce oxidative stress, and protect dopaminergic neurons (Valotto Neto et al., 2024) .
- **Clinical Corroboration:** One small randomised trial in patients with AD and mild cognitive impairment even suggested an effect comparable to donepezil, a conventional AD medication, highlighting a compelling need for large-scale confirmation studies (Valotto Neto et al., 2024).

6. Molecular Mechanisms of Action

The multi-faceted therapeutic effects of *B. monnieri* are underpinned by several sophisticated molecular pathways, primarily driven by the triterpenoid bacosides.

6.1. Antioxidant and Anti-inflammatory Properties

B. monnieri is a potent antioxidant, protecting neurons from oxidative stress by boosting antioxidant defence mechanisms and scavenging free radicals. This is critical for neuroprotection, as oxidative damage is a core component of both ageing and neurodegenerative pathology, and it is also the mechanism underlying its systemic protective effects in the liver and heart. Furthermore, it exerts an anti-inflammatory effect by modulating microglial cell activation and inhibiting the production of pro-inflammatory biomarkers such as TNF-alpha and IL-6 (Gościniak et al., 2025).

6.2. Synaptic Plasticity and Neurotransmission

The bacosides are known to enhance protein and RNA production in specific brain regions, notably the hippocampus, which is vital for memory (Gościniak et al., 2025). This is evidenced to:

- **Repair Neurons:** Stimulate kinase activity and upregulate neuronal synthesis, thereby repairing damaged neurons and restoring synaptic function.
- **Modulate Acetylcholine:** *B. monnieri* inflects the cholinergic system by affecting acetylcholine release, muscarinic cholinergic receptor binding, and choline acetylase activity—the enzyme responsible for synthesizing acetylcholine, a key neurotransmitter

for memory and learning.

7. Advances in Cultivation Practices

Being a nootropic plant, which is categorized as least concerned plant by IUCN, the studies have been focused toward the preservation of germplasms by using standard in-vitro tissue culture techniques and approaches for scalability of cultivation processes (P. Bhardwaj et al., 2019).

The effect of nanoparticles on the propagation of *Bacopa monnieri* and the effect on bioactive compounds, Bacosides, have also been reported. In one of the significant study the role of zinc nanoparticles has been observed in affecting the growth and bacoside yield (Bhardwaj et al., 2018). Some studies have also performed a detailed analysis of the role of tissue culture conditions on the growth of *Bacopa monnieri*. Some of the key factors, affecting the growth and metabolism of this plants includes light intensity (Aggarwal & Mathur, 2020), media supplementation by nano particles (Bhardwaj et al., 2018), and others.

The recent advances towards the propagation of this nootropic plant are focused towards exploration hydroponics, as a suitable alternative, driven by environment mediated changes in bioactive compounds composition and challenges of cultivation due to depleting cultivable land driven by globalization and industrialization.

8. Challenges and Future Directions

Despite the myriad and numerous data, shortcomings and challenges in drug development and discovery remain unanswered and the bioavailability of catalogues of bioactive compounds is a major hurdle, due to poor water solubility and bitterness of the bioactive compound bacoside A. Recent pharmaceutical advances are focused on formulation strategies, such as developing beta-cyclodextrin inclusion complexes and dispersible tablets, to enhance solubility and mask taste, thereby improving patient compliance and overall efficacy. Furthermore, computational approaches like cheminformatics and network pharmacology are being used to identify novel, highly potent phytochemicals from the herb, such as Asiatic acid and Loliolide, that can serve as leading drug candidates for complex, multi-target neurological and systemic diseases.

The plant is also one of the least concerned plant as per IUCN categorization, despite of the myriad of bioactivities associated with the plant system. Many studies have also explored the role of *Bacopa monnieri* plant for associated environmental remediation processes, including removal of heavy metals and toxicants have been explored (Dineshkumar et al., 2019; Sinha &

Chandra, 1990).

9. Conclusion

Bacopa monnieri has a strong hold on its position as a cornerstone of modern nootropics. The current state of the art confirms its clinical application in enhancing specific memory functions and reducing anxiety, while demystifying its deeper mechanistic roles in combating neuroinflammation and oxidative stress. Its protective roles across the liver and cardiovascular system strengthen its promise as a versatile, multi-target therapeutic agent. The focus has now shifted from merely verifying traditional uses to optimizing its delivery and isolating its potent metabolites as templates for contemporary, multi-target pharmaceuticals against debilitating neurodegenerative and systemic diseases. This Rasayanic herb continues to offer promising pathways for future therapeutic interventions in holistic health.

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Conflict of Interest

The authors declare no conflict of interest

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