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A review on phytochemical potential and enormous nutraceutical benefits of Brahmi (*Bacopa monnieri* L.)

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Abstract

Bacopa monnieri L., widely known as Brahmi, is a prominent medicinal herb in traditional Ayurvedic and folk healthcare systems, valued for its rejuvenating and cognition-enhancing properties. In recent years, it has gained considerable scientific interest due to its diverse phytochemical composition and broad nutraceutical potential. The plant is particularly rich in bacosidesits major bioactive constituentsalong with a wide spectrum of alkaloids, flavonoids, phenolic acids, saponins, sterols and triterpenoids. These compounds function synergistically to impart multiple therapeutic effects, notably antioxidant, anti-inflammatory, neuroprotective, adaptogenic and hepatoprotective actions. Extensive pharmacological investigations support the role of *B. monnieri* as a natural nootropic, enhancing memory retention, learning ability and mental clarity. Its neuroprotective functions are linked to modulation of cholinergic transmission, enhancement of synaptic plasticity and reduction of oxidative stress, making it a potential candidate for managing neurological conditions such as anxiety, depression, Alzheimer's disease and age-related cognitive decline. Beyond its influence on brain health, Brahmi shows significant potential in supporting systemic wellbeing through its antidiabetic, cardioprotective, antimicrobial, antiulcer and anticancer activities. Its strong antioxidant capacity contributes to cellular protection by neutralizing free radicals and boosting endogenous defense enzymes.The growing demand for plant-based nutraceuticals has positioned Brahmi as a valuable ingredient in functional foods, dietary supplements and herbal therapeutic formulations. However, achieving consistent therapeutic efficacy remains challenging due to variability in phytochemical content, influenced by environmental conditions, cultivation practices and extraction methods. Moreover, comprehensive human clinical studies remain limited, highlighting the need for standardized protocols, optimized dosage guidelines and long-term safety evaluations.This review synthesizes current knowledge on the phytochemical richness and nutraceutical value of *B.monnieri*, emphasizing its promise as a multifunctional herb for cognitive and systemic health. It also identifies existing research gaps and underscores the importance of advanced interdisciplinary investigations to fully harness Brahmi's therapeutic potential and support the development of reliable, high-quality nutraceutical products.

1. Introduction

Plants have long served as foundational resources for therapeutic applications, forming the basis of traditional medicinal systems and contributing substantially to the development of modern pharmacology. Among the extensive repertoire of medicinal plants valued across cultures, *Bacopa monnieri* L., commonly known as Brahmi, holds a distinguished place in the Indian traditional medical heritage. This small, creeping, semi-succulent perennial herb, belonging to the family Scrophulariaceae, thrives naturally in moist, marshy and waterlogged environments across India and other tropical regions. Historically, *B. monnieri* has been revered in Ayurveda as a potent Medhya Rasayana, a rejuvenative herb specifically recognized for enhancing cognitive function, mental clarity, memory retention and emotional balance (Dubey and Chinnathambi, 2019). Ancient Ayurvedic texts, including the Charaka Samhita, Sushruta Samhita and Atharva Veda, document Brahmi's use in promoting intellect (Dhi), retention (Dhriti) and recall (Smriti). Over thousands of years, practitioners have relied on Brahmi-based preparations to treat

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disorders such as anxiety, insomnia, epilepsy, cognitive impairment andbehavioral disturbances (Dubey and Chinnathambi, 2019). The herb's extensive therapeutic reputation led to its inclusion in classical formulations prepared to strengthen the nervous system, improve learning ability and restore psychological resilience.

With the evolution of modern scientific research, *B.monnieri* has re-emerged as a plant of high pharmacological interest. Among India's medicinal flora, it is now recognized as one of the most promising species in terms of therapeutic potential, phytochemical richness, commercial value and future prospects in the herbal industry. Numerous studies have confirmed its anxiolytic, antidepressant, antiepileptic, anti-inflammatory, antiulcerogenic, adaptogenic and antineoplastic properties (Thomson *et al*., 2000). Traditionally, it has also been used as a digestive stimulant, cardiotonic and respiratory aid for individuals experiencing bronchoconstriction or chronic respiratory ailments. The phytochemical diversity of *B. monnieri* underpins its wide-ranging medicinal actions. The plant is richly endowed with saponins particularly bacoside A and bacoside B which are widely regarded as the primary constituents responsible for its neuropharmacological effects. Alongside bacosides, the herb also contains alkaloids, flavonoids, sterols, phenolic acids and triterpenoids. These compounds work synergistically to enhance synaptic communication, modulate neurotransmitter activity, reduce oxidative stress and protect neuronal integrity.

Mounting evidence suggests that *B.monnieri* acts as a natural nootropic, capable of improving memory acquisition, consolidation and retrieval. Research demonstrates that the herb influences cholinergic pathways, enhances hippocampal synaptic plasticity and increases the activity of endogenous antioxidant enzymes. These effects explain its traditional use for sharpening memory and improving cognitive performance in both young and elderly groups (Thomson *et al*., 2000). Furthermore, clinical studies involving children diagnosed with ADHD have shown improvements in attention span, behavioral regulation and working memory following Brahmi supplementation.The herb's significance extends beyond cognitive enhancement. *B.monnieri* shows potential therapeutic benefits in conditions involving stress, neuroinflammation, oxidative damage and endocrine dysregulation. Its ability to modulate serotonin and dopamine levels, as well as regulate the hypothalamic pituitary adrenal (HPA) axis, highlights its role in mood stabilization and emotional support. These properties also position Brahmi as a potential natural therapy for insomnia, especially considering that conventional insomnia treatments benzodiazepines, antidepressants, anti-histamines and melatonin analogues often have adverse effects such as dizziness, daytime drowsiness, tolerance and weight gain (Sathyanarayanan *et al*., 2013).

In studies exploring its role in sleep regulation, Brahmi has demonstrated the capacity to reduce inflammatory cytokines, decrease oxidative stress and regulate neurotransmitters linked to sleepwake cycles. Bacoside A, in particular, has been shown to suppress beta-amyloid toxicity, protect neuronal cells from oxidative damage and stabilize brain inflammation, all of which are factors associated with sleep disturbances and cognitive decline (Kadali *et al*., 2014). Another emerging area of scientific interest is the detoxification and environmental remediation potential of *B. monnieri*. The herb acts as a natural chelating agent, capable of binding toxic heavy metals and facilitating their removal from biological systems. Studies have revealed its effectiveness in the phytoremediation of contaminated soils and water bodies, particularly in absorbing heavy metals like cadmium and chromium (Saha *et al*., 2020). This dual rolein human health and environmental sustainabilityexpands the relevance of Brahmi in modern science. Growing international demand for natural, plant-based nootropics and adaptogens has resulted in the widespread incorporation of Brahmi into nutraceuticals, functional foods, herbal supplements and wellness formulations. Its presence in syrups, powders, capsules, fortified beverages and anti-stress formulations demonstrates its evolving significance in global healthcare markets. However, the rapid commercialization of Brahmi also underscores the need for rigorous scientific evaluation, standardization of bacoside content, optimized extraction techniques and robust clinical safety assessments.

Despite substantial progress, several gaps persist in the scientific understanding of *B. monnieri*. Variability in phytochemical composition due to environmental factors, cultivation practices and extraction methods challenges the consistency of commercial preparations. Moreover, while a considerable body of preclinical evidence exists, more comprehensive clinical trials are essential to establish precise dosing guidelines, pharmacokinetic profiles and potential herb drug interactions. Given its immense historical, medicinal, nutraceutical and environmental significance, there is a compelling need for a systematic and comprehensive review of *B.monnieri*. Such a review would strengthen the scientific foundation for future investigations and foster advancements in herbal product development. The present work aims to explore the morphological characteristics, phytochemical profile, traditional and modern therapeutic uses, neuroprotective mechanisms and potential applications of Brahmi in food and pharmaceutical formulations (Saloni *et al*., 2022). By integrating traditional knowledge and contemporary scientific insights, this review highlights the remarkable value of *B. monnieri* and underscores its growing importance in global health research.

2. Taxonomical classification

B. monnieri is a small, succulent, creeping herb that belongs to the kingdom Plantae, representing all multicellular green plants. It is placed in the division Magnoliophyta, indicating its status as a true flowering plant. As a member of the class Dicotyledonae, it produces seeds with two cotyledons and within the subclass Gamopetalae, it is recognized for having flowers with united petals. The plant is taxonomically grouped under the family Scrophulariaceae, which includes many medicinally important species. Within this family, it forms part of the genus Bacopa, a group of moisture-loving herbs often found in wetlands and marshy habitats. The species *monnieri* is distinct for its fleshy leaves, prostrate growth habit and notable medicinal qualities, making it widely valued in traditional healing systems such as Ayurveda for its cognitive and restorative benefits.

3. Biological description

The plant is initially succulent in its fresh form but gradually shrivels upon drying, resulting in a mixture of broken and interwoven fragments of roots, stems, leaves, flowers and a few delicate fruits. It possesses a mildly bitter taste and is devoid of any distinct aroma (Thorat *et al*., 2018). The roots are represented by dried primary fragments that are off-white, cylindrical and approximately 5 mm in diameter, marked by characteristic longitudinal wrinkles. The stem is smooth and cylindrical with prominent nodes and is ventrally connected to clusters of brittle, twisted roots; it may also bear vertically growing branches. The internodes are light yellowish-green with a purplish tint, ranging from about 1-21.5 cm in length and 3-5 mm in width (Thorat *et al*., 2018). The leaves are simple, glabrous, oblong, arranged oppositely in a decussate pattern and measure between 0.6-2.5 cm in length. The flowers occur singly in the axils, are nearly regular and display a light blue to pinkish-white hue. They measure 0.6-3 cm in length typically longer than the leaves and feature a deeply five-lobed corolla, a short pedicel, a smooth calyx and two linear bracteoles. The floral structure includes a syncarpous pistil with two chambers containing numerous ovules, a style ending in a bilobed stigma, four didynamous stamens and two-celled anthers (Thorat *et al*., 2018). The fruit consists of a globose to ovoid capsule enclosed by a smooth, persistent calyx measuring 1-3 cm in length; the capsule itself is about 5 mm long and contains many min, irregular, oblong seeds, each less than one centimeter wide (Saha *et al*., 2020).

4. Formulation of brahmi in ayurveda

Brahmi capsule: Made from an extract of the brahmi plant (*B. monnieri*), brahmi capsules are packed with health-promoting qualities and only natural, pure, organic components. In addition to treating a number of nervous system issues, Brahmi Ayurvedic medicine also helps with stress, anxiety and sleep disturbances. Dosage: Take one or two capsules with milk or water, twice a day, after meals (Mishra *et al*., 2013).

Brahmi oil: Because it lessens hair loss, brahmi oil is beneficial for hair. Additionally, it stimulates the formation of new hair and fortifies hair follicles. It lessens dandruff and stops hair from graying too soon. This oil has benefits for your hair in addition to being a well-known natural sleep aid and stress reliever. It also relieves joint pain and aids in the healing of mouth ulcers. Finally, brahmi oil maintains healthy, radiant skin and helps with digestion. It is applied to massage joints and alleviate pain and arthritis (Gubbannavar *et al*., 2012).

Brahmi juice: Brahmi juice is most well-known for its memory-enhancing properties, but it can also lessen anxiety and insomnia, boost intelligence and aid with focus and alertness. Ingredients: Brahmi stems and leaves, a small handful of pudina or mint leaves (optional), two tsp lemon juice, one and a half tsp honey and three glasses of water. Prepare by blending brahmi in a grinder with pudina or mint. Grind in a glass of water. Once the mixture is in the saucepan, bring it to a boil over medium heat until bubbles form. Once the temperature reaches room temperature, turn off the heat. Add the optional honey and lemon juice now. After that, pour in two more glasses of water and serve. One uses brahmi juice as a dietary supplement. It enhances learning and gives neurons nourishment. It improves sharpness and learning capacity. Brahmi's alkaloids, namely bacopasides, are what give it its memory enhancing properties. Use as directed: Take 30 or 60 milliliters before meals once a day, either straight or diluted with water (Mishra *et al*., 2013).

Brahmi powder: A concentrated form of the Brahmi herb, known for its ability to improve cognitive wellbeing. To make the powder, the leaves are carefully dried and ground. Brahmi powder, also known as *B. monnieri*, is a plant with antioxidant and anti-inflammatory properties. It is packed with vitamins and minerals that support healthy brain function and mental clarity. One Ayurvedic Brahmi powder treats both the brain and the nervous system, strengthening the nervous system as a whole. Brahmi powder is used as a Rasayana and improves the body's nutritional condition. The chemical makeup of brahmi has a relaxing impact on the mind, improves mental function, reduces stress, anxiety and sadness and promotes restful sleep (Deo and Reddy, 2012).

5. Phytochemical composition of *B. monnieri*

5.1 Overview of traditional use and phytochemistry

B. monnieri commonly known as Brahmi, occupies a central place in Ayurvedic, Siddha and Unani systems of medicine, where it has been traditionally used as a brain tonic, memory enhancer and rejuvenating herb for centuries. Ancient Ayurvedic texts describe Brahmi as a *medhyarasayana* a class of herbal formulations known to enhance intellect and cognitive function. Historically, the plant has been recommended for treating conditions such as epilepsy, anxiety, poor cognition, chronic inflammation, asthma, fever and general debility. Its revered status in indigenous medicine prompted a substantial amount of modern phytochemical and pharmacological investigation (Pandey *et al*., 2022). The therapeutic qualities of Brahmi are attributed to its rich phytochemical profile, which includes saponins, triterpenoids, alkaloids, flavonoids, phenylethanoid glycosides, amino acids, sterols and essential minerals. These diverse phytoconstituents act synergistically, contributing to the plant's broad pharmacological spectrum encompassing neuroprotection, anti-inflammatory action, antioxidant defense and memory enhancement. Scientific research into the phytochemistry of *B. monnieri* began as early as the mid-19th century, with initial studies reporting the isolation of alkaloids such as brahmine, herpestine and nicotine. Subsequent investigations expanded the list of bioactive compounds, revealing several classes of saponins, glycosides, flavonoids, sterols and small organic molecules (Parveen *et al*., 2016). In particular, two groups of steroidal saponins bacoside A and bacoside B have been consistently linked to the nootropic and neuroprotective actions of the plant. These compounds, along with related saponins such as bacopasides, bacopasaponins and bacopasides I-XII, contribute significantly to the pharmacological potency of Brahmi. Modern analytical techniques, including HPLC, LC-MS/MS, NMR spectroscopy and chromatographic profiling, have deepened the understanding of these compounds' structural diversity, bioavailability and interactions with biological targets. Thus, the phytochemical richness of *B. monnieri* not only supports its traditional applications but also positions the herb as a promising candidate in contemporary drug discovery.

5.2 Major bioactive groups in *B. monnieri*

5.2.1 Saponins and bacosides

Saponins constitute the most extensively studied class of phytochemicals in *B. monnieri*, with bacosides considered the principal contributors to its cognitive enhancing and neuroprotective actions. Bacoside A is not a single molecule but a mixture of saponin glycosides, including bacoside A3, bacopaside II, bacopasaponin C and the aglycone jujubogenin or pseudojujubogenin. Similarly, bacoside B represents a closely related mixture of triterpenoid saponins. These compounds are believed to work synergistically to improve synaptic communication, enhance neuronal repair and stabilize neural membranes. Structurally, bacosides are amphipathic molecules that contain both hydrophilic sugar moieties and hydrophobic aglycone portions, enabling them to interact with lipid bilayers. This structural feature enhances their ability to penetrate the blood brain barrier and modulate neuronal activity (Pandey *et al*., 2022). In addition to bacosides A and B, a series of related compounds called bacopasides (I-XII) have been identified. These saponins demonstrate a wide array of biological properties, including free-radical scavenging, anti-inflammatory activity, modulation of neurotransmitter systems and regulation of neuronal calcium dynamics. Early reports established that bacosides enhance memory through actions on serotonin, acetylcholine and glutamate receptors, while more recent studies point to their ability to regulate expression of neurotrophic factors and protect against β-amyloid toxicity (Silpa *et al*., 2019). The unique structural variety of saponins in Brahmi makes them key chemotaxonomic markers and central to the plant's pharmacological identity.

5.2.2 Alkaloids

Alkaloids are among the earliest documented phytochemicals isolated from *B. monnieri*. Brahmine, herpestine and nicotine have been consistently reported in classical phytochemical studies (Bhardwaj *et al*., 2016). These nitrogenous compounds possess diverse biological activities, including mild anxiolytic effects, antispasmodic action and modulation of neurotransmission. Although, present in smaller quantities than saponins, alkaloids contribute to the complex pharmacological matrix of Brahmi. Herpestine has attracted attention for its potential antioxidant and neuroprotective actions, while brahmine has been linked to sedative and anticonvulsant properties. The role of alkaloids in enhancing cholinergic function and protecting neurons from oxidative imbalance, although less explored than saponins, provides an additional layer of bioactivity.

5.2.3 Flavonoids and polyphenols

Flavonoids and phenolic compounds are integral to *B. monnieri*'s medicinal value due to their pronounced antioxidant properties. Compounds such as luteolin, apigenin, quercetin and their glycosides have been identified, along with phenylethanoid glycosides like acteoside (verbascoside). These molecules exhibit strong free-radical-scavenging capabilities, inhibit lipid peroxidation and modulate oxidative stress pathways associated with aging and neurodegeneration (Jain *et al*., 2017). Phenolics in Brahmi also modulate inflammatory pathways by suppressing enzymes such as COX-2 and downregulating pro-inflammatory cytokines. Moreover, flavonoids enhance cerebral blood flow, support synaptic plasticity and protect against excitotoxicity, thereby reinforcing the plant's cognition enhancing properties.

5.2.4 Terpenoids and glycosides

Terpenoids, including monnierin, hersaponin and various diterpenes, have been detected in *B. monnieri*. These compounds often exhibit antimicrobial, anti-inflammatory and antioxidant activities. Terpenoid glycosides contribute to the plant's adaptogenic and stress-modulating properties, while several minor glycosides enhance bioavailability and support synergistic interactions among major phytochemicals. The plant's glycosidic molecules stabilize cell membranes, modulate enzyme activity, influence mitochondrial function and protect against oxidative stress. Their structural diversity contributes to the complex biochemical matrix of Brahmi and enhances its therapeutic versatility.

5.2.5 Amino acids, sterols and other phytoconstituents

Amino acids such as aspartic acid, glutamic acid, β-alanine and serine have been reported in *B. monnieri*, along with sterols such as β-sitosterol and stigmasterol (Parveen *et al*., 2016). These compounds support general neurophysiology by participating in neurotransmitter synthesis, membrane fluidity modulation and synaptic signaling. β-sitosterol, for instance, exhibits anti-inflammatory and neuroprotective actions, while glutamic acid plays a central role in excitatory neurotransmission. Additional phytochemicals such as D-mannitol, potassium salts and various sugars contribute to osmotic balance, antioxidant defense and metabolic regulation. Together, these constituents reinforce the therapeutic value of Brahmi by contributing to both systemic and neurological health.

5.3 Chemical diversity and chemotaxonomic significance

The chemical diversity of *B. monnieri* reflects its evolutionary adaptation to diverse ecological niches and contributes to its broad pharmacological spectrum. Variations in bacoside content have been observed across geographical regions, growth conditions and harvest stages. These chemotypic differences have implications for both therapeutic efficacy and standardization of herbal formulations. Bacosides serve as important chemotaxonomic markers due to their specificity, structural complexity and relative abundance in the plant. Research has shown that environmental factors such as salinity, soil nutrient composition, light intensity and water availability significantly influence saponin concentration, phenolic levels and antioxidant capacity. Chemotaxonomic evaluations also highlight the ecological significance of phytochemical diversity. For example, saponins may protect the plant from herbivory and microbial infection, while phenolics help mitigate oxidative stress induced by environmental factors. Understanding these variations is essential for developing standardized extracts, ensuring clinical efficacy and guiding commercial cultivation programs aimed at optimizing phytochemical yield. Modern metabolomic tools allow for precise profiling of *B. monnieri* chemotypes and help identify elite genotypes with high levels of therapeutically relevant compounds.

5.4 Extraction, isolation and characterization approaches

Advances in extraction and analytical technologies have significantly deepened the understanding of *B. monnieri*'s phytochemical profile. Traditional extraction methods employed aqueous or alcoholic solvents to prepare decoctions, infusions and tinctures. However, modern methods employ gradient elution, supercritical fluid extraction, ultrasonic-assisted extraction and microwave-assisted extraction to enhance the yield and purity of bioactive compounds. Ethanol-water mixtures are commonly used for isolating saponins, while methanol extracts are often rich in flavonoids.

For purification of bacosides and related saponins, techniques such as column chromatography, high-performance liquid chromatography (HPLC), preparative TLC and solid-phase extraction have been widely adopted. Recent advances using LC-MS/MS and UPLC provide high-resolution separation and accurate quantification of complex saponin mixtures. Nuclear magnetic resonance (NMR) techniques further elucidate structural configurations, stereochemistry and linkage patterns among the glycosides. These analytical tools have made it possible to isolate pure compounds such as bacoside A3, bacopaside I, bacopaside II and jujubogenin derivatives, enabling targeted pharmacological investigations and the development of standardized formulations.

5.5 Pharmacological relevance of key phytochemicals

The pharmacological spectrum of *B. monnieri* is directly linked to the activities of its diverse phytochemicals. Bacosides enhance memory and learning by improving synaptic transmission, stabilizing neuronal membranes and promoting dendritic branching. These compounds also reduce β-amyloid accumulation and attenuate oxidative damage in neuronal cells. Alkaloids contribute to anticonvulsant, anxiolytic and neuromodulatory effects, supporting traditional uses of the plant in treating epilepsy and anxiety. Flavonoids and phenolics act as potent antioxidants that protect neuronal lipids, proteins and DNA from free radical induced degeneration. Sterols and diterpenes support anti-inflammatory activity by modulating prostaglandin synthesis and cytokine expression. The synergistic interactions among saponins, flavonoids, sterols and alkaloids amplify the therapeutic effects of Brahmi. These interactions contribute to its adaptogenic potential, enabling the plant to modulate stress responses, stabilize neurotransmission and protect against neurodegeneration. The combined actions of these compounds validate the traditional claims regarding Brahmi's role in improving cognition, enhancing resilience to stress and supporting overall neurological well-being.

5.6 Mode of action of bioactive compounds from *B. monnieri*

The therapeutic potential of *B. monnieri* is deeply rooted in the multifaceted mechanisms through which its phytochemicals modulate cellular, molecular and systemic pathways. The interactions of bacosides, alkaloids, flavonoids, sterols and glycosides with neuronal receptors, enzymes, signaling cascades, neurotransmitters and inflammatory mediators collectively underpin the plant's well-documented neuroprotective and cognitive-enhancing actions. Unlike single-target synthetic drugs, the phytochemical matrix of Brahmi exerts broad and complementary effects, enabling it to influence multiple aspects of brain function simultaneously including oxidative balance, cholinergic activity, synaptic plasticity, neuroinflammation, mitochondrial efficiency and neuroendocrine regulation. These diverse mechanisms contribute not only to the plant's adaptogenic profile but also to its effectiveness in neurological conditions such as Alzheimer's disease, Parkinson's disease, schizophrenia and age-associated cognitive decline (Chaudhari *et al*., 2017; Pandey *et al*., 2022). The following subsections provide an in-depth analysis of the molecular, cellular and systemic mechanisms through which *B. monnieri* exerts its pharmacological effects.

5.6.1 Molecular targets in the nervous system

The bioactive constituents of *B. monnieri* interact with a spectrum of molecular targets in the brain, including neurotransmitter receptors, synaptic proteins, ion channels and intracellular signaling molecules. Bacosides modulate the function of muscarinic acetylcholine receptors, nicotinic receptors, NMDA glutamate receptors and serotonin (5-HT) receptors, thereby influencing synaptic transmission and promoting long-term potentiation (Dethe*et al*., 2016). They also regulate kinase pathways such as ERK, CaMKII, PI3K/Akt and CREB, all of which are critical for memory consolidation, neuronal survival and synaptic growth. Through these interactions, bacosides enhance synaptogenesis and neuritogenesis, facilitating improvements in learning and memory. Flavonoids in *B. monnieri* target inflammatory enzymes, modulate microglial signaling and influence transcription factors such as NF-κB and Nrf2. These interactions result in reduced oxidative stress, suppression of neuroinflammation and enhanced cellular resilience. Alkaloids like herpestine contribute additional neuromodulatory activity by influencing calcium channels, supporting neurotransmitter release and stabilizing neuronal firing patterns. Thus, the molecular targets of Brahmi's phytochemicals encompass both neurochemical and structural components of brain function, positioning it as a multi-target neurotherapeutic.

5.6.2 Antioxidant and free radical scavenging mechanisms

Oxidative stress is a central contributor to neurodegenerative diseases, cognitive decline and mitochondrial dysfunction. The brain's high oxygen consumption and abundance of polyunsaturated fatty acids make it particularly vulnerable to oxidative injury. *B. monnieri* enhances the intrinsic antioxidant defense system by elevating the activity of primary enzymatic antioxidants such as superoxide dismutase, catalase and glutathione peroxidase. It also increases levels of glutathione (GSH), a major intracellular antioxidant that protects neurons from oxidative insults (Jain *et al*., 2017). Bacosides reduce lipid peroxidation, DNA fragmentation and protein carbonylation, thereby preserving membrane integrity and preventing oxidative damage. Flavonoids such as luteolin and apigenin scavenge reactive oxygen species, inhibit free radical chain reactions and chelate transition metals that catalyze oxidative processes. The combined antioxidant activity of these compounds supports mitochondrial health, enhances ATP synthesis and reduces the accumulation of oxidative by-products associated with aging and neurodegeneration. Furthermore, *B. monnieri* modulates Nrf2 signaling, promoting the transcription of antioxidant response elements and reinforcing cellular detoxification pathways.

5.6.3 Cholinergic modulation and synaptic plasticity

The cholinergic system plays a central role in attention, memory and cognition. Dysfunction of cholinergic neurotransmission is a hallmark of Alzheimer's disease and age related cognitive impairment. Several studies have demonstrated that *B. monnieri* enhances cholinergic activity by increasing acetylcholine levels in the hippocampus, inhibiting acetylcholinesterase and stimulating choline acetyltransferase activity (Dethe *et al*., 2016). These actions improve synaptic transmission and promote long-term memory formation. Bacosides also enhance synaptic plasticity by increasing the expression of synaptic proteins such as synapsin I, PSD-95, MAP-2 and neurofilament proteins. Through the activation of CREB (cAMP-response element-binding protein) and other transcription factors, bacosides stimulate dendritic branching, synaptogenesis and hippocampal neurogenesis. These structural changes support sustained improvements in learning ability, attention span and working memory, as confirmed by both animal and human studies. The synergistic action of cholinergic modulation and synaptic plasticity enhancement distinguishes *B. monnieri* from many nootropic agents with narrower mechanisms.

5.6.4 Anti-inflammatory mechanisms and microglial modulation

Neuroinflammation is a major pathological process contributing to neuronal degeneration, synaptic loss and cognitive dysfunction. Microglial cells, the resident immune cells of the brain, play a central role in orchestrating inflammatory responses. When activated excessively, microglia release pro-inflammatory cytokines such as

TNF-α, IL-1β and IL-6, generating neurotoxic environments that exacerbate neurological disease. *B. monnieri* exerts a potent anti-inflammatory effect by suppressing microglial activation and inhibiting the release of inflammatory mediators. Chaudhari *et al.* (2017) demonstrated that Bacopa extracts and bacoside A significantly reduced the secretion of TNF-α and IL-6 in activated microglial cultures. This suppression is mediated through the inhibition of NF-κB signaling, reduction of COX-2 expression and downregulation of inducible nitric oxide synthase (iNOS). The overall effect is the attenuation of chronic neuroinflammation, preservation of neuronal integrity and enhancement of cognitive resilience. These mechanisms are particularly relevant in conditions such as Alzheimer's disease, Parkinson's disease and neuropathic pain syndromes.

5.6.5 Effects on β-amyloid and tau pathology

β-Amyloid aggregation and tau hyperphosphorylation are defining features of Alzheimer's disease. Bacosides interfere with the amyloidogenic pathways by inhibiting the formation of Aβ oligomers and fibrils, reducing their interaction with neuronal membranes and promoting their clearance. In SH-SY5Y neuronal cells, bacoside A inhibited Aβ42 fibrillation, reduced cytotoxicity and protected membrane integrity (Kulkarni, 2021). In addition to modulating amyloid pathology, *B. monnieri* influences tau phosphorylation pathways by regulating kinases such as GSK-3β and CDK5, thereby preventing the destabilization of microtubules. These actions collectively reduce synaptic loss, enhance neuronal survival and slow the progression of Alzheimer's pathology. By targeting both amyloid and tau pathways, *B. monnieri* demonstrates a multi-dimensional neuroprotective potential superior to conventional single-target agents.

5.6.6 Regulation of neurotransmitters

Neurotransmitter balance is essential for mood regulation, cognition, stress response and motor functions. *B. monnieri* modulates multiple neurotransmitter systems, including dopamine, serotonin, glutamate and GABA. Chronic administration has been associated with increased serotonin and decreased norepinephrine levels, contributing to its anxiolytic and antidepressant effects (Piyabhan *et al.*, 2019). In models of Schizophrenia, Brahmi co-administration with antipsychotics improved dopaminergic balance and enhanced therapeutic outcomes. Flavonoids and saponins in Brahmi help regulate glutamate signaling by reducing excitotoxicity, stabilizing calcium homeostasis and enhancing NMDA receptor function. These neurotransmitter-modulating effects contribute to improved mood, better memory consolidation and healthier neural circuitry.

5.6.7 Modulation of the HPA axis and stress response

Chronic stress disrupts the hypothalamic pituitary adrenal (HPA) axis, elevating cortisol levels and impairing memory, mood and immune function. *B. monnieri* acts as an adaptogen by stabilizing HPA axis activity and reducing levels of circulating cortisol. Bacosides protect neurons in the Hippocampus a region highly sensitive to stress hormones thereby preventing stress-induced cognitive decline (Chaudhari *et al.*, 2017). The herb's ability to regulate stress responses also supports its historical use as a tonic for children and aging individuals. By reducing physiological and psychological stress markers, Brahmi improves attention, learning and emotional stability.

5.6.8 Neuroprotection, learning and cognitive enhancement

The cumulative effect of antioxidant, anti-inflammatory, neurotransmitter-modulating and synaptogenic pathways confers strong neuroprotective properties upon *B. monnieri*. Saloni *et al.* (2022) demonstrated that long-term administration of *B. monnieri* (100 mg/kg) significantly improved memory, reduced oxidative stress and restored ATPase activity in animal models of Alzheimer's disease. Bacosides enhance learning by supporting hippocampal neurogenesis, increasing synaptic density and improving neural signaling efficiency. In human clinical trials, chronic supplementation with standardized Bacopa extracts improved working memory, attention, processing speed and learning ability. The herb also reduced anxiety and mental fatigue in cognitively demanding tasks, demonstrating its dual role as a neuroprotective and cognitive enhancing agent.

5.6.9 Bioavailability, pharmacokinetics and blood brain barrier penetration

The pharmacokinetics of *B. monnieri* are influenced by its lipophilic constituents, particularly bacosides, which readily cross the blood–brain barrier by dissolving in neuronal lipid membranes. This property enhances their ability to modulate synaptic function directly within the central nervous system (Pandey *et al.*, 2022). Bacosides are metabolized into active aglycones that accumulate in neural tissues, prolonging their neuroprotective effects. Although oral bioavailability varies depending on extraction methods and formulation, advances in phytochemical standardization and nano-delivery systems have significantly improved uptake and tissue distribution. Understanding these pharmacokinetic parameters is crucial for optimizing therapeutic applications and designing effective clinical dosages. Release of Ca^{2+} and Hypertroph (Aithal and Rajeswari, 2019)

6. Neuroprotective activity of brahmi

B. monnieri is thought to include a major nootropic component called bacosides, which are dammarane kinds of triterpenoid saponins with pseudojujubogenin moieties acting as aglycone units. According to Deolankar *et al.* (2023) 12 analogs are recognized within the family of bacosides. More recently, 39 novel saponins known as bacopasides I-XII have been discovered Choudhary *et al.* (2021). The list includes the alkaloids d-mannitol, apigenin, hersaponin, monnierasides I-III, cucurbitacins and plantainoside B (Aguiar and Borowski, 2013). Other alkaloids include brahmine, nicotine and herpestine.43-50 The component that has been investigated the most is bacoside A, which is a combination of bacoside A3, bacopaside II, bacopa saponin C and an isomer of baco saponin C called jujubogenin (Ayyathan *et al.*, 2015). The plant extract used in these tests is entire andthe concentration of bacosides varies depending on the section of the plant that is extracted. When free radicals chemical entities with unpaired electrons created during normal metabolism overcome a cell's homeostatic defensive mechanisms, oxidative stress (OS) results. Enzymes that quench free radicals and provide protection include glutathione reductase (GSR), superoxide dismutase, catalase and glutathione peroxidase GPx(Phukan *et al.*, 2015). Antioxidant substances, such as vitamins A, C and E and a variety of phytonutrients (especially phenols), also have a major protective effect. By destroying ligands, peroxidizing lipids, upsetting metabolic processes, denaturing proteins and shattering DNA strands, Oxidative stress contributes to a variety of illnesses, including ageing itself (Shalini *et al.*, 2021).

6.1 Neurotheological activity of brahmi

When free radicals chemical entities with unpaired electrons created during normal metabolism overcome a cell's homeostatic defensive mechanisms, oxidative stress (OS) results. Superoxide dismutase, catalase, glutathione peroxidase (GPx), glutathione reductase (GSR) and other enzymes are protective, free radical quenching agents. Antioxidant substances such as vitamins A, C and E and a variety of phytonutrients (especially phenols), also have a major protective effect (Hosamani, 2009). By destroying ligands, peroxidizing lipids, upsetting metabolic processes, denaturing proteins and shattering DNA strands, OS contributes to a variety of illnesses, including aging itself (Choudhary *et al*., 2021).

7. Cognitive enhancement and memory improvement in brahmi

A course of modest and prolonged treatment of *B. monnieri* appears to nourish rather than deplete neurons, in contrast to the potentially addictive and strong impact of commonly used psychostimulants. This activity is consistent with 1400 years of Ayurvedic research. In writings like the Charaka Samhita, Athar-Ved and Susrutu Samhita, BM was first mentioned in the sixth century A.D. as a medhya-rasayana class herb used to hone intelligence and lessen mental impairments (Khot *et al*., 2022).

In the United States, an estimated 3.4 million people suffer with dementia, with the elderly being the most affected population. By 2030, the number of people over 65 is predicted to double, making up 72 million people, or 20% of the country's overall population. *B. monnieri* exhibits significant clinical promise for the reduction of dementia through many pathways, including dose dependent acetylcholine potentiation and scavenging of free radicals. *B. monnieri* showed a median lethal dosage (LD_{50}) of 2400 mg/kg and a no-observed adverse effect level (NOAEL) of 500 mg/kg in a 90day oral administration study in rats. The typical daily dose for human experimentation is 150-3000 mg equivalent. Mild gastrointestinal distress is the most frequent clinical adverse effect of *B. monnieri*, yet there are not enough long-term clinical investigations (Aguiar and Borowski, 2013).

Studies on human ability to improve cognitive function was shown in 2014. After taking in a modest (17 patient) randomized control experiment, *B. monnieri's* one dose of bacopa (320 mg and 640 mg), they observed statistically significant improvements in mood, reduced cortisol response from stress and increased cognitive function (mental arithmetic, Stroop, word search and visual tracking). The 640 mg dosage had a more pronounced effect. A different small study (30 individuals) examined the effects of a daily dose of 450 mg in healthy people over the course of a 12-week period; the results showed that there was a trend toward decreased anxiety in the Bacopa group but no discernible change in the scores on cognitive tests (learning and memory, information processing) (Stough *et al*., 2001).

Nine randomized controlled trials with 437 participants were included in the meta analysis, which showed faster attention and cognition as well as faster reaction times. A 300 mg standardized extract of either Bacopa or a placebo was administered to patients (54 adults) in a randomized, double-blinded, placebo-controlled research. Assessments of attention, memory and psychological state were used to get measurements both before and after a 12-week study. In comparison to the placebo, the treated group showed improved delayed word recall memory scores and a higher capacity to ignore irrelevant information (Stroop's test) (Sathyanarayanan *et al*., 2013).

In a randomized, double-blinded trial on memory acquisition, 81 persons 55 years of age and above were included. The results showed that a 12-week cycle of Bacopa dramatically increased memory retention and acquisition in older, healthy Australians (Watthan-asuebsin and Sittiprapaporn, 2017). The results of six investigations lasting 12 weeks or more were combined into a meta-analysis, which revealed that bacopa enhanced memory-free recall but had no effect on other cognitive functions. A dosage of 300-450 mg of bacopa extract standardized to 10-20% bacopa glycosides was utilized in these investigations (Uabundit *et al*., 2010). Bacopa has been demonstrated to have anxiolytic properties in elderly patients. In double blind, randomized clinical trials, bacopa and gotu kola (*Centella asiatica*) have been demonstrated to successfully alleviate general anxiety symptoms.

Enhancement of cognition usually comes with a psychological and toxic cost. At regular concentrations, the milieu of nootropic phytochemicals presents in *B. monnieri,* primarily triperpenoid saponins known as bacosides, show negligible deleterious effects. Antioxidant, hepatoprotective and neuroprotective properties are demonstrated by *B. monnieri*. A number of mechanisms of action, including acetylcholinesterase inhibition, choline acetyl-transferase activation, b-amyloid reduction, improved cerebral blood flow and monoamine potentiation, are demonstrated by emerging research (McPhee *et al*., 2016).

Eighty percent of the world's population regularly uses herbal medicine and its use is growing in North America and Europe. In the past year, 17.7% of treatments provided by complementary and alternative medicine (CAM) have included herbal medication. Higher educated people are more likely to use complementary and alternative medicine (CAM); this may be partly due to the fact that public health insurance, which is typically unavailable to the poor, does not cover CAM. Despite being less standardized, herbal medication is typically less expensive than pharmaceuticals. Western biomedicine is currently exploring the Eastern pharmacopeia's possible utility. 118 of the 150 most popular pharmaceutical medications in the US were made from plants. Conventional medical systems include an extensive array of neurological agents that may be therapeutic. However, thorough experimental research on *B. monnieri* is still in its early stages (Aguiar and Borowski, 2013).

8. Clinical studies and research findings of brahmi

8.1 Ethnopharmacology

It is bitter, astringent and has cooling qualities. It is also said to enhance one's intelligence. It is frequently used to treat a variety of conditions, including epilepsy, heart problems, anemia, dermatitis, asthma, hoarseness and diabetes. It is also used as a blood purifier for boils and for problems related to cataracts. The entire plant is used medicinally; for example, children can take leaf juice to treat bronchitis and diarrhea; rheumatism can be treated with leaf paste; in west Bengal, people are known to eat the leaves and tender stalks; and cough disorders can be treated with leaf decoction. Additionally, it has been noted to be a safe heart tonic and to relieve anxiety neurosis in patients when combined with sugar, bark and ginger juice (Shukia *et al*., 1987).

8.2 Antianxiety and stress relieving power

8.2.1 Antianxiolytic properties

When Brahmi leaf is consumed, the active ingredients of *B. monnieri* raise serotonin levels in the brain, relieving anxiety, nervousness and sadness and promoting mental relaxation (Khot *et al*., 2022). Brahmi has anxiolytic (anti-anxiety) properties that may aid with anxiety management. It might alleviate the symptoms of mental exhaustion and worry. Furthermore, Brahmi may be able to stop neuroinflammation, which is the root cause of anxiety. An inflammation of the neurological system is called neuroinflammation. Brahmi is useful in alleviating anxiety symptoms and indications. Vata is said to control the nerve system in Ayurveda. Anxiety is mostly caused by imbalance. Brahmi balances therefore soothing the nervous system (Saloni *et al*., 2022).

8.2.2 Antidepressant properties

Brahmi leaf extract at doses of 80 mg/kg demonstrated a significant response of anxiolytic effects, while the methanolic extract of *B. monnieri* at doses of 100 and 200 mg/kg was found to exhibit potential antidepressant effects and enhanced motility (Saloni *et al*., 2022). In rodents, *B. monnieri* methanolic extract may have antidepressant effects. The extract was found to have considerable antidepressant action in forced swim and learned helplessness models of depression when given in the dose of 20 and 40 mg/kg, orally for 5 days (Ramanamurty Kadali *et al*., 2014).

8.3 Antioxidant properties

Antioxidants have been shown to counteract oxidative damage from free radicals, which causes a variety of human illnesses including arthrosclerosis, diabetes mellitus, hypertension, arthritis, Alzheimer's disease, ischemic gastritis and AIDS. Bacopa's antioxidant qualities can help protect against free radical damage in cardiovascular disease and certain forms of cancer (Banerjee *et al*., 2021). Reportedly, bacosides scavenge free radicals such as superoxides, peroxides and hydroxyl radicals. The antioxidant effects of alcoholic and hexane extracts of *B. monnieri* on lipid peroxidation by cumene hydroperoxide and ferrous sulphate have been documented in rat homogenate liver (Russo *et al*., 2003).

Bacosides were discovered to have antioxidant activity in the hippocampus, frontal cortex and striatum based on animal studies, as well as to modulate the expression of certain enzymes involved in the generation and scavenging of reactive oxygen species in the brain. Bacoside A3 was also shown to have an inhibitory effect on superoxides released from polymorphonuclear cells in a nitroblue tetrazolium assay in a hydroalcoholic extract of the whole plant (Russo and Borrelli, 2005). Sumathy *et al*. (2001) investigated the hepatoprotective efficacy of an orally administered alcoholic extract on the liver antioxidant state of morphine-treated rats. The methanolic extract protects rat astrocytes against the toxicity caused by the NO donor (S-nitroso-Nacetyl-penicillamine, SNAP), reducing DNA damage (Saha *et al*., 2020). Janani *et al*. (2009) found that the herb protected the rat brain's hippocampus from aluminum-induced oxidative damage. The plant's methanolic extract's free radical scavenging action protected non-immortalized human cells against DNA damage.

8.4 Anti-inflammatory properties

B. monnieri substantially inhibited experimentally produced inflammatory reactions by decreasing prostaglandin synthesis and, in part, maintaining lysosomal membranes, while causing little stomach distress at anti-inflammatory doses. The methanol extract of the whole plant significantly inhibited acetic acid-induced writhing in mice at oral doses of 250 and 500 mg/kg ($p<0.001$), comparable to 25 mg/kg diclofenac sodium. The anti-inflammatory effects of various *B. monnieri* extracts on carrageenan-induced edema in the hind paws of rats were studied (Mathur *et al*., 2010). The methanol extract and aqueous fractions (100 mg/kg) significantly reduced the volume of edema paw; however, hexane extracts and petroleum ether did not diminish inflammation (Saha *et al*., 2020). *B. monnieri* has anti-inflammatory properties that are also observed in macrophages. As the primary line of defense against infections caused by pathogens or inflammatory signals, microglia move to the site of infection. Upon activation, microglia can assume two distinct phenotypes: the neurotoxic M1 phenotype and the neuroprotective M2 phenotype. Microglia continue to exist in two distinct functional states: the M1 phenotype, which is in charge of producing proinflammatory cytokines such as TNF-α and interleukin 6 (IL-6). The M2 phenotype, which secretes inflammatory cytokines like IL-10 and downregulates the M1 response, is the second functional state. Chronic inflammation is caused by an imbalance between the M1 and M2 subgroups of microglia (Long *et al*., 2023).In cases of disease or damage, microglia switch to the M1 phenotype, leading to an ongoing inflammatory response. Upregulation of proinflammatory cytokines causes neuronal cell death.

Recent findings suggest that this type of overexpression and activation occurs not only in neurodegenerative illnesses, but also in schizophrenia, anxiety and depression. *B. monnieri* decreases the release of IL-6 and TNF-alpha from monocytes treated with lipopolysaccharide. However, it improves the M1 microglial response by reducing TNF-alpha and IL-6 levels, resulting in less neuroinflammation. LPS-activated microglial cultures emit a modest quantity of IL-10, which *B. monnieri* does not affect. Bacopa's bacosides activate neurotransmitters including acetylcholine, serotonin, GABA and glutamate (Rajan *et al*., 2015). *B. monnieri* is hypothesized to raise the concentration of 5-hydroxytryptamine in the hippocampus, hypothalamus and cerebral cortex (Kulkarni, 2021).

B. monnieri possesses the capacity to suppress inflammation by means of modulation. Of pro-inflammatory mediator release, meaning that it has strong anti-inflammatory properties that could explain why it works so well in conventional therapy to treat a range of inflammatory disorders. Moreover, it markedly reduced the activities of 15-LOX, 5-lipoxygenase (5-LOX) and cyclooxygenase-2 (COX-2). The presence of the triterpenoids and bacosides in it may be the cause of this activity (Tamboli *et al*., 2022).

8.5 Antiasthmaticactivity

In the tracheal muscles of rabbits and guinea pigs, *B. monnieri* extract exhibited relaxing qualities, partially due to prostaglandins and (beta)-adrenoreceptors. Additionally, it caused bronco dilatation in rats under anesthesia, which validated the plant's historical use for treating a variety of respiratory conditions. The extract's bronchodilator property may be demonstrated by the antagonistic effects of carbachol on expiratory and inspiratory pressures. The extract shown a twofold effect on carbachol-induced bronchoconstriction. Mostly lowered inspiratory pressure at low dosages (25 and 37 mg/kg), but only inhibited expiratory pressure at high doses (50 mg/kg). This characteristic of the plant extract suggests that bronchodilation could be caused by many mechanisms of action. The methanolic extract of BM leaves had a strong ability to stabilize mast cells, suggesting that BM leaves may have some utility for treating allergies (Deo and Reddy, 2013).

Ayurvedic medicine has suggested bacopa as an anticonvulsive treatment for epilepsy. Its anticonvulsant properties were demonstrated in clinical and animal studies, but only at large doses for prolonged periods of time. Additionally, it has been demonstrated that in experimental animals, *B. monnieri* crude water extract reduces epilepsy. It has a naturally occurring sedative effect and greatly extended the hypnotic effects of phenobarbitone. It is well known that drugs that activate GABA have sedative, anxiolytic and anticonvulsant properties. It implies that the central nervous system is mediated by the GABA-ergic system. BM was tested for its effects on the PA task, maximum electroshock seizures and locomotor activity in mice, both alone and in combination with phenytoin (PHT). Improvements were seen in memory acquisition and retention without compromising PHT's anticonvulsive action. To fully investigate BM's potential in epilepsy, more research utilizing BM alone or in conjunction with other antiepileptic medications is necessary (Yamada *et al*., 2011).

8.6 Antinociceptive activity

B. monnieri aqueous extract (AEBM) demonstrates analgesia activity *via* several pain pathways. This includes the role of 5-HT, β1- and α^2-adrenergic receptors in analgesic action. Additionally, it was noted that administering AEBM along with naloxone did not lengthen the time it took for analgesic effects to occur, suggesting that opioid receptors are involved in analgesic activity (Deo and Reddy, 2013).

8.7 Antispasmodic action

In smooth muscles, *B. monnieri* extract exhibits spasmolytic action. Because the cell membrane's voltage- and receptor-operated calcium channels are both inhibiting the influx of calcium. On the other hand, the fact that neither nor-adrenaline nor caffeine-induced contractions were altered in the presence of *B. monnieri* extract indicates that this organic substance has no discernible impact on intracellular calcium mobilization (Choudhary *et al*., 2021).

8.8 Hepatoprotective activity

It was discovered that *B. monnieri* extract pretreatment demonstrated a substantial protective effect against morphine-induced liver and kidney functions as measured by the levels of urea, creatinine and uric acid, as well as the activities of lactate dehydrogenases, alkaline phosphatase. Glutamate oxaloacetate transaminase, glutamate pyruvate transaminase and gamma-glutamyl transferase, respectively Additionally, pretreatment with Bacoside A preserves the antioxidant system, inhibits the rise in serum marker enzyme activity and LPO (lipid peroxidase) and shields the rats from diethyl nitrosamine-induced liver damage (Ghosh *et al*., 2007).

9. Potential applications of *B. monnieri* in neurological disorders

Neurological disorders represent a major public health challenge due to their increasing global prevalence, chronic progression and lack of fully curative therapies. These disorders encompass a wide spectrum of conditions including neurodegenerative diseases such as Alzheimer's disease (AD) and Parkinson's disease (PD), psychiatric disturbances like schizophrenia and a range of cognitive and behavioral impairments. Although, neurological illnesses primarily manifest in older individuals, recent evidence suggests that pathophysiological changes begin much earlier in life, progressing gradually until clinical symptoms become evident. One of the critical underlying mechanisms common to many neurological disorders is oxidative stress, especially lipid peroxidation resulting from the reaction between free radicals and polyunsaturated fatty acids present in neuronal membranes. Lipid peroxidation disrupts membrane integrity, increases neuronal vulnerability and contributes significantly to neurodegenerative processes (Brimson *et al*., 2021). Given the absence of definitive cures and the substantial economic and emotional burden on patients and families, there is an urgent need for novel neuroprotective strategies (Behera *et al*., 2016*)*. *B. monnieri* (Brahmi), widely recognized in traditional medicine as a memory enhancer, has emerged as a promising candidate due to its multifaceted mechanisms, including antioxidant activity, anti-inflammatory effects, cholinergic modulation, mitochondrial protection and the ability to regulate protein aggregation. These properties position *B. monnieri* as a potentially valuable therapeutic agent in managing neurological disorders.

9.1 Alzheimer's disease

Alzheimer's disease is the most prevalent neurodegenerative disorder and is clinically characterized by progressive memory loss, cognitive decline, impairment in reasoning, personality changes and behavioral disturbances. Pathologically, AD is defined by extracellular accumulation of amyloid-beta (Aβ) peptides forming senile plaques and intracellular aggregation of hyperphosphorylated TAU proteins into neurofibrillary tangles. Oxidative stress plays a pivotal role in accelerating Aβ toxicity. The brain is inherently susceptible to oxidative damage because of its high metabolic rate, enriched content of polyunsaturated fatty acids, abundant iron and relatively low antioxidant enzyme activity (Chaudhari, 2021). As AD progresses, depletion of enzymatic antioxidants such as catalase (CAT), superoxide dismutase (SOD) and glutathione peroxidase (GPx), along with reduced levels of non-enzymatic antioxidants including glutathione (GSH), vitamins A, C and E, further exacerbate neuronal damage.

B. monnieri has been extensively studied for its potential to counteract the oxidative damage central to AD pathology. The herb enhances endogenous antioxidant defenses by elevating GSH concentrations and upregulating CAT, GPx and SOD, thereby mitigating free-radical mediated neuronal injury. This antioxidant augmentation helps preserve neuronal membrane integrity and supports synaptic function (Valotto Neto *et al*., 2024). A particularly compelling aspect of *B. monnieri* relates to its anti-amyloidogenic effects. Research indicates that bacoside A, one of the major active constituents, interferes with Aβ42 aggregation by inhibiting fibril formation and preventing toxic oligomer interactions with neuronal membranes. In SH-SY5Y cell models, pre-incubation of bacoside A with Aβ42 significantly decreased fibrillation, reduced cytotoxicity and prevented membrane disruption. Since the formation of Aβ oligomers and fibrils is considered a key driver of synaptic dysfunction and neuronal loss, the ability of bacoside A to inhibit these processes provides a strong mechanistic basis for its potential role in AD management (Kulkarni, 2021).

In addition to its antioxidant and anti-amyloidogenic actions, *B. monnieri* modulates cholinergic neurotransmission, which is essential for learning and memory. AD is strongly associated with a decline in acetylcholine levels due to degeneration of cholinergic neurons. Extracts of *B. monnieri* have demonstrated the capacity to inhibit acetylcholinesterase (AChE), thereby increasing synaptic availability of acetylcholine and improving cholinergic signaling. Furthermore, bacosides support dendritic proliferation, enhance synaptic plasticity and improve neurotransmitter efficiency, all of which contribute to enhanced cognitive performance. The herb also exhibits anti-inflammatory activity by modulating signaling pathways such as NF-κB and reducing the expression of pro-inflammatory cytokines, including IL-1β and TNF-α. This anti-inflammatory effect further supports its protective role in AD, as neuroinflammation is known to exacerbate amyloid deposition and neurodegeneration. Collectively, these diverse mechanisms suggest that *B. monnieri* could play a complementary therapeutic role in delaying AD progression and preserving cognitive function.

9.2 Parkinson's disease

Parkinson's disease is a progressive neurodegenerative disorder characterized by bradykinesia, resting tremor, muscular rigidity and postural instability. At the cellular level, PD is defined by the degeneration of dopaminergic neurons in the substantia nigra pars compacta and excessive aggregation of alpha-synuclein (α-syn) into Lewy bodies. Oxidative stress, mitochondrial impairment and neuroinflammation are recognized as critical contributors to disease progression. Current pharmacological treatments such as levodopa primarily manage symptoms but do not halt or reverse neurodegeneration. Preclinical studies have provided evidence for the neuroprotective potential of *B. monnieri* in PD. Using *Caenorhabditis elegans* strains engineered to express human PD-associated phenotypes, Jadiya *et al*. (2011) demonstrated that *B. monnieri* reduced dopaminergic neuron degeneration and decreased α-syn aggregation. The herb also restored lipid homeostasis and improved survival in the nematode model, indicating its multifaceted protective effects (Saloni *et al*., 2022). These findings suggest that its neuroprotective actions may stem from suppression of oxidative stress, enhancement of mitochondrial function and inhibition of protein misfolding.

Another important aspect of *B. monnieri* in PD lies in its dopaminergic modulatory effects. The herb has been shown to improve dopamine levels, protect dopaminergic neurons from oxidative insults and modulate neurotransmitter metabolism. By stabilizing mitochondrial membranes and reducing apoptotic signaling, *B. monnieri* may also protect neurons from degeneration triggered by mitochondrial dysfunction, a hallmark of PD pathology. Its anti-inflammatory properties further support neuronal survival by attenuating microglial activation and reducing inflammatory mediators that contribute to dopaminergic cell death. Together, these mechanisms highlight the potential of *B. monnieri* as an adjunct therapeutic candidate aimed at slowing disease progression and enhancing neuronal resilience in Parkinson's disease.

9.3 Schizophrenia and cognitive dysfunction

Schizophrenia is a complex neuropsychiatric disorder characterized by a constellation of positive symptoms (hallucinations, delusions, disorganized thoughts), negative symptoms (social withdrawal, anhedonia, avolition) and cognitive deficits including impaired memory, attention and executive function. Although, antipsychotic medications, particularly dopamine D2 receptor antagonists, are highly effective in managing positive symptoms, they are often inadequate in addressing cognitive impairmentsthe strongest predictors of functional outcomes. Furthermore, long-term antipsychotic usage is frequently associated with adverse effects such as extrapyramidal symptoms and metabolic disturbances (Piyabhan *et al*., 2019). *B. monnieri* has been explored as a complementary therapy in schizophrenia due to its neuroprotective and cognition-enhancing properties. The herb's mechanisms of action include cholinergic modulation, antioxidant activity, adaptogenic effects and enhancement of synaptic integrity. In certain clinical observations, the combination of *B. monnieri* with the atypical antipsychotic drug olanzapine resulted in improved symptom management and better psychopathology scores. These improvements may be attributed to *B. monnieri*'s ability to promote synaptic repair, upregulate kinase activity necessary for neuronal communication and strengthen glutamatergic and dopaminergic pathways that are often compromised in schizophrenia (Kulkarni, 2021).

At the neurochemical level, bacosides have been shown to enhance dendritic complexity, elevate neurotrophic factors and improve synaptic plasticity. These effects support cognitive enhancement and may help mitigate the cognitive deficits associated with schizophrenia. Although, current evidence is still preliminary, the herb demonstrates notable potential in improving cognitive functions such as memory and attentiondomains poorly addressed by conventional antipsychotics. Further systematic studies and clinical trials are required to elucidate optimal dosage, long-term safety and synergistic interactions with antipsychotic medications.

9.4 Anxiety and depression

Beyond degenerative and psychotic conditions, *B. monnieri* has shown potential in mood disorders such as anxiety and depression, which often coexist with neurological illnesses. The herb's anxiolytic and antidepressant effects are attributed to modulation of neurotransmitters including serotonin, dopamine and gamma-aminobutyric acid (GABA). Its adaptogenic activity reduces stress-induced biochemical alterations while its antioxidant properties protect neurons from stress-mediated oxidative damage. Studies have also demonstrated that *B. monnieri* regulates the hypothalamic-pituitaryadrenal (HPA) axis, thereby reducing cortisol levels and improving physiological resilience to stress (Saloni *et al*., 2022). These combined actions suggest a therapeutic role in managing mood disturbances commonly associated with chronic neurological diseases.

9.5 Epilepsy and anticonvulsant activity

Epilepsy is associated with abnormal neuronal excitability and oxidative stress, both of which contribute to seizure generation and neuronal injury. *B. monnieri* exerts anticonvulsant effects by modulating GABAergic transmission, stabilizing neuronal membranes and reducing glutamate-mediated excitotoxicity. Its antioxidant properties further protect against seizure-induced oxidative damage. Although, the evidence is primarily preclinical, these findings highlight its potential as an adjunct therapy in managing seizure disorders and preventing neuronal damage associated with recurrent seizures (Behera *et al*., 2016).

9.6 Neurodevelopmental disorders

Attention-deficit/hyperactivity disorder (ADHD) and autism spectrum disorders are characterized by impaired attention, hyperactivity, impulsivity and cognitive dysfunction. *B. monnieri* has been traditionally used to enhance cognition in children and several modern studies indicate improvements in attention span, working memory and learning ability. The herb's cholinergic modulation, along with enhancement of synaptic communication and antioxidant protection, may contribute to these effects (Saloni *et al*., 2022). In ADHD models, *B. monnieri* helps normalize dopamine levels and reduces hyperactivity, suggesting potential therapeutic benefit. However, more rigorous clinical trials are needed to confirm efficacy in pediatric populations.

9.7 Mechanistic overview of neuroprotective actions

The therapeutic potential of *B. monnieri* in neurological disorders is derived from its diverse and synergistic mechanisms. The herb's antioxidant effects reduce lipid peroxidation and protect neuronal membranes, while its anti-inflammatory actions inhibit cytokine production and glial activation. Its cholinergic and dopaminergic modulation improves neurotransmission critical for cognition and motor control, whereas its anti-amyloidogenic properties prevent toxic protein aggregation (Behera *et al*., 2016). Enhancement of synaptic plasticity, mitochondrial stabilization and upregulation of neurotrophic factors further support long-term neuronal health. These integrated mechanisms explain its broad-spectrum applicability across multiple neurological disorders.

10. The dosage of brahmi intake

The typical dosage for bacopa was five to ten grams of non-standardized powder taken once a day. 8-16 ml of infusion and 30 ml of Brahmi syrup each day. The recommended daily dosage for a 1:2 fluid extract is 5-12 milliliters for adults and 2.5-6 milliliters for kids aged 6-12. Adults should take 200-400 mg of bacopa extracts standardized to 20% bacosides A and B daily in divided doses, while children should take 100-200 mg daily in divided doses (Deo and Reddy, 2013).

11. Future aspect

A developing and promising approach is to combine *B. monnieri* with other herbs and nutrients, which may work synergistically to increase efficacy. Recently, an extract of the herbs *Withania somnifera, Emblica officinalis* and *B. monnieri* was shown to be useful in the treatment or prevention of amyloid-related disorders such as Alzheimer's disease. *B. monnieri* is increasingly being used as a dietary supplement to promote memory and brain health. Interestingly, a combination of bacopa, lycopene, astaxanthin and vitamin B12 protected human neuronally differentiated SH"SY5Y cells from hydrogen peroxide induced damage by modulating proteins implicated in neuronal life and death pathways. Thus, *B. monnieri* containing dietary supplements have the potential to be used as a preventative or adjuvant to established treatments for brain diseases research indicates that Bacopa may improve memory recall in non-demented individuals, making it a viable memory enhancer for clinical use. There is currently inadequate evidence to support the claim that bacopa can improve cognitive performance in other domains. Measures used in studies across cognitive areas may vary, which could explain this. Future research should investigate the cognitive-enhancing effects of Bacopa at various dosages, during longer durations of supplementation and in specific demographics, as the field is still in its early stages. Bacopa is increasingly being used in herbal products as a memory enhancer and health supplement. Ethnobotanical surveys showed numerous therapeutic qualities. Ethnobotanical investigations found that this plant is an excellent source of anti-venomous medicines. The juice from this plant can also be utilized to prevent hair loss. Although, ethnobotanical research suggest that this plant contains anti-sickling, anti-paralytic and anti-venomous qualities, it has yet to be tested experimentally. The plant's phytochemicals and bioactive characteristics have yet to be studied against many ailments, indicating significant potential in this field.

12. Conclusion

The use of Ayurvedic plants is greatly increasing and extensive research has been conducted on them worldwide for a number of reasons. Significant attempts have also been made to standardize both the finished and raw Ayurvedic pharmaceuticals. But for these endeavors to succeed, it is vital that neglected plants like brahmi be properly utilized regulation, cognitive enhancement in healthy individuals, prophylactic prevention of oxidative damage and the amelioration of cognitive diseases are all areas where BM shows great promise. Although, BM biomedical research is still in its early stages, initial findings like these are starting to pave the way for future investigations. Longer-term research is crucial since combining BM with other drugs as the Ayurvedic system recommends may have synergistic effects that need further investigation. Researchers must carefully temper their optimistic expectations about the social implications of cognition-enhancing medications with ethical considerations as they venture into the exciting field of brain enhancement.

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Conflict of interest

The authors declare no conflicts of interest relevant to this article.

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