

## HERBAL NOOTROPICS: A CRITICAL REVIEW OF PHYTOCHEMICAL CONSTITUENTS AND MECHANISTIC PATHWAYS IN MEMORY ENHANCEMENT AND COGNITIVE FUNCTION — WITH SPECIAL REFERENCE TO PONGAMIA PINNATA LINN. AND GARCINIA INDICA

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### ABSTRACT

Memory impairment and cognitive decline are increasingly prevalent concerns globally, necessitating the exploration of safe, effective, and naturally derived nootropic agents. Herbal plants have been integral to traditional medicine systems such as Ayurveda, Unani, and Chinese medicine for centuries, with numerous species demonstrating significant memory-enhancing and neuroprotective properties. The present review critically examines the phytochemical constituents and neuropharmacological mechanisms underlying the nootropic potential of selected medicinal herbs, with special emphasis on *Pongamia pinnata* Linn. (Family: Fabaceae) and *Garcinia indica* (Family: Clusiaceae). *Pongamia pinnata*, rich in flavonoids such as karanjin, pongapin, kanjone, and various terpenoids, exhibits potent acetylcholinesterase (AChE) inhibitory activity, antioxidant neuroprotection, and anti-

inflammatory effects on neural tissues. *Garcinia indica*, containing hydroxycitric acid (HCA), garcinol, isogarcinol, and xanthone derivatives, demonstrates significant cognitive-enhancing properties through serotonin modulation, GABA-ergic activity, and reduction of oxidative neuronal stress. This review also discusses the ethnobotanical significance, phytochemical profiling methods, in vitro and in vivo pharmacological evaluation models, and the mechanistic basis of nootropic activity. Furthermore, the review highlights the therapeutic

relevance of these plants in managing neurodegenerative conditions such as Alzheimer's disease, dementia, and age-related cognitive decline. Future directions for clinical translation and standardization of herbal nootropic formulations are also addressed.

**KEYWORDS:** Nootropics, Memory Enhancement, *Pongamia pinnata*, *Garcinia indica*, Acetylcholinesterase Inhibition, Neuroprotection, Phytochemistry, Cognitive Function, Alzheimer's Disease.

## 1. INTRODUCTION

Cognitive function encompasses a wide spectrum of mental processes including memory, attention, perception, reasoning, problem-solving, and decision-making. Among these, memory is considered the cornerstone of cognitive integrity and is essential for an individual's ability to function effectively in daily life. Memory impairment, ranging from mild cognitive decline to severe neurodegenerative disorders such as Alzheimer's disease (AD), vascular dementia, and Parkinson's disease-related cognitive decline, represents one of the most significant public health burdens of the 21st century.

According to the World Health Organization (WHO), over 55 million people worldwide currently suffer from dementia, with approximately 10 million new cases reported annually. Projections indicate that this number will nearly triple to 139 million by 2050, placing an enormous strain on healthcare systems and economies globally. Alzheimer's disease alone accounts for 60–70% of all dementia cases, making it the most common form of progressive cognitive degeneration.

Conventional pharmacotherapy for cognitive disorders primarily includes acetylcholinesterase (AChE) inhibitors such as donepezil, rivastigmine, and galantamine, along with NMDA receptor antagonists like memantine. However, these drugs are associated with significant limitations including dose-dependent adverse effects (nausea, bradycardia, hepatotoxicity), high cost, and limited disease-modifying capacity. These drawbacks have stimulated growing scientific interest in the exploration of plant-derived nootropic agents as safer, more affordable, and potentially more efficacious alternatives.

Medicinal plants have served as the foundation of healthcare across civilizations. The Indian Ayurvedic system, Traditional Chinese Medicine (TCM), and African ethnomedicine have extensively documented the use of numerous botanical species for enhancing mental

faculties, memory, and intelligence — collectively referred to as 'Medhya Rasayana' in Ayurveda. Plants such as *Bacopa monnieri* (Brahmi), *Centella asiatica* (Mandukparni), *Withania somnifera* (Ashwagandha), and *Convolvulus pluricaulis* are well-documented nootropics. More recent investigations have revealed similar potentials in lesser-studied species including *Pongamia pinnata* Linn. and *Garcinia indica*.

*Pongamia pinnata*, commonly known as Indian Beech or Karanja, is a medium-sized deciduous tree belonging to the family Fabaceae. It is widely distributed across the Indian subcontinent, Southeast Asia, and Australia. The plant has a long history in Ayurvedic and folk medicine for treating skin disorders, rheumatism, diabetes, and nervous system ailments. Phytochemical investigations have revealed a rich array of bioactive compounds including flavonoids (karanjin, pongapin, kanjone), coumarins, alkaloids, and terpenoids — many of which demonstrate significant neuropharmacological activities.

*Garcinia indica*, commonly known as Kokum, is a tropical fruit-bearing tree of the family Clusiaceae, native to the Western Ghats of India. It has been extensively used in Ayurvedic medicine for its anti-inflammatory, anti-obesity, and digestive properties. Modern phytochemical studies have identified garcinol, isogarcinol, hydroxycitric acid (HCA), and xanthone derivatives as its principal bioactive constituents, several of which display promising central nervous system (CNS) activity and neuroprotective effects.

This review aims to comprehensively summarize the ethnobotanical background, phytochemical composition, neuropharmacological mechanisms, and therapeutic potential of *Pongamia pinnata* and *Garcinia indica* as herbal memory-enhancing agents. The review also provides a broader perspective on the current landscape of plant-based nootropics, analytical characterization methods, and future research directions for clinical development.

## 2. ETHNOBOTANICAL SIGNIFICANCE

### 2.1 *Pongamia pinnata* Linn.

*Pongamia pinnata* (syn. *Millettia pinnata*) is widely distributed across South and Southeast Asia, including India, Sri Lanka, Myanmar, Malaysia, Indonesia, and northern Australia. The tree holds considerable importance in Ayurvedic, Siddha, and Unani medicinal traditions. Classical Ayurvedic texts including the Charaka Samhita and Sushruta Samhita document its use under the Sanskrit name 'Karanja' for treating skin conditions, respiratory disorders, and neurological ailments.

Various parts of the plant — leaves, seeds, bark, roots, and flowers — have been used in traditional medicine. The seeds yield Karanja oil, which is applied topically for skin diseases and used in folk medicine for arthritis and nervous disorders. The leaves are used as poultices for wound healing, and decoctions of the bark and roots are employed for digestive complaints and fevers. Ethnobotanical surveys across India have recorded the use of Pongamia leaf extracts by tribal communities for improving memory and treating convulsive disorders.

In Ayurvedic classification, Pongamia is attributed with 'Tikta' (bitter) and 'Kashaya' (astringent) tastes and 'Laghu' (light) and 'Ruksha' (dry) qualities, indicating its capacity to penetrate tissues and act on neural channels (Majjavaha srotas), thereby supporting its reputation as a brain tonic.

## 2.2 *Garcinia indica* (Choisy)

*Garcinia indica*, locally known as Kokum, Amsul, or Brindleberry, is indigenous to the coastal regions of the Western Ghats of India, particularly in Maharashtra, Goa, Karnataka, and Kerala. It has been a staple ingredient in coastal Indian cuisine and medicine for centuries. The dried rind of the fruit, known as 'Kokum butter' and 'Kokum sol', is used extensively in traditional preparations.

In Ayurvedic medicine, *Garcinia indica* is classified as 'Amla' (sour) in taste and is recognized for its 'Deepana' (digestive stimulant), 'Pachana' (digestive), and 'Hridya' (cardiotonic) properties. Ethnomedicinal reports document its use for treating heat strokes, liver disorders, infections, and as a CNS coolant in conditions associated with agitation and mental fatigue. The fruit pulp is used in folk preparations for improving mood, reducing anxiety, and enhancing mental clarity.

Several tribal communities in the Konkan region of Maharashtra employ *Garcinia indica* fruit preparations as traditional remedies for nervous weakness, mental exhaustion, and memory disorders in elderly individuals, highlighting its ethnopharmacological relevance as a cognitive enhancer.

### 3. PHYTOCHEMICAL PROFILING

#### 3.1 Phytochemical Constituents of *Pongamia pinnata*

Extensive phytochemical investigations of *Pongamia pinnata* have revealed a remarkably diverse chemical composition varying with the plant part, geographical origin, and extraction solvent. The major phytochemical classes identified include:

- **Flavonoids and Flavones:** Karanjin, pongapin, kanjone, pongamol, isopongaflavone, lanceolatin B, pinnatin, and gamatin are the principal flavonoid constituents. Karanjin is considered the characteristic marker compound of the species and demonstrates potent antioxidant and anti-inflammatory activities.
- **Coumarins:** Pongaglabrone, karanjachromene, and related chromeno-flavone hybrids have been isolated from seeds and leaves, exhibiting significant enzyme inhibitory activities.
- **Alkaloids:** Indole alkaloids including pongamine, hydroxy-pongamine, and demethoxy-pongamine have been identified and are associated with CNS activity.
- **Terpenoids and Steroids:** Beta-sitosterol, cycloartenol, and various triterpenoids including lupeol and betulinic acid derivatives have been reported. These compounds contribute to the anti-inflammatory and neuroprotective profile.
- **Phenolic Acids:** Gallic acid, caffeic acid, chlorogenic acid, and ferulic acid are present and contribute to the antioxidant potential of the plant.
- **Fixed Oils:** Karanja oil (approximately 30–40% from seeds) contains oleic acid, linoleic acid, palmitic acid, and stearic acid, providing nourishing effects on neural membranes.

Quantitative phytochemical analysis reveals that methanolic and ethanolic leaf extracts yield higher concentrations of polyphenols and flavonoids compared to aqueous extracts, suggesting that polar organic solvents are more efficient for extracting the bioactive memory-enhancing constituents.

#### 3.2 Phytochemical Constituents of *Garcinia indica*

*Garcinia indica* possesses a rich phytochemical profile, particularly in its fruit rind, seeds, and leaves. The principal bioactive constituents include:

- **Hydroxycitric Acid (HCA):** The predominant organic acid of *Garcinia indica*, HCA exists as a lactone and free acid form. It inhibits ATP-citrate lyase, influencing lipid metabolism and serotonin synthesis in the brain.

- Garcinol and Isogarcinol: Polyisoprenylated benzophenone derivatives that exhibit potent antioxidant, anti-inflammatory, and neuroprotective activities. Garcinol demonstrates significant inhibition of histone acetyltransferase (HAT), influencing gene expression related to neuroinflammation.
- Xanthonoids: Alpha-mangostin, beta-mangostin, garcinone derivatives, and camboginol have been isolated. Xanthonoids are known for their potent antioxidant, anticancer, and CNS-active properties.
- Anthocyanins: Cyanidin-3-glucoside and cyanidin-3-sambubioside are responsible for the deep red/purple pigmentation of Kokum and contribute to its strong antioxidant activity.
- Flavonoids: Rutin, quercetin, kaempferol, and catechin derivatives are present and contribute to neuroprotective and anti-inflammatory activities.
- Kokum Butter: A solid fat rich in stearic and oleic acids extracted from *Garcinia indica* seeds, used in pharmaceutical formulations for topical and oral applications.
- Organic Acids: Tartaric acid, malic acid, and citric acid are present in the fruit and contribute to its characteristic taste and metabolic effects.

#### 4. NEUROPHARMACOLOGICAL MECHANISMS OF MEMORY ENHANCEMENT

##### 4.1 Cholinergic Pathway Modulation

The cholinergic hypothesis of memory and learning postulates that degeneration of cholinergic neurons and reduction in acetylcholine (ACh) levels in the hippocampus and cortex are primary contributors to cognitive decline in Alzheimer's disease and related dementias. Acetylcholinesterase (AChE) and butyrylcholinesterase (BuChE) are the key enzymes responsible for the hydrolysis of acetylcholine at the synaptic cleft.

Flavonoids from *Pongamia pinnata*, particularly karanjin and pongapin, have demonstrated significant *in vitro* AChE inhibitory activity in multiple studies. The flavone scaffold, with its planar ring structure and hydroxyl substituents, allows it to interact with both the catalytic anionic site (CAS) and peripheral anionic site (PAS) of AChE through hydrophobic interactions and hydrogen bonding. This dual-site inhibition is considered pharmacologically superior as it also prevents the amyloidogenic properties attributed to the PAS of AChE.

Similarly, garcinol from *Garcinia indica* has shown AChE inhibitory potential in computational docking studies and *in vitro* assays, suggesting a complementary mechanism of cholinergic enhancement. The polyisoprenylated structure of garcinol enables favorable binding interactions with the active site of AChE.

#### 4.2 Antioxidant and Neuroprotective Mechanisms

Oxidative stress is a central mechanism in the pathogenesis of neurodegenerative diseases. Reactive oxygen species (ROS) and reactive nitrogen species (RNS) cause lipid peroxidation of neuronal membranes, protein oxidation, and DNA damage, ultimately leading to neuronal apoptosis. The hippocampus and prefrontal cortex, regions critical for memory formation and consolidation, are particularly vulnerable to oxidative damage due to their high metabolic activity and relatively low intrinsic antioxidant defenses.

*Pongamia pinnata* extracts demonstrate potent free radical scavenging activity attributable to their high polyphenolic content. Studies report significant inhibition of DPPH (2,2-diphenyl-1-picrylhydrazyl) and ABTS (2,2'-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid)) radicals, reduction of lipid peroxidation (TBARS assay), and upregulation of endogenous antioxidant enzymes including superoxide dismutase (SOD), catalase (CAT), and glutathione peroxidase (GPx) in animal models of oxidative stress-induced memory impairment.

Garcinol from *Garcinia indica* is one of the most potent natural antioxidants identified, with an Oxygen Radical Absorbance Capacity (ORAC) value reportedly exceeding that of well-known antioxidants including vitamin C and alpha-tocopherol. Garcinol inhibits NF- $\kappa$ B signaling, reduces production of pro-inflammatory cytokines (TNF- $\alpha$ , IL-1 $\beta$ , IL-6), and suppresses COX-2 expression in neural tissues, collectively providing neuroprotection against inflammatory neurodegeneration. Anthocyanins in *Garcinia indica* further contribute by crossing the blood-brain barrier and directly scavenging ROS in neural tissue.

#### 4.3 Serotonergic and GABAergic Modulation

Serotonin (5-hydroxytryptamine, 5-HT) plays a pivotal role in mood regulation, anxiety, and cognitive processing. Hydroxycitric acid (HCA) from *Garcinia indica* inhibits ATP-citrate lyase, an enzyme involved in the biosynthesis of acetyl-CoA. This indirectly elevates serotonin availability in the CNS by increasing tryptophan uptake across the blood-brain barrier and augmenting 5-HT synthesis. Elevated serotonin levels are associated with improved mood, reduced anxiety, and enhanced memory consolidation, particularly in the hippocampus.

Additionally, xanthone derivatives from *Garcinia indica* exhibit anxiolytic and cognitive-enhancing effects through modulation of GABA-A receptors. Camboginol and related xanthenes have demonstrated benzodiazepine-like activity in animal behavioral tests

including the elevated plus maze and open field test, suggesting an anxiolytic mechanism that indirectly supports cognitive performance by reducing anxiety-related interference with memory processes.

#### **4.4 Anti-inflammatory Neuroprotection**

Neuroinflammation, characterized by microglial activation and excessive production of pro-inflammatory mediators, is increasingly recognized as a key contributor to synaptic dysfunction and neuronal death in cognitive disorders. Garcinol inhibits histone acetyltransferase p300/CBP-associated factor (PCAF), leading to epigenetic regulation of inflammatory gene expression. This mechanism is particularly relevant to long-term neuroprotection and may offer disease-modifying potential beyond symptomatic relief.

Terpenoids and alkaloids from *Pongamia pinnata*, including lupeol and pongamine, inhibit cyclooxygenase (COX) enzymes and reduce prostaglandin synthesis in neural tissue. This anti-inflammatory activity reduces microglial-mediated neuroinflammation and protects hippocampal neurons from inflammatory damage, thereby preserving synaptic plasticity and memory function.

#### **4.5 Neurotransmitter Regulation and Synaptic Plasticity**

Synaptic plasticity, including long-term potentiation (LTP) and long-term depression (LTD), are cellular correlates of learning and memory formation. Bioactive constituents from *Pongamia pinnata* and *Garcinia indica* appear to modulate NMDA and AMPA glutamate receptors, influence BDNF (Brain-Derived Neurotrophic Factor) expression, and regulate Ca<sup>2+</sup> homeostasis in neurons — all critical to the maintenance of synaptic plasticity and neuronal communication networks essential for memory formation.

### **5. PHARMACOLOGICAL STUDIES AND EXPERIMENTAL EVIDENCE**

#### **5.1 In Vitro Studies**

Multiple in vitro studies have established the neuropharmacological potential of *Pongamia pinnata* and *Garcinia indica* extracts. AChE inhibitory assays using Ellman's colorimetric method have demonstrated IC<sub>50</sub> values of flavonoid-enriched *Pongamia* extracts ranging from 45–120 microg/mL, comparable to reference standards such as quercetin and physostigmine. DPPH radical scavenging assays consistently show IC<sub>50</sub> values of 25–75 microg/mL for methanolic leaf extracts of *Pongamia pinnata*.

For *Garcinia indica*, garcinol demonstrates AChE inhibitory IC<sub>50</sub> values in the range of 30–85 microg/mL in standardized Ellman assays. Antioxidant studies using FRAP (Ferric Reducing Antioxidant Power) and ORAC assays consistently rank garcinol among the most potent natural antioxidants. MTT cytotoxicity assays on neuronal cell lines (SH-SY5Y, PC12) demonstrate that *Garcinia indica* extracts at physiologically relevant concentrations are non-toxic and exhibit cytoprotective effects against hydrogen peroxide-induced oxidative damage.

## 5.2 In Vivo Animal Studies

Animal behavioral models of memory and cognition represent the gold standard for preclinical evaluation of nootropic agents. Several validated models are employed in nootropic research:

- **Morris Water Maze (MWM):** Tests spatial memory and hippocampal-dependent learning. Animals treated with *Pongamia pinnata* ethanolic extracts (200–400 mg/kg, p.o.) demonstrate significantly reduced escape latency and increased time spent in the target quadrant compared to scopolamine-induced amnesic controls, indicating improved spatial memory.
- **Elevated Plus Maze (EPM):** Measures transfer latency as an index of memory. Studies report that *Pongamia pinnata* extract-treated animals show significantly shorter transfer latency in both acquisition and retention trials compared to scopolamine-treated groups.
- **Passive Avoidance Test:** A step-through or step-down paradigm assessing fear-motivated memory. *Garcinia indica* fruit extract at doses of 100–400 mg/kg demonstrates dose-dependent improvement in passive avoidance latency, indicative of enhanced retention memory.
- **Novel Object Recognition Test (NORT):** Assesses non-spatial declarative memory. Treatment with garcinol significantly increases the discrimination index compared to vehicle controls, suggesting enhancement of recognition memory.

Biochemical estimations in brain tissue of treated animals consistently show elevated ACh levels, reduced AChE activity, decreased malondialdehyde (MDA) — a marker of lipid peroxidation — and increased activities of SOD, CAT, and GPx in animals receiving *Pongamia pinnata* and *Garcinia indica* extracts, corroborating the behavioral observations with mechanistic biochemical evidence.

## 6. ANALYTICAL CHARACTERIZATION METHODS

Rigorous analytical characterization is essential for quality control, standardization, and pharmacological validation of herbal nootropic preparations. The following methods are commonly employed:

- Preliminary Phytochemical Screening: Standard chemical reagent tests (Mayer's, Dragendorff's, Molisch's, Fehling's, Ferric chloride) provide initial qualitative identification of major phytochemical classes including alkaloids, flavonoids, tannins, saponins, glycosides, and steroids.
- High-Performance Thin Layer Chromatography (HPTLC): HPTLC fingerprinting provides characteristic chromatographic profiles and allows semi-quantitative estimation of marker compounds. Karanjin in *Pongamia pinnata* and garcinol in *Garcinia indica* serve as marker compounds for HPTLC standardization.
- High-Performance Liquid Chromatography (HPLC): RP-HPLC methods using C18 columns with UV or DAD detection provide quantitative estimation of individual phenolic acids, flavonoids, and specific marker compounds with high precision and accuracy.
- Gas Chromatography-Mass Spectrometry (GC-MS): GC-MS profiling of volatile and semi-volatile constituents provides detailed chemical fingerprints and aids in identification of terpenoids, fatty acids, and other GC-amenable compounds.
- Nuclear Magnetic Resonance (NMR) Spectroscopy: <sup>1</sup>H-NMR and <sup>13</sup>C-NMR spectroscopy are used for structural elucidation of isolated pure compounds, providing definitive identification of flavonoids, terpenoids, and other bioactive constituents.
- Fourier Transform Infrared Spectroscopy (FTIR): FTIR analysis provides functional group information and aids in rapid identification of major phytochemical classes in crude extracts.
- LC-MS/MS: Liquid chromatography coupled with tandem mass spectrometry allows simultaneous identification and quantification of multiple bioactive constituents in complex herbal matrices with high sensitivity.

## 7. SAFETY PROFILE AND TOXICOLOGICAL CONSIDERATIONS

The safety of herbal nootropic preparations is of paramount importance, particularly given their intended use in elderly and neurologically vulnerable populations. Acute and subacute toxicity studies of *Pongamia pinnata* extracts conducted in rodents (mice and rats) according to OECD guidelines 423 and 407 demonstrate an LD<sub>50</sub> exceeding 2000 mg/kg for ethanolic

leaf extracts, classifying them in Category 5 (relatively non-toxic) according to GHS classification. No significant changes in hematological parameters, hepatic enzymes (SGOT, SGPT, ALP), or renal function markers (serum creatinine, blood urea nitrogen) have been observed at therapeutic doses.

*Garcinia indica* fruit preparations have a long history of safe dietary use as a food ingredient in Indian coastal cuisine, providing a strong basis for their safety profile. Acute toxicity studies of standardized *Garcinia indica* extracts report LD50 values greater than 5000 mg/kg in rodents. Subacute toxicity studies at doses up to 1000 mg/kg for 28 days reveal no significant toxicological findings in hematological, biochemical, or histopathological evaluations. The genotoxicity profile, assessed by Ames test and micronucleus assay, is negative for both plant extracts at tested concentrations.

However, it is pertinent to note that *Pongamia pinnata* seeds and seed oil contain toxic karanjin at higher concentrations, and prolonged consumption of seed-derived preparations should be approached with caution. The leaves and bark, which form the basis of nootropic preparations, demonstrate a significantly more favorable safety profile. Standardized and quality-controlled preparations derived from specific plant parts at validated doses remain the key to ensuring safety in clinical applications.

## 8. FUTURE DIRECTIONS AND RESEARCH OPPORTUNITIES

Despite the promising preclinical evidence supporting the nootropic potential of *Pongamia pinnata* and *Garcinia indica*, several critical research gaps remain to be addressed:

- **Clinical Trials:** Rigorously designed randomized controlled trials (RCTs) in human subjects are essential to establish the clinical efficacy, optimal dosing, and long-term safety of standardized extracts of both plants in patients with mild cognitive impairment (MCI) and early Alzheimer's disease.
- **Mechanistic Studies:** Advanced molecular biology techniques including RNA sequencing, proteomics, and epigenomic analyses should be employed to fully elucidate the multi-target mechanisms by which these plants exert nootropic effects, including their influence on BDNF signaling, neurogenesis, and synaptic plasticity pathways.
- **Bioavailability Enhancement:** The oral bioavailability of key constituents such as karanjin and garcinol is limited due to poor aqueous solubility, extensive first-pass metabolism, and P-glycoprotein efflux. Novel drug delivery systems including nanoparticles,

liposomes, phytosomes, and solid dispersions should be explored to enhance brain bioavailability.

- **Combination Therapy:** Synergistic combinations of *Pongamia pinnata* and *Garcinia indica* with established nootropics such as *Bacopa monnieri* or with conventional AChE inhibitors should be systematically evaluated for additive or synergistic cognitive benefits with potentially reduced side effect profiles.
- **Standardization and Quality Control:** Development of validated HPTLC and HPLC methods for simultaneous quantification of multiple marker compounds in commercial herbal preparations is critical to ensure batch-to-batch consistency and therapeutic reliability.
- **Computational and Network Pharmacology:** In silico molecular docking, molecular dynamics simulations, and network pharmacology analyses should be pursued to identify precise binding targets and map the phytochemical-target interaction networks relevant to cognitive enhancement.

## 9. CONCLUSION

The escalating global burden of cognitive disorders and the limitations of existing pharmacotherapies underscore the urgent need for novel, safe, and effective memory-enhancing agents. *Pongamia pinnata* Linn. and *Garcinia indica* represent two botanically and pharmacologically distinct yet complementary herbal resources with well-documented ethnomedicinal histories and compelling phytochemical profiles relevant to cognitive enhancement.

The rich flavonoid content of *Pongamia pinnata* — particularly karanjin and pongapin — confers significant AChE inhibitory and antioxidant neuroprotective activities, while the hydroxycitric acid, garcinol, and xanthone constituents of *Garcinia indica* collectively provide multifaceted neuroprotection through serotonergic modulation, antioxidant mechanisms, and anti-inflammatory epigenetic regulation. Together, these plants represent a multi-target pharmacological approach to memory enhancement that aligns well with the complex, multifactorial pathophysiology of neurodegenerative cognitive disorders.

The preclinical evidence accumulated to date provides a strong scientific rationale for advanced clinical investigation. With appropriate standardization, rigorous clinical evaluation, and innovative delivery system development, these traditional herbal nootropics

hold considerable promise for integration into evidence-based neurotherapeutic strategies for the prevention and management of cognitive decline in the 21st century.

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