

# Tea Consumption, Gut Microbiota Modulation, and Cognitive Health: An Integrated Review of the Microbiota-Gut-Brain Axis

Mepully Thomas Antony Mathew<sup>1\*</sup>, Ravi Aiswarya Krishna<sup>2</sup>,  
Sasidharan Perumal<sup>1</sup>, Murugan Mukilan<sup>2</sup>, Karithikeyan Murali<sup>1</sup>

1.Plant Physiology and Biotechnology, UPASI Tea research foundation

2.Sri Ramakrishna college of arts and science,Biotechnology Division

## Abstract

Tea (*Camellia sinensis*) is the second most widely consumed beverage in the world after water, and interest in its role in brain health has grown alongside the rising global burden of dementia and mild cognitive impairment (MCI). This narrative review synthesizes epidemiological, mechanistic, and gut-microbiome literature examining how habitual tea consumption may protect cognitive function, with particular attention to the microbiota-gut-brain axis as a candidate unifying pathway. Cohort studies and meta-analyses consistently associate regular tea intake with reduced risk of cognitive decline, MCI, and dementia, with evidence for a dose-response relationship<sup>1-3</sup>. Mechanistically, tea catechins such as (–)-epigallocatechin-3-gallate (EGCG) exhibit measurable, if limited, blood-brain barrier permeability and exert direct antioxidant, iron-chelating, and anti-amyloidogenic actions<sup>4-7</sup>, while the majority of ingested polyphenols reach the colon unabsorbed, where they reshape gut microbial communities, increase short-chain fatty acid (SCFA) production, and strengthen gut-barrier integrity<sup>8-14</sup>. These microbial changes are proposed to reduce systemic and neuro-inflammation via vagal, endocrine, and immune signaling along the microbiota-gut-brain axis<sup>15,16</sup>. Six figures summarize tea-processing chemistry, dose-response data, vascular and cognitive outcomes, direct neuroprotective mechanisms, gut-microbial taxa shifts, and a dual-pathway mechanistic model, alongside a summary table of key studies. We conclude that tea consumption is a promising, low-risk dietary strategy for supporting cognitive and gut health, while highlighting methodological limitations that must be addressed before firm clinical recommendations can be made.

**Keywords:** tea; catechins; cognitive impairment; gut microbiota; microbiota-gut-brain axis; polyphenols

## Introduction

Age-related cognitive decline encompasses a broad continuum, ranging from subtle impairments in memory and executive function to clinically recognizable mild cognitive impairment (MCI) and ultimately dementia. With increasing life expectancy and a growing aging population worldwide,

cognitive disorders have emerged as a major public-health and socioeconomic challenge. Cognitive deterioration not only compromises independence and quality of life but also places a substantial burden on families, caregivers, and healthcare systems. Despite considerable advances in neuroscience and clinical medicine, effective disease-modifying therapies for major neurodegenerative disorders remain limited. Consequently, increasing attention has been directed toward preventive strategies and modifiable lifestyle factors that may help preserve cognitive function and delay the onset or progression of age-related neurodegeneration. Among these factors, dietary habits have attracted particular interest because of their long-term influence on metabolic health, inflammation, oxidative stress, vascular function, and brain physiology. Tea, prepared from the leaves of *Camellia sinensis*, is one of the most widely consumed beverages globally and has been an integral component of human diets for centuries. Depending on the degree of oxidation and processing, tea is consumed in several forms, including green, oolong, black, and fermented teas, each characterized by a distinct profile of bioactive compounds. Tea contains a complex mixture of polyphenols, particularly catechins and their oxidation products such as theaflavins, in addition to L-theanine, caffeine, flavonoids, and other secondary metabolites. These compounds have received considerable scientific attention because of their antioxidant, anti-inflammatory, vascular, metabolic, and neuromodulatory properties. Among them, catechins, especially epigallocatechin-3-gallate (EGCG), have been extensively investigated for their potential role in reducing oxidative damage, regulating inflammatory signaling, modulating neuronal survival pathways, and influencing pathological processes associated with neurodegenerative diseases. Epidemiological studies have further suggested that habitual tea consumption may be associated with a reduced risk of cognitive decline and neurocognitive disorders, although the underlying biological mechanisms remain incompletely understood. Traditionally, the potential neuroprotective effects of tea have been explained primarily through the direct actions of its bioactive constituents on oxidative stress, inflammation, vascular function, and neuronal signaling. However, this explanation may not fully account for the biological effects of tea polyphenols. A substantial proportion of ingested tea polyphenols exhibit limited absorption in the upper gastrointestinal tract and subsequently reach the colon, where they interact extensively with resident microbial communities. The gut microbiota can metabolize complex tea-derived polyphenols into smaller phenolic compounds with altered bioavailability and biological activity. At the same time, these compounds may selectively influence the composition and metabolic activity of intestinal microorganisms. Thus, the interaction between tea and the gut microbiome represents a potentially important, but still underexplored, mechanism through which dietary tea consumption may exert systemic and neurological effects<sup>8,9</sup>.

Over the past two decades, growing recognition of the bidirectional communication between the gastrointestinal tract and the central nervous system has transformed understanding of the relationship between diet and brain health. This complex communication network, commonly referred to as the microbiota-gut-brain axis, involves neural, immune, endocrine, and metabolic signaling pathways that enable gut-derived signals to influence brain function. Microbial metabolites, including short-chain fatty acids (SCFAs) and phenolic metabolites derived from dietary polyphenols, can influence intestinal barrier integrity, immune regulation, systemic inflammation, and neuroinflammatory processes. Alterations in gut microbial composition and function have also been increasingly associated with aging, cognitive impairment, and neurodegenerative disorders. Given that diet is one of the most powerful modifiable determinants of gut microbial ecology,

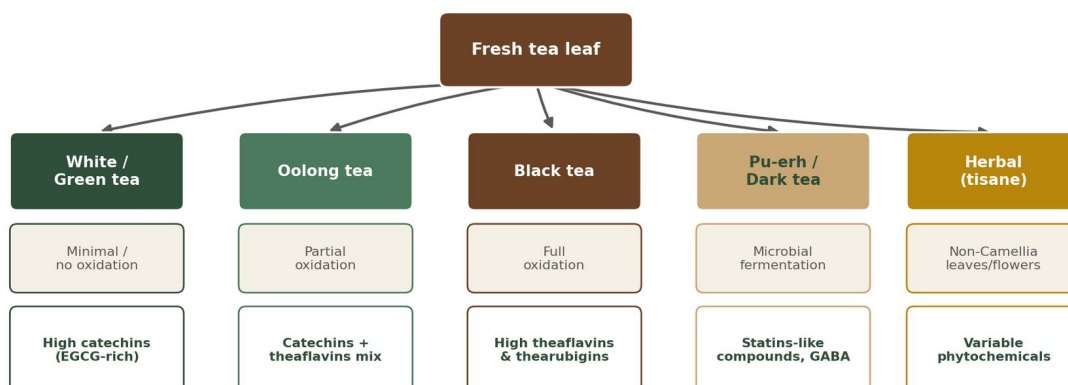
regular consumption of polyphenol-rich beverages such as tea may have implications that extend beyond direct antioxidant activity and include microbiome-mediated pathways affecting brain health. This emerging perspective raises an important integrative question: can the cognitive benefits associated with habitual tea consumption be explained, at least in part, through tea-induced modulation of the gut microbiota and its downstream communication with the brain? Addressing this question requires the integration of evidence that has often been considered separately. Epidemiological studies provide population-level observations linking tea intake with cognitive outcomes, while experimental studies have identified direct neuroprotective properties of tea catechins and other bioactive compounds. In parallel, an expanding body of research demonstrates that tea polyphenols can alter gut microbial composition, promote the production of biologically active metabolites, and influence pathways associated with inflammation and metabolic homeostasis. The convergence of these findings provides a rationale for examining tea consumption within the broader framework of the microbiota-gut-brain axis.

Accordingly, this review integrates three interconnected areas of research: (i) epidemiological evidence linking tea consumption with cognitive function and the risk of cognitive decline; (ii) molecular and cellular mechanisms underlying the direct neuroprotective effects of tea-derived bioactive compounds; and (iii) the capacity of tea polyphenols to modulate the gut microbiota and influence gut-derived signaling pathways relevant to brain function. Sources were identified through targeted searches of PubMed and Web of Science for English-language articles on tea, catechins, EGCG, gut microbiota, short-chain fatty acids, and the microbiota-gut-brain axis in relation to cognition; this is a narrative rather than a systematic review, and reference selection reflects the areas of mechanistic and epidemiological convergence most relevant to the integrative framework rather than an exhaustive or protocol-driven search. By bringing these lines of evidence together, the review aims to develop a more comprehensive mechanistic perspective on how a widely consumed and accessible dietary beverage may contribute to healthy cognitive aging. Particular emphasis is placed on the microbiota-gut-brain axis as a potential biological bridge connecting tea-derived compounds, microbial metabolism, systemic signaling, and neuroprotection. At the same time, the review considers current limitations in the available evidence and highlights key research gaps that must be addressed before definitive conclusions regarding causality and clinical application can be established.

### **Tea composition and bioactive compounds**

All true teas originate from the same plant, *Camellia sinensis*; differences between green, oolong, black, and dark (fermented) teas arise almost entirely from the degree and type of post-harvest oxidation and microbial fermentation applied to the leaf. This processing step determines which polyphenol classes predominate in the final beverage, shaping bioavailability, taste, and biological activity (Figure 1).

## Camellia sinensis Leaf → Oxidation Level Determines Tea Type & Bioactive Profile

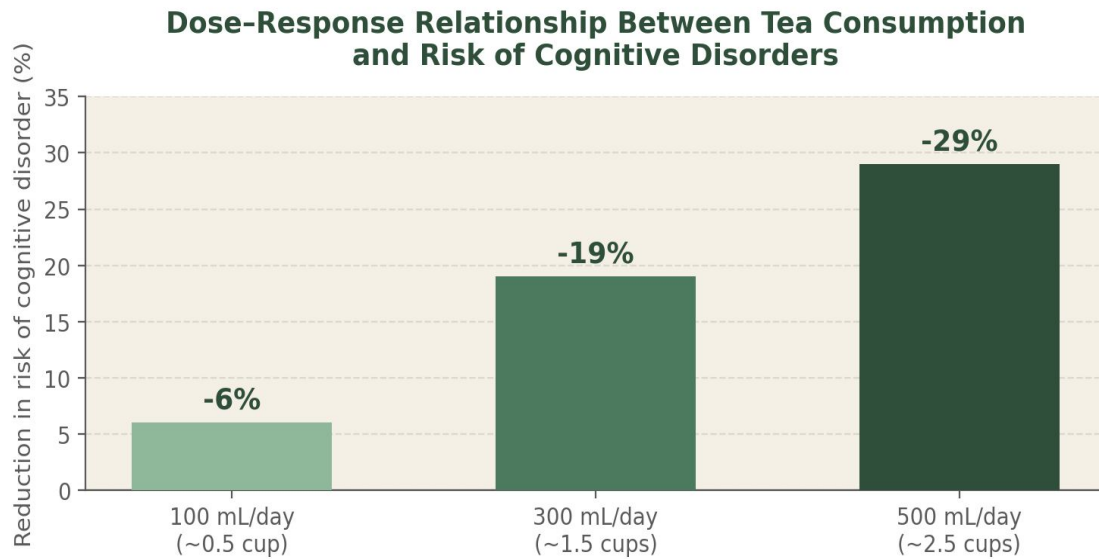


**Figure 1. Oxidation and fermentation pathways from fresh tea leaf to major tea types, and the dominant bioactive compound classes associated with each.**

Green and white teas undergo minimal oxidation and therefore retain the highest concentrations of monomeric catechins, particularly EGCG. Oolong tea is partially oxidized, yielding a mixture of catechins and theaflavins. Black tea is fully oxidized, converting most catechins into theaflavins and thearubigins, which retain antioxidant capacity but differ structurally from their green-tea precursors. Pu-erh and other dark teas undergo microbial fermentation, generating additional metabolites, and both Pu-erh and Fuzhuan (fermented) teas have been shown to reshape gut microbial composition and attenuate diet-induced metabolic disturbance in animal models <sup>11,12</sup>. Alongside polyphenols, tea leaf also contains caffeine and the unique amino acid L-theanine, both of which have independent effects on alertness, mood, and neurotransmission.

### Tea consumption and cognitive function: epidemiological evidence

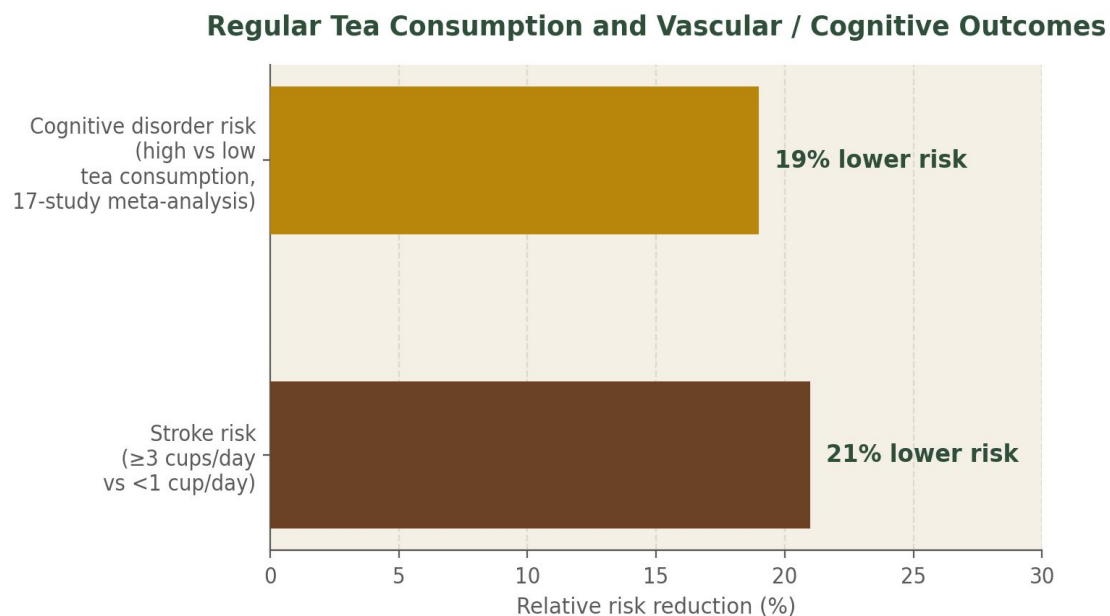
A substantial body of observational research links habitual tea drinking to better cognitive outcomes in later life. Cross-sectional and prospective cohort studies in Asian and Western populations report that regular tea consumers have a lower prevalence of cognitive impairment than non- or infrequent drinkers, and several large cohorts describe reduced risk of progression to dementia among long-term tea drinkers <sup>17-20</sup>. A dose-response meta-analysis of 17 studies comprising 48,435 participants found that higher tea consumption was associated with a significantly reduced risk of cognitive disorders (OR = 0.73, 95% CI: 0.65-0.82), with a graded benefit rising from approximately 6% risk reduction at 100 mL of tea per day to 29% risk reduction at 500 mL per day — roughly two to three standard cups (Figure 2) <sup>1</sup>. Notably, this dose-response association was significant for green tea but not for black or oolong tea in that analysis, whereas other prospective cohorts have reported comparable protective associations for black and oolong tea as the predominant types consumed <sup>1,18</sup>. This apparent discrepancy may partly reflect differences between catechin-dominant (green) and theaflavin/thearubigin-dominant (black, oxidized) polyphenol profiles, differences in habitual intake levels and population genetics across the underlying cohorts, or simply limited statistical power to detect type-specific effects in individual studies; distinguishing between these explanations will require dose-standardized, tea-type-specific comparisons (see Future Directions).



Source: dose-response meta-analysis of 8 prospective cohort studies (Xu et al., 2021)

**Figure 2. Dose-response relationship between daily tea intake and reduction in the risk of cognitive disorders, derived from a pooled dose-response meta-analysis of 17 prospective and cross-sectional studies <sup>1</sup>.**

Cerebrovascular protection appears to contribute to these cognitive benefits. Independent meta-analytic evidence indicates that higher-volume tea consumption is associated with materially lower stroke risk, a magnitude of benefit comparable to that observed for cognitive-disorder risk reduction at similar intake levels (Figure 3), consistent with a shared vascular contribution to the neuroprotective profile of tea <sup>2,3</sup>.



**Figure 3. Comparable magnitude of relative risk reduction for cognitive disorder and cerebrovascular outcomes associated with regular, higher-volume tea consumption <sup>1-3</sup>.**

Table 1 summarizes representative studies spanning cohort, cross-sectional, meta-analytic, and interventional designs.

**Table 1. Representative epidemiological and meta-analytic studies linking tea consumption to cognitive and cerebrovascular outcomes.**

| Study focus                  | Population / design                                                     | Tea type                     | Key finding                                                                                    | Ref.          |
|------------------------------|-------------------------------------------------------------------------|------------------------------|------------------------------------------------------------------------------------------------|---------------|
| Dose-response meta-analysis  | 17 studies, 48,435 participants                                         | Green / black / oolong       | Linear dose-response; 6-29% lower risk of cognitive disorders across 100-500 mL/day            | <sup>1</sup>  |
| Meta-analysis, older adults  | Observational studies, community-dwelling elderly                       | Mixed                        | High tea intake associated with reduced odds of cognitive disorders                            | <sup>3</sup>  |
| Meta-analysis, green tea     | Multiple pooled cohorts (2004-2024)                                     | Green tea                    | Green tea intake inversely associated with cognitive decline risk                              | <sup>2</sup>  |
| Cross-sectional cohort       | 3,868 (MMSE subgroup) and 806 (MoCA subgroup) adults >40 y (APAC study) | Habitual tea, any type       | Habitual, high-frequency, and green tea intake linked to lower cognitive-impairment prevalence | <sup>17</sup> |
| Prospective cohort           | 2,501 community-dwelling adults ≥55 y (Singapore)                       | Black / oolong (predominant) | Dose-dependent reduction in cognitive impairment and decline over 1-2 y follow-up              | <sup>18</sup> |
| Prospective cohort           | ~950 Chinese elderly, 7-y follow-up                                     | Habitual tea                 | Regular tea consumption reduced incident neurocognitive-disorder risk by up to 50%             | <sup>19</sup> |
| Cross-sectional / MCI cohort | Community-dwelling older adults with and without MCI                    | Habitual tea                 | Better global cognition in healthy elderly; association attenuated once MCI established        | <sup>21</sup> |

Findings are not entirely uniform. Some cohorts report null or type-specific associations <sup>1</sup>, and null associations have also been reported for coffee intake despite its shared caffeine content, suggesting that catechins and related polyphenols, rather than caffeine, more plausibly drive the tea-specific cognitive benefit <sup>18,22</sup>. This pattern — stronger associations in cognitively healthy or pre-clinical populations than in those with diagnosed impairment — recurs across the literature and has implications for when, in the life course, tea-based interventions might be most effective <sup>21,23</sup>.

## Molecular mechanisms of direct neuroprotection

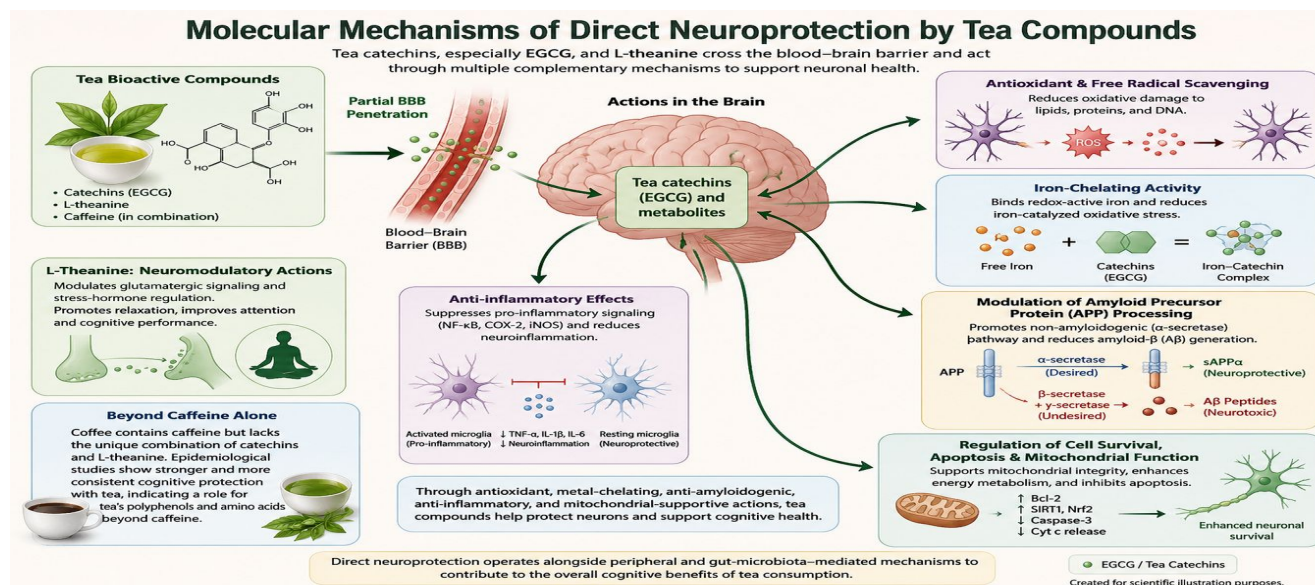
Tea-derived bioactive compounds have attracted considerable attention for their potential to influence multiple molecular processes involved in brain aging and neurodegeneration. Among these compounds, catechins, particularly (–)-epigallocatechin-3-gallate (EGCG), have been most extensively investigated because of their broad antioxidant, anti-inflammatory, metal-chelating, and

neuroprotective activities. Although the systemic bioavailability of intact tea catechins is relatively limited, experimental evidence indicates that a fraction of these compounds and their metabolites can reach the central nervous system. EGCG exhibits limited but measurable permeability across the blood-brain barrier (BBB), allowing direct interaction with neural tissues. Pharmacokinetic studies in experimental animals have reported low oral bioavailability and comparatively restricted brain distribution of EGCG, suggesting that its direct effects within the brain are likely modest in terms of concentration. Nevertheless, even limited exposure may be biologically relevant because catechins can interact with multiple molecular targets and signaling pathways. Importantly, the restricted penetration of intact catechins also supports the possibility that their direct central actions operate in parallel with peripheral and microbiota-mediated mechanisms rather than representing the sole explanation for the neuroprotective effects associated with tea consumption <sup>4,7</sup>.

One of the principal mechanisms through which tea catechins may support neuronal health is the attenuation of oxidative stress. The brain is particularly vulnerable to oxidative damage because of its high oxygen consumption, abundance of oxidizable lipids, and comparatively limited antioxidant defense capacity. Excessive production of reactive oxygen species can damage neuronal membranes, proteins, nucleic acids, and mitochondrial components, thereby contributing to progressive cellular dysfunction. Catechins possess multiple hydroxyl groups capable of scavenging reactive oxygen and nitrogen species and may also influence endogenous antioxidant defense systems. Through these combined actions, tea polyphenols may help reduce oxidative injury and maintain cellular redox homeostasis in neural tissues. This antioxidant capacity is particularly relevant to aging and neurodegenerative disorders, where chronic oxidative stress is closely associated with mitochondrial dysfunction, protein aggregation, and neuronal loss <sup>5,6</sup>. Another potentially important mechanism involves the ability of tea catechins to chelate transition metals, particularly iron. Dysregulated iron accumulation has been implicated in several neurodegenerative conditions because free or poorly bound iron can catalyze the generation of highly reactive radicals through redox cycling. This process may amplify lipid peroxidation and oxidative damage within vulnerable brain regions. By binding redox-active metal ions, catechins may reduce their participation in oxidative reactions and thereby limit iron-mediated neuronal injury. The combination of direct radical scavenging and metal-chelating activity provides a complementary mechanism through which tea-derived polyphenols may reduce oxidative pressure in the aging brain. Tea catechins have also been investigated for their potential influence on protein-processing pathways associated with Alzheimer's disease. Experimental studies suggest that EGCG may modulate amyloid precursor protein processing by favoring non-amyloidogenic pathways, including activation of  $\alpha$ -secretase-mediated processing. Such modulation could potentially reduce the generation and accumulation of amyloid- $\beta$  peptides, which are central pathological features of Alzheimer's disease. In addition to influencing amyloid-related processes, catechins may interfere with protein aggregation and protect neurons from amyloid-induced oxidative and inflammatory stress. These observations suggest that the neuroprotective potential of tea compounds may extend beyond general antioxidant activity to include interactions with disease-specific molecular pathways. At the cellular level, tea catechins may further support neuronal survival through regulation of intracellular signaling pathways involved in apoptosis, inflammation, and mitochondrial function. Mitochondria play a central role in neuronal energy metabolism, and mitochondrial impairment is a common feature of brain aging and neurodegeneration. By reducing oxidative stress and modulating cell-survival signaling, catechins may help preserve mitochondrial

integrity and limit activation of apoptotic pathways. The ability to influence multiple interconnected targets may be particularly important in complex disorders where oxidative stress, inflammation, mitochondrial dysfunction, and abnormal protein accumulation occur simultaneously. In addition to polyphenols, tea contains L-theanine, a distinctive non-protein amino acid that may contribute independently to neurological function. L-theanine has been associated with modulation of glutamatergic neurotransmission and stress-related neurophysiological responses, potentially influencing relaxation, attention, and cognitive performance. Its actions may complement those of caffeine and catechins, suggesting that the biological effects of tea arise from interactions among multiple constituents rather than from a single compound <sup>5</sup>.

The role of caffeine also warrants consideration. Although caffeine can influence alertness and cognitive performance, epidemiological observations indicate that caffeine alone may not fully explain the associations between tea consumption and long-term cognitive health. Coffee contains substantial amounts of caffeine but differs markedly from tea in its catechin and L-theanine composition. Several cohort studies have reported stronger or more consistent associations between tea consumption and cognitive protection than with coffee intake <sup>18,22</sup>. Collectively, these findings suggest that the potential neuroprotective effects of tea are likely attributable to the combined actions of polyphenols, amino acids, and other bioactive constituents. However, given the limited BBB penetration of intact catechins, direct molecular effects within the brain should be considered alongside peripheral metabolic and microbiota-mediated pathways, which may together contribute to the overall relationship between habitual tea consumption and cognitive health.

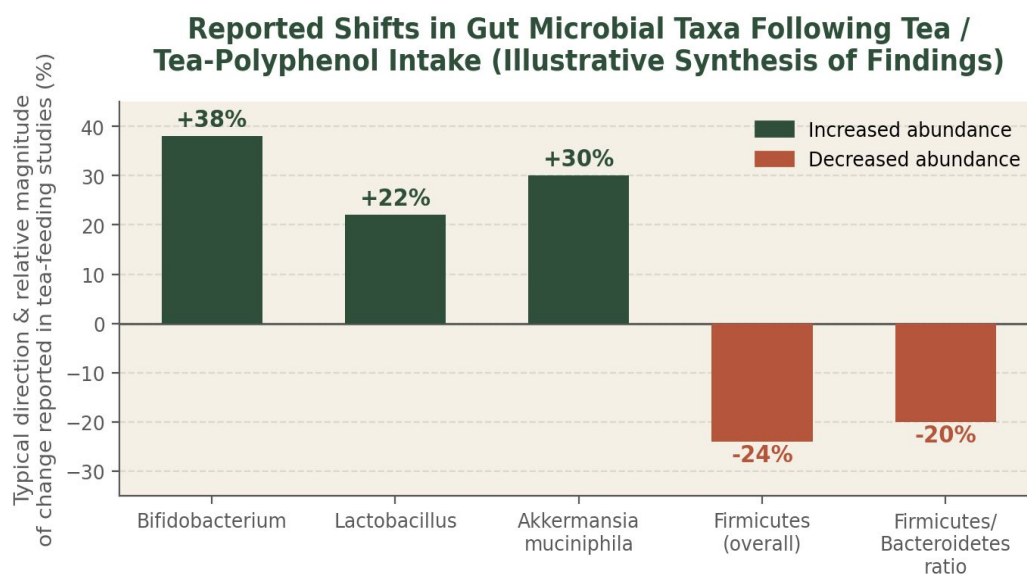


**Figure 4. Molecular mechanisms of direct neuroprotection by tea compounds.**

## Tea and the gut microbiome

A defining pharmacokinetic feature of tea polyphenols is their low oral bioavailability: the majority of ingested catechins and theaflavins are not absorbed in the small intestine and instead travel to the colon, where resident microbiota transform them into smaller phenolic acids and other bioactive metabolites <sup>9</sup>. This positions the gut microbiome as both a transformer of tea polyphenols and a target of their biological activity.

Across human trials and animal studies, tea and tea-polyphenol supplementation have been associated with a consistent set of directional shifts: increases in beneficial genera such as *Bifidobacterium* and *Lactobacillus*, bloom of the mucin-associated organism *Akkermansia muciniphila*, and reductions in the relative abundance of Firmicutes together with a lowered Firmicutes-to-Bacteroidetes ratio — a pattern often used as a marker of a healthier, less obesogenic microbial community (Figure 5)<sup>8-11</sup>. Green and black tea phenolics undergo extensive colonic biotransformation, and the resulting metabolites themselves further modulate the composition of the colonic microbiota, establishing a bidirectional relationship between tea polyphenols and gut bacteria<sup>9</sup>.



*Illustrative synthesis based on human trials and animal/mechanistic studies (Bond & Derbyshire 2019; Fu et al. 2024; Ma et al. 2024)*

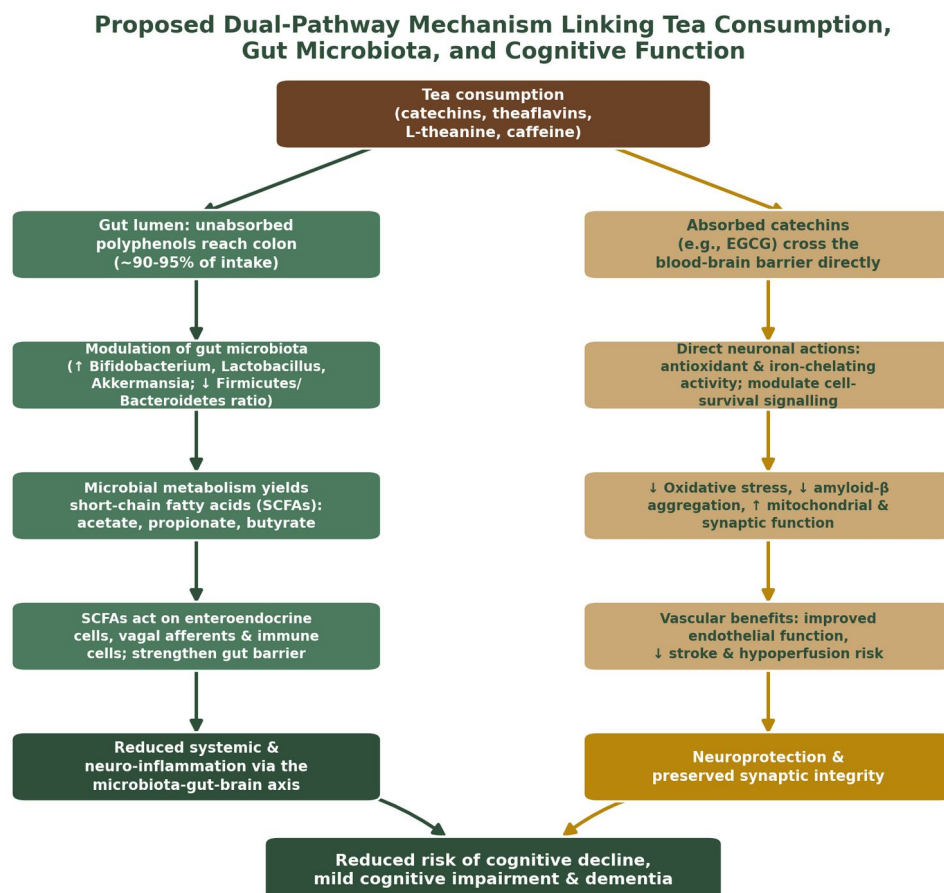
**Figure 5. Illustrative synthesis of directional shifts in gut microbial taxa commonly reported following tea or tea-polyphenol intake across human and animal studies<sup>8-11</sup>.**

Fermented and high-fat-diet intervention studies provide some of the clearest mechanistic evidence. Tea polyphenols have been shown to intervene positively in gut redox status and microbiota composition in high-fat-diet-fed mice with hyperlipidemia<sup>11</sup>, ripened Pu-erh tea extract has been shown to protect mice from diet-induced obesity by remodeling gut microbiota composition<sup>12</sup>, and Fuzhuan brick tea attenuates high-fat-diet-induced obesity and associated metabolic disturbance through similar gut-microbiota-shaping mechanisms<sup>13</sup>. Non-extractable polyphenols from Fu brick tea have additionally been shown to alleviate ulcerative colitis in mice by controlling colon-microbiota-targeted polyphenol release, thereby inhibiting intestinal inflammation — evidence that tea-derived polyphenols can exert colon-localized anti-inflammatory action mediated through the microbiota<sup>14</sup>.

## The microbiota-gut-brain axis: a candidate unifying pathway

The gut and brain communicate bidirectionally through immune, endocrine, and neural (principally vagal) routes, collectively termed the microbiota-gut-brain axis. Short-chain fatty acids (SCFAs) — chiefly acetate, propionate, and butyrate — generated by microbial fermentation of dietary substrates

including tea polyphenols are among the best-characterized signaling molecules in this axis <sup>15</sup>. SCFAs act locally on enteroendocrine cells and the gut epithelial barrier and can directly influence vagal afferent signaling, providing a route by which gut-derived signals reach the brain. In preclinical rodent models of Alzheimer's disease, the SCFA acetate has been shown to exert anti-neuroinflammatory effects by upregulating the receptor GPR41 and inhibiting the ERK/JNK/NF- $\kappa$ B signaling cascade in amyloid- $\beta$ -stimulated microglia; this mechanism has not yet been confirmed in human studies and should be regarded as mechanistic and hypothesis-generating rather than established in people <sup>16</sup>. More broadly, animal and in vitro evidence indicates that SCFAs regulate microglial activation state, energy metabolism, and synaptic remodeling through what has recently been termed the SCFA-microglia pathway, with proposed but not yet clinically confirmed relevance to neuroinflammatory and age-related neurodegenerative conditions in humans <sup>15</sup>. Figure 6 integrates this evidence into a dual-pathway model: tea polyphenols act both indirectly, through gut microbiota modulation, SCFA production, barrier strengthening, and vagal/immune signaling, and directly, through catechins acting on neural tissue to exert antioxidant and anti-amyloidogenic effects. Both routes plausibly converge on reduced neuroinflammation, oxidative stress, and vascular risk — mechanisms consistent with, but not yet directly proven to mediate, the cognitive benefits observed in epidemiological studies <sup>1-7,15-21,23</sup>.



**Figure 6. Proposed dual-pathway mechanism linking tea consumption, gut microbiota modulation, and cognitive protection via the microbiota-gut-brain axis.**

### Clinical evidence, limitations, and controversies

Despite converging mechanistic plausibility, several limitations temper firm clinical conclusions. First, most human evidence linking tea to cognitive outcomes is observational, leaving open the possibility of residual confounding by socioeconomic status, overall diet quality, or health-conscious behavior clustering among tea drinkers<sup>17,21</sup>. Second, tea intake is typically assessed via self-report questionnaires, introducing recall and measurement error<sup>17</sup>. Third, results are not fully consistent across tea types and populations, with some analyses finding significant dose-response protection for green tea but not for black or oolong tea, and vice versa in other cohorts<sup>1,18</sup>; as noted above, this may reflect true differences in polyphenol composition across tea types as readily as it reflects methodological heterogeneity, and the two possibilities are not yet distinguishable with existing data. Fourth, most gut-microbiome mechanistic data derive from animal models or short-duration human trials, and translating rodent microbial shifts to durable, clinically meaningful human outcomes remains an open question<sup>8,10</sup>. Finally, direct blood-brain-barrier penetration of intact catechins is low, meaning that microbial ring-fission metabolites and gut-mediated signaling may in fact account for a substantial share of the observed cognitive benefit — an area that remains comparatively understudied relative to direct catechin pharmacology<sup>7</sup>.

### Future directions

Priority areas for future research include:

- Adequately powered, long-duration randomized controlled trials of tea or isolated tea catechins in cognitively healthy midlife adults, when neuroprotective windows may be widest.
- Mechanistic human trials that simultaneously profile gut microbiota, SCFA output, systemic inflammatory markers, and cognitive performance to directly test the mediating role of the gut-brain axis.
- Dose-standardized comparisons across tea types (green, black, oolong, dark/fermented) to clarify whether oxidation state meaningfully alters cognitive benefit and to resolve the green-tea-versus-black/oolong discrepancy noted above.
- Pharmacokinetic studies quantifying brain-region-specific delivery of catechin microbial metabolites, building on existing rodent BBB-permeability data<sup>7</sup>.

### Conclusion

The available epidemiological, experimental, and microbiome-based evidence collectively suggests that habitual tea consumption may contribute to the maintenance of cognitive health during aging. Tea represents a complex dietary matrix containing biologically active compounds, including catechins, theaflavins, L-theanine, and other polyphenolic metabolites, which may influence multiple pathways associated with neurodegeneration. Rather than acting through a single mechanism, the potential cognitive benefits of tea are likely to arise from complementary and interconnected biological processes. Direct mechanisms include attenuation of oxidative stress, modulation of inflammatory signaling, metal-chelating activity, regulation of amyloid-related pathways, and support of mitochondrial and neuronal function. An equally important emerging perspective is the indirect role of tea through the gut microbiota. Because a substantial proportion of tea polyphenols reaches the gastrointestinal tract, these compounds can interact extensively with resident microbial communities and undergo microbial biotransformation. Such interactions may alter microbial

composition and metabolic activity, promote the production of beneficial metabolites such as short-chain fatty acids, and influence intestinal barrier integrity and systemic immune signaling. Through neural, endocrine, and immune communication pathways, these gut-derived signals may ultimately influence neuroinflammation and brain function, providing a plausible mechanistic link between tea consumption and cognitive health. Nevertheless, important uncertainties remain. Much of the available evidence is derived from observational studies and experimental models, limiting definitive conclusions regarding causality in humans. Future well-designed, long-term clinical studies integrating dietary assessment, cognitive evaluation, microbiome profiling, and metabolomic analyses are required to establish mechanistic relationships. Overall, the current body of evidence supports regular tea consumption as a promising and accessible component of a brain- and gut-healthy dietary pattern, while emphasizing the need for further confirmatory research.

## References

1. Liu X, Du X, Han G, Gao W. Association between tea consumption and risk of cognitive disorders: a dose-response meta-analysis of observational studies. *Oncotarget*. 2017;8:43306-43321.
2. Zhou S, Zhu Y, Ren N, Wu M, Liu Y. The association between green tea consumption and cognitive function: a meta-analysis of current evidence. *Neuroepidemiology*. 2025. doi:10.1159/000543784.
3. Shi M, Cao L, Liu H, Zhou Y, Zhao Y, Xia Y. Association between tea drinking and cognitive disorders in older adults: a meta-analysis of observational studies. *Front Aging Neurosci*. 2022;14:845053.
4. Zhao Y, Zhao B. Protection of green tea polyphenols against neurodegenerative diseases: evidence and possible mechanisms. *J Nutr*. 2025;155:1077-1088.
5. Weinreb O, Mandel S, Amit T, Youdim MB. Neurological mechanisms of green tea polyphenols in Alzheimer's and Parkinson's diseases. *J Nutr Biochem*. 2004;15:506-516.
6. Farzaei MH, Bahramsoltani R, Abbasabadi Z, Braidly N, Nabavi SM. Role of green tea catechins in prevention of age-related cognitive decline: pharmacological targets and clinical perspective. *J Cell Physiol*. 2019;234:2447-2459.
7. Lin LC, Wang MN, Tseng TY, Sung JS, Tsai TH. Pharmacokinetics of (-)-epigallocatechin-3-gallate in conscious and freely moving rats and its brain regional distribution. *J Agric Food Chem*. 2007;55:1517-1524.
8. Bond T, Derbyshire E. Tea compounds and the gut microbiome: findings from trials and mechanistic studies. *Nutrients*. 2019;11:2364.
9. Liu Z, Bruins ME, Ni L, Vincken JP. Green and black tea phenolics: bioavailability, transformation by colonic microbiota, and modulation of colonic microbiota. *J Agric Food Chem*. 2018;66:8469-8477.
10. Zhao Z, Chen R, Ng K. Effects of differently processed tea on the gut microbiota. *Molecules*. 2024;29:4020.
11. Ma H, Zhang B, Hu Y, et al. Correlation analysis of intestinal redox state with the gut microbiota reveals the positive intervention of tea polyphenols on hyperlipidemia in high-fat-diet-fed mice. *J Agric Food Chem*. 2019;67:7325-7335.

12. Lu X, Liu J, Zhang N, et al. Ripened Pu-erh tea extract protects mice from obesity by modulating gut microbiota composition. *J Agric Food Chem.* 2019;67:6978-6994.
13. Liu D, Huang J, Luo Y, et al. Fuzhuan brick tea attenuates high-fat-diet-induced obesity and associated metabolic disorders by shaping gut microbiota. *J Agric Food Chem.* 2019;67:13589-13604.
14. Yang C, Yang W, Wang Y, Du Y, Zhao T, Shao H, et al. Nonextractable polyphenols from Fu brick tea alleviate ulcerative colitis by controlling colon microbiota-targeted release to inhibit intestinal inflammation in mice. *J Agric Food Chem.* 2024;72:7397-7410.
15. Cao Q, Shen M, Li R, Liu Y, Zeng Z, Zhou J, Niu D, Zhang Q, Wang R, Yao J, Zhang G. Elucidating the specific mechanisms of the gut-brain axis: the short-chain fatty acids-microglia pathway. *J Neuroinflammation.* 2025;22:133.
16. Pu D, Jin Y, Wang L, Wang R, Li L, Song Y, Han X, et al. Anti-neuroinflammatory effect of short-chain fatty acid acetate against Alzheimer's disease via upregulating GPR41 and inhibiting ERK/JNK/NF- $\kappa$ B. *J Agric Food Chem.* 2022. doi:10.1021/acs.jafc.0c02807.
17. Zhang J, Wang A, Zhang X, Chen S, Wu S, Zhao X, Zhang Q. Association between tea consumption and cognitive impairment in middle-aged and older adults. *BMC Geriatr.* 2020;20:447.
18. Ng TP, Feng L, Niti M, Kua EH, Yap KB. Tea consumption and cognitive impairment and decline in older Chinese adults. *Am J Clin Nutr.* 2008;88:224-231.
19. Feng L, Chong MS, Lim WS, Gao Q, Nyunt MSZ, Lee TS, Collinson SL, Tsoi T, Kua EH, Ng TP. Tea consumption reduces the incidence of neurocognitive disorders: findings from the Singapore Longitudinal Aging Study. *J Nutr Health Aging.* 2016;20:1002-1009.
20. Feng L, Gwee X, Kua EH, Ng TP. Cognitive function and tea consumption in community dwelling older Chinese in Singapore. *J Nutr Health Aging.* 2010;14:433-438.
21. Xu H, Fiocco AJ, Liu X, Wang T, Li G, Xiao S; Research Group of the Shanghai Brain Aging Study. Association between tea consumption and cognitive function in cognitively healthy older adults and older adults with mild cognitive impairment. *Gen Psychiatr.* 2021;34:e100512.
22. Noguchi-Shinohara M, Yuki S, Dohmoto C, Ikeda Y, Samuraki M, Iwasa K, et al. Consumption of green tea, but not black tea or coffee, is associated with reduced risk of cognitive decline. *PLoS One.* 2014;9:e96013.
23. Sukik L, Liu J, Shi Z. Tea consumption is associated with reduced cognitive decline and interacts with iron intake: a population-based longitudinal study on 4,820 old adults. *J Alzheimers Dis.* 2022. doi:10.3233/JAD-220344.