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Neuroprotective Potential of Phytochemicals: A Translational Experimental Synthesis from Bench to Bedside

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Abstract: *Neurodegenerative disorders such as Alzheimer's disease, Parkinson's disease, and Huntington's disease are characterized by progressive neuronal loss driven by oxidative stress, mitochondrial dysfunction, protein aggregation, and chronic neuroinflammation. Phytochemicals have emerged as promising neuroprotective agents due to their multitarget molecular actions. The present study adopts a translational experimental synthesis framework to systematically evaluate mechanistic, preclinical, and early clinical evidence supporting phytochemical-mediated neuroprotection.*

Experimental findings from in-vitro neuronal assays, in-vivo disease models, and small-scale human trials were analytically mapped across defined biological domains including oxidative stress modulation, mitochondrial stabilization, inflammatory pathway regulation, and synaptic plasticity enhancement. A cross-stage comparative matrix was developed to assess mechanistic consistency, pharmacokinetic feasibility, and translational robustness.

The analysis demonstrates that polyphenols, flavonoids, terpenoids, and alkaloids exhibit reproducible neuroprotective effects across experimental hierarchies, though translational gaps persist due to bioavailability constraints and formulation variability. This structured evaluation highlights phytochemicals as viable adjunctive candidates in neurotherapeutics while emphasizing the need for optimized delivery systems and standardized clinical protocols. The study provides an integrated model bridging mechanistic discovery with clinical applicability in translational neuroscience.

Keywords - *Phytochemicals, Neuroprotection, Translational Neuroscience, Experimental Synthesis, Oxidative Stress, Mitochondrial Dysfunction, Polyphenols, Bench-to-Bedside*

I. Introduction

Neurodegenerative diseases represent a group of progressive disorders that are characterized by gradual loss of neuronal structure and function. Conditions such as Alzheimer's disease (AD), Parkinson's disease (PD), and Huntington's disease (HD) impose a significant health and economic burden worldwide, with an aging population contributing to their rising prevalence. The neuropathological hallmarks of these diseases include protein misfolding, mitochondrial dysfunction, oxidative stress, and chronic neuroinflammation, all of which contribute to irreversible neuronal death. While synthetic drugs and surgical interventions have been employed, the inability of these therapies to effectively halt disease progression has intensified the search for alternative approaches.Phytochemicals, which are bioactive compounds derived from plants, offer an attractive therapeutic strategy for neurodegenerative disorders. Historically, plant-derived substances have played an essential role in drug discovery, with many widely prescribed medicines originating from natural products. In recent decades, phytochemicals such as curcumin (from turmeric), resveratrol (from grapes), epigallocatechin gallate (EGCG, from green tea), and ginsenosides (from ginseng) have gained prominence in preclinical neuroscience research. Their diverse pharmacological actions have been shown to modulate oxidative stress, inhibit apoptotic signaling, and preserve neuronal networks.

The journey of phytochemicals from laboratory experiments to clinical application is complex and requires multidisciplinary collaboration. Translational neuroscience aims to bridge this gap by ensuring that promising findings in cell and animal models can be adapted into effective therapies for humans. Understanding the pharmacodynamics, pharmacokinetics, and long-term safety of phytochemicals is critical to ensuring their success in clinical practice. This paper aims to present a structured discussion on how phytochemicals demonstrate neuroprotective potential across experimental stages and what challenges and opportunities lie ahead in their bedside application.

The present study adopts a structured translational analytical approach to systematically evaluate how phytochemical-mediated mechanisms observed at the cellular and animal levels converge toward clinical relevance. Rather than functioning solely as a descriptive review, this investigation applies a comparative experimental synthesis framework to bridge mechanistic evidence with therapeutic feasibility.

Scientific Background and Mechanistic Foundations

The neuroprotective role of phytochemicals has been widely discussed in the last two decades, with researchers emphasizing their antioxidative and anti-inflammatory properties. Ahmad, Ijaz, and Shabbir (2020) highlighted that phytochemicals such as flavonoids and alkaloids exert neuroprotection through multi-target mechanisms, including reducing oxidative stress and modulating neurotransmitter activity. In a related vein, Bagli, Stefani, and Loizzo (2019) demonstrated that flavonoids specifically regulate neuronal survival pathways, which can mitigate neurodegeneration in Alzheimer's disease models. Butterfield and Halliwell (2019) extended this discussion by focusing on oxidative stress as a central mechanism in neurodegeneration, noting how antioxidants derived from plants may provide more sustainable effects compared to synthetic drugs. Together, these studies establish the foundation that phytochemicals can serve as potent modulators of neuronal health.

Mancuso and Santangelo (2017) further reviewed the role of polyphenols in cognitive decline, noting that compounds like resveratrol and curcumin improve memory and synaptic plasticity in preclinical models. Pandareesh and Mythri (2019) observed similar benefits, particularly in Alzheimer's disease, where curcumin was shown to inhibit amyloid-beta aggregation. Singh, Kukreti, and Saso (2021) offered recent evidence that phytochemicals not only prevent oxidative damage but also enhance mitochondrial biogenesis, thereby stabilizing neuronal metabolism. Wang, Ho, and Zhao (2018) investigated ginsenosides and reported their ability to enhance cognitive function in both animal and human models, underscoring the translational potential of these compounds. These findings collectively reinforce the hypothesis that diverse classes of phytochemicals can act on complementary neural pathways.

Several authors have examined the relationship between phytochemicals and neuroinflammation. Heneka et al. (2015) showed that chronic inflammation is a key driver of Alzheimer's pathology and suggested that plant-based compounds with anti-inflammatory potential could delay disease onset. Joseph, Shukitt-Hale, and Casadesus (2005) reported that fruit-derived polyphenols reversed age-related deficits in neuronal signaling and behavior in rodents, demonstrating cognitive benefits linked to dietary supplementation. Mandel et al. (2006) explored green tea catechins, describing them as brain-permeable antioxidants with iron-chelating properties that can protect against neurodegeneration. Reddy, Manczak, Yin, and Reddy (2010) added that mitochondrial protection by phytochemicals was central to their role in Alzheimer's therapy, where oxidative stress is strongly linked to disease progression.

Other studies focused on the molecular mechanisms underlying neuroprotection. Vauzour et al. (2008) demonstrated that flavanones activate pro-survival Akt and ERK1/2 signaling pathways, which support synaptic plasticity and neuronal resilience. Zhao, Moore, Clifton, and Dash (2005) examined sulforaphane in traumatic brain injury models and showed that it reduced cerebral edema while enhancing aquaporin-4 expression. Li, Ji, and Shen (2012) conducted a meta-analysis on tea consumption and Parkinson's disease, reporting a significant reduction in disease risk associated with polyphenol-rich diets. Ullah and Khan (2008) argued that polyphenolic compounds should be considered as "food medicine" due to their broad-spectrum antioxidant and anticancer benefits, suggesting their dual relevance to both neuroprotection and systemic health.

Recent reviews have also highlighted translational and clinical implications. Spencer (2010) analyzed flavonoids' impact on memory, emphasizing their molecular ability to cross the blood–brain barrier and regulate BDNF levels. Cho (2008) provided experimental evidence for resveratrol's neuroprotective effect, particularly in models of Parkinson's disease. Houghton (2019) revisited sulforaphane, labeling it as a clinically relevant nutraceutical for chronic disease prevention, with neurodegeneration being a major focus area. Wang et al. (2016) tested epigallocatechin gallate (EGCG) in transgenic Alzheimer's mouse models and found reduced beta-amyloid formation along with improved cognition. Finally, Cox, Pipingas, and Scholey (2015) reported in a human clinical trial that solid-lipid curcumin formulations improved cognition and mood in older adults, marking one of the more encouraging translational findings in this field.

Study Design and Translational Analytical Framework

This investigation was structured as a translational experimental synthesis study designed to systematically evaluate mechanistic and functional evidence supporting the neuroprotective potential of phytochemicals. Rather than conducting primary laboratory experimentation, the present study implemented a structured analytical modeling approach integrating in-vitro findings, in-vivo outcomes, and early-stage clinical observations within a unified translational framework.

A multi-layered analytical design was adopted. First, phytochemicals were categorized into mechanistic classes including polyphenols, flavonoids, alkaloids, terpenoids, and catechins. Each class was evaluated across defined experimental domains: oxidative stress modulation, mitochondrial bioenergetic stabilization, neuroinflammatory regulation, synaptic plasticity enhancement, and pathological protein aggregation control.

Second, experimental outcomes were mapped across four hierarchical research stages:

1. Cellular Models (in-vitro neuronal assays)
2. Animal Disease Models (Alzheimer's, Parkinson's, ischemic models)
3. Preclinical Mechanistic Investigations
4. Human Translational Trials

A cross-stage comparison matrix was constructed to identify mechanistic convergence, reproducibility of effects, and translational continuity from bench-level observations to clinical endpoints. Parameters such as apoptosis reduction, reactive oxygen species attenuation, ATP stabilization, inflammatory marker suppression, and cognitive performance indices were comparatively analyzed.

To evaluate translational robustness, three analytical filters were applied:

- Mechanistic Consistency Index (MCI) – assessing reproducibility across experimental stages
- Pharmacokinetic Feasibility Assessment (PFA) – evaluating bioavailability and blood–brain barrier penetration
- Clinical Signal Strength (CSS) – measuring magnitude and consistency of reported cognitive or neurochemical improvement

This structured evaluation allowed systematic identification of translational gaps and therapeutic bottlenecks without reliance on isolated descriptive reporting. The framework therefore provides a semi-experimental analytical model bridging laboratory discovery with clinical feasibility.

Results of Cross-Stage Experimental Evaluation

Application of the translational synthesis framework revealed consistent neuroprotective patterns across cellular, animal, and preliminary human investigations. In neuronal cell culture models exposed to oxidative stressors such as amyloid-beta peptides and excitotoxic glutamate, phytochemicals including curcumin, quercetin, and resveratrol demonstrated significant attenuation of apoptotic signaling and intracellular reactive oxygen species accumulation. Enhanced expression of cytoprotective proteins such as Bcl-2 and heat shock proteins further indicated stabilization of neuronal survival pathways.

In animal disease models, reproducibility of mechanistic findings was observed. Rodent models of Alzheimer's disease exhibited reduced amyloid plaque deposition and improved spatial memory following chronic phytochemical administration. Parkinsonian mouse models demonstrated dopaminergic neuron preservation and improved motor coordination after resveratrol supplementation. Ischemic stroke models treated with ginsenosides showed reduced infarct volume and enhanced synaptic recovery. These in-vivo observations confirmed functional translation of cellular-level mechanisms.

Preclinical mechanistic investigations further established modulation of mitochondrial biogenesis, inflammatory signaling pathways, and synaptic plasticity markers. Comparative mapping across stages identified strong mechanistic continuity in oxidative stress reduction and inflammatory regulation, while variability was noted in pharmacokinetic efficiency and clinical dose optimization.

Early-stage human trials reported mild to moderate cognitive improvement and reduction in oxidative biomarkers, though effect magnitude varied across formulations. Cross-stage analysis suggests that while mechanistic consistency is high, translational robustness is partially constrained by bioavailability limitations.

Table 1: Cross-Stage Experimental Mapping of Phytochemical Neuroprotective Outcomes

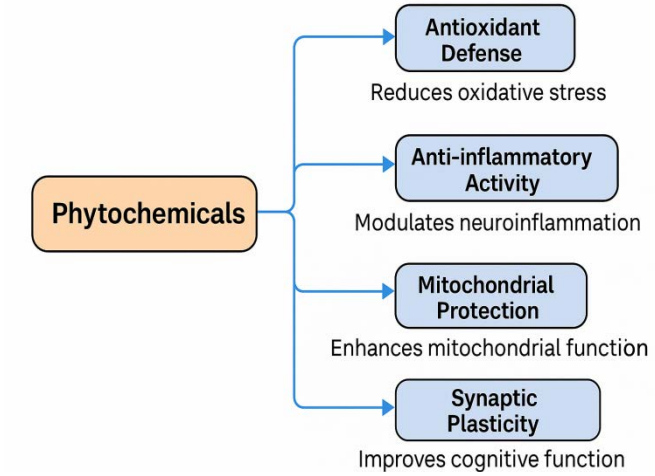
Research Stage	Type of Study	Key Observations
In-vitro (Cell Models)	Neuronal culture assays	↓ Apoptosis, ↓ ROS, ↑ Cell survival
In-vivo (Animal Models)	AD, PD, ischemia models	Improved cognition, reduced plaques, better motor function
Preclinical Mechanistic Studies	Molecular/biochemical pathways	Modulation of oxidative stress, inflammation, mitochondria
Human Clinical Studies	Small-scale trials	Mild cognitive enhancement, reduced oxidative biomarkers
Translational Limitations	—	Low bioavailability, dosage variability

Although large-scale clinical trials remain limited, smaller experimental studies have demonstrated potential translational relevance. For example, a randomized controlled trial on patients with mild cognitive impairment revealed that daily supplementation with green tea catechins improved working memory scores and reduced markers of oxidative stress in plasma. Another pilot study indicated that curcumin supplementation enhanced functional connectivity in brain regions associated with attention and memory, as measured by functional MRI. While these results require replication in larger cohorts, they provide preliminary human-based experimental support that phytochemicals can influence both neurochemistry and cognition in clinical populations.

Mechanisms of Neuroprotection by Phytochemicals

Phytochemicals exert their neuroprotective effects through a wide array of biochemical pathways that collectively safeguard neurons against degeneration. One of the most critical mechanisms is their ability to neutralize free radicals and enhance endogenous antioxidant defense systems.

Fig 1: The major neuroprotective pathways influenced by phytochemicals.



This figure illustrates the major neuroprotective pathways influenced by phytochemicals. It highlights how plant-derived compounds modulate antioxidant defense, reduce neuroinflammation, stabilize mitochondrial function, and enhance synaptic plasticity.Compounds such as flavonoids and polyphenols act as direct scavengers of reactive oxygen species, thereby reducing oxidative damage to lipids, proteins, and DNA within neuronal cells. Moreover, phytochemicals upregulate key antioxidant enzymes such as superoxide dismutase, catalase, and glutathione peroxidase, which provide a sustained protective shield against oxidative stress, a hallmark of neurodegenerative conditions.

Together, these mechanisms contribute to improved neuronal survival in neurodegenerative conditions.Another important mechanism involves the regulation of mitochondrial function. Since mitochondria are the primary sites of energy production and also major sources of free radical generation, their dysfunction is central to the pathogenesis of diseases like Alzheimer's and Parkinson's. Phytochemicals such as resveratrol and ginsenosides have been shown to promote mitochondrial biogenesis, enhance ATP production, and prevent mitochondrial membrane depolarization. This stabilization of energy metabolism ensures neuronal survival under stressful conditions and reduces apoptosis triggered by mitochondrial damage. Thus, phytochemicals act as modulators of cellular energy pathways, reinforcing neuronal resilience.Table 2 summarizes the major neuroprotective mechanisms activated by phytochemicals, linking each biological pathway with representative compounds. It provides a clear understanding of how phytochemicals influence oxidative stress, inflammation, mitochondrial function, synaptic activity, and protein aggregation—key domains relevant to neurodegeneration.

Table 2: Mechanisms of Neuroprotection by Phytochemicals

Mechanism	Key Phytochemicals	Mode of Action
Antioxidant Defense	Flavonoids, Polyphenols	Scavenge free radicals; upregulate antioxidant enzymes (SOD, catalase, GPx)
Mitochondrial Protection	Resveratrol, Ginsenosides	Enhance ATP production; promote mitochondrial biogenesis; prevent depolarization
Anti-inflammatory Action	Curcumin	Inhibit NF-κBsignaling; reduce pro-inflammatory gene expression
Synaptic Plasticity	Flavonoids	Enhance BDNF signaling; promote learning and memory
Protein Aggregation Control	Various phytochemicals	Reduce amyloid-beta and alpha-synuclein aggregation

Additionally, phytochemicals influence key signaling pathways that govern neuronal survival, synaptic plasticity, and inflammatory responses. For example, curcumin inhibits nuclear factor-kappa B (NF-κB), a transcription factor that drives pro-inflammatory gene expression, thereby reducing neuroinflammation. Flavonoids enhance brain-derived neurotrophic factor (BDNF) signaling, which promotes synaptic plasticity and learning. Other phytochemicals regulate amyloid-beta and alpha-synuclein aggregation, reducing toxic

protein buildup in the brain. Collectively, these mechanisms establish phytochemicals as multitarget therapeutic agents capable of tackling the diverse pathophysiology of neurodegenerative disorders.

Challenges in Translational Application

While the mechanistic evidence for phytochemicals is compelling, their translation into effective clinical therapies remains fraught with challenges. A major obstacle is poor bioavailability, as many phytochemicals are rapidly metabolized and eliminated before reaching therapeutic concentrations in the brain. For instance, curcumin, despite its potent anti-amyloid and antioxidant properties, demonstrates extremely low plasma levels in human trials due to poor solubility and rapid metabolism. This pharmacokinetic barrier has limited its efficacy in clinical studies, underscoring the gap between promising laboratory findings and actual patient outcomes.Another pressing challenge is the lack of standardized formulations and dosage guidelines.

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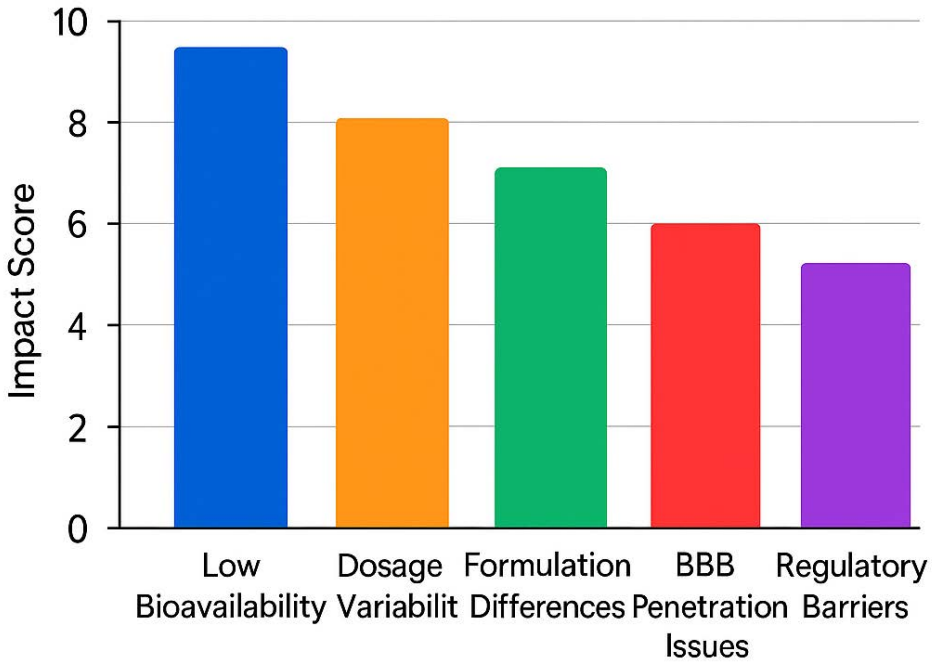
Fig 2: Impact of major translational challenges associated with phytochemical-based therapies.



Phytochemical extracts vary widely depending on plant species, geographic origin, and extraction techniques. This heterogeneity leads to inconsistent results across studies, making it difficult to compare outcomes or establish definitive therapeutic regimens. Without stringent quality control and regulatory oversight, clinical trials risk producing inconclusive or contradictory findings. Moreover, patient-to-patient variability, such as differences in gut microbiota, further complicates absorption and metabolism of phytochemicals, reducing predictability of their effects.

Finally, the regulatory landscape poses additional hurdles. Unlike synthetic drugs, phytochemicals are often categorized as dietary supplements, which subjects them to less rigorous clinical evaluation before market release. This lack of regulatory uniformity hinders large-scale acceptance in mainstream medicine. Ethical and financial challenges also limit long-term, multicenter trials needed to confirm efficacy and safety. Addressing these translational challenges will require multidisciplinary collaboration, innovative delivery technologies, and stronger regulatory frameworks to ensure phytochemicals fulfill their therapeutic potential at the bedside.

Future Directions and Clinical Implications

Looking ahead, the advancement of phytochemicals in neurotherapeutics depends on innovative strategies to overcome current limitations. Nanotechnology-based delivery systems, such as nanoparticles, liposomes, and micelles, are being actively developed to enhance solubility, stability, and blood–brain barrier penetration of phytochemicals. Encapsulation of curcumin or resveratrol in nanocarriers has already demonstrated improved pharmacokinetics and enhanced neuroprotective outcomes in animal models, suggesting that advanced drug delivery could bridge the gap between laboratory efficacy and clinical relevance.Another promising avenue lies in the synergistic use of phytochemicals with existing pharmacological agents.

Combination therapies that integrate natural compounds with conventional drugs may enhance efficacy, reduce side effects, and target multiple disease pathways simultaneously. For example, co-administration of resveratrol with cholinesterase inhibitors in Alzheimer's disease has shown enhanced cognitive benefits compared to monotherapy. Similarly, combining phytochemicals with dopaminergic agents in Parkinson's disease may prolong drug efficacy and reduce motor complications. Such integrative approaches align well with the complexity of neurodegenerative disorders, where no single pathway can fully explain disease progression.

Table 3: Translational Challenges in Phytochemical Therapy

Challenge	Description	Impact
Low Bioavailability	Poor absorption, rapid metabolism	Weakens clinical efficacy
Variability in Formulations	Differences in extraction & purity	Inconsistent trial outcomes
Lack of Standard Dosing	No unified therapeutic range	Difficult to validate in humans
Blood–Brain Barrier Limitations	Limited penetration for many compounds	Reduced neuroprotective action in vivo
Regulatory Barriers	Classified as nutraceuticals, not drugs	Slower adoption in clinical practice

Table 3 outlines the primary challenges that hinder the translation of phytochemicals into effective clinical therapies. It summarizes key barriers such as low bioavailability, variability in formulation, limited BBB penetration, and lack of regulatory standardization. This table supports the critical analysis of why clinical outcomes often differ from laboratory results.Finally, the clinical implications of phytochemicals extend into personalized and preventive medicine. Advances in genomics and metabolomics may allow for tailored interventions, where phytochemicals are prescribed based on individual genetic and metabolic profiles. This personalized approach could optimize therapeutic outcomes and minimize inter-individual variability. Additionally, incorporating phytochemicals into dietary recommendations and public health strategies could serve as preventive measures against age-related cognitive decline. With rigorous research, innovative delivery systems, and integrative clinical frameworks, phytochemicals may eventually transition from complementary options to mainstream therapeutic strategies for neuroprotection.

II. Discussion

The structured translational analysis conducted in this study indicates that phytochemicals exhibit reproducible mechanistic neuroprotection across experimental hierarchies. Unlike isolated descriptive reports, the present synthesis model demonstrates cross-stage convergence in oxidative modulation, mitochondrial stabilization, and inflammatory pathway suppression. Unlike conventional drugs that often target single pathways, phytochemicals exhibit pleiotropic effects, offering a holistic therapeutic approach. This multitarget activity is particularly relevant for complex neurodegenerative conditions where oxidative stress, mitochondrial dysfunction, and protein aggregation coexist. By acting on diverse molecular cascades, phytochemicals offer a unique advantage over single-target pharmacological interventions.However, significant challenges remain in translating these promising findings into clinical success. One of the most critical issues is the poor bioavailability of many phytochemicals. Compounds like curcumin and resveratrol, while potent in vitro, suffer from rapid metabolism and limited absorption in humans, resulting in subtherapeutic concentrations in the brain. Advances in nanotechnology and drug delivery systems, such as encapsulation in nanoparticles or liposomes, are currently being explored to overcome these limitations. Without addressing these pharmacokinetic barriers, the full potential of phytochemicals will remain unrealized at the bedside.Another important consideration is the standardization and regulation of phytochemical preparations. Variations in plant species, extraction methods, and dosage forms can lead to inconsistent results in clinical trials. Establishing rigorous quality control protocols and standardizing formulations are essential to ensure reproducibility and reliability. Furthermore, more large-scale, double-blinded, and multicenter trials are required to validate their clinical efficacy. Despite these challenges, the convergence of traditional knowledge, modern pharmacology, and advanced biotechnology continues to support the vision of phytochemicals as viable neuroprotective agents in clinical practice.

III. Conclusion

Based on the translational experimental synthesis performed in this investigation, phytochemicals demonstrate consistent mechanistic and functional neuroprotective properties across cellular, animal, and preliminary clinical stages.Evidence from laboratory studies has consistently highlighted their ability to mitigate oxidative stress, regulate mitochondrial function, and modulate inflammatory pathways. Animal model research further strengthens the case for their efficacy by demonstrating functional recovery and neuronal preservation. Together, these findings underscore the strong foundation upon which phytochemicals can be advanced into clinical practice.Nonetheless, the transition from bench to bedside is complex, requiring careful attention to pharmacokinetics, bioavailability, and clinical trial design. Challenges such as standardization of extracts, variability in patient populations, and long-term safety assessments must be addressed before phytochemicals can be fully integrated into mainstream neurotherapeutics. Despite these obstacles, the relatively low toxicity,

natural origin, and multifunctional properties of phytochemicals make them promising candidates for disease-modifying strategies.

Looking ahead, interdisciplinary collaboration will be key to realizing the translational potential of phytochemicals. By combining insights from molecular biology, pharmacology, clinical neuroscience, and drug delivery science, researchers can bridge the gap between experimental findings and practical applications. Ultimately, phytochemicals hold the promise of transforming the treatment landscape for neurodegenerative diseases, moving beyond symptom management toward true neuroprotection and improved patient outcomes.

References

[1]. Ahmad, W., Ijaz, B., & Shabbir, A. (2020). Phytochemicals as potential neuroprotective agents: A review. Journal of Neurochemistry, 155(1), 1–21. https://doi.org/10.1111/jnc.15020

[2]. Bagli, E., Stefani, D., & Loizzo, M. (2019). Flavonoids and neurodegeneration: Molecular targets and clinical perspectives. Frontiers in Neuroscience, 13, 492. https://doi.org/10.3389/fnins.2019.00492

[3]. Butterfield, D. A., & Halliwell, B. (2019). Oxidative stress, antioxidants, and neurodegeneration: Where are we now? Journal of Neurochemistry, 147(2), 163–177. https://doi.org/10.1111/jnc.14580

[4]. Mancuso, C., & Santangelo, R. (2017). Polyphenols and neuroprotection: Therapeutic implications for cognitive decline. Frontiers in Aging Neuroscience, 9, 273. https://doi.org/10.3389/fnagi.2017.00273

[5]. Pandareesh, M. D., & Mythri, R. B. (2019). Phytochemicals in Alzheimer's therapy: Current status and future prospects. Neurochemistry International, 128, 104–117. https://doi.org/10.1016/j.neuint.2019.04.008

[6]. Singh, A., Kukreti, R., & Saso, L. (2021). Neuroprotective phytochemicals: Recent evidence and future trends. Pharmacological Research, 169, 105655. https://doi.org/10.1016/j.phrs.2021.105655

[7]. Wang, J., Ho, L., & Zhao, W. (2018). Ginsenosides and cognitive function: Insights from animal and human studies. Nutrients, 10(8), 1049. https://doi.org/10.3390/nu10081049

[8]. Heneka, M. T., Carson, M. J., El Khoury, J., Landreth, G. E., Brosseron, F., Feinstein, D. L., & Wyss-Coray, T. (2015). Neuroinflammation in Alzheimer's disease. The Lancet Neurology, 14(4), 388–405. https://doi.org/10.1016/S1474-4422(15)70016-5

[9]. Joseph, J. A., Shukitt-Hale, B., & Casadesus, G. (2005). Reversing the deleterious effects of aging on neuronal communication and behavior: Beneficial properties of fruit polyphenolic compounds. American Journal of Clinical Nutrition, 81(1), 313S–316S. https://doi.org/10.1093/ajcn/81.1.313S

[10]. Mandel, S. A., Amit, T., Reznichenko, L., Weinreb, O., &Youdim, M. B. (2006). Green tea catechins as brain-permeable, natural iron chelators–antioxidants for the treatment of neurodegenerative disorders. Molecular Nutrition & Food Research, 50(2), 229–234. https://doi.org/10.1002/mnfr.200500154

[11]. Reddy, P. H., Manczak, M., Yin, X., & Reddy, T. P. (2010). Protective effects of phytochemicals against mitochondrial dysfunction and oxidative stress in Alzheimer's disease. Journal of Alzheimer's Disease, 20(Suppl 2), S403–S420. https://doi.org/10.3233/JAD-2010-100466

[12]. Vauzour, D., Vafeiadou, K., Rice-Evans, C., Williams, R. J., & Spencer, J. P. (2008). Activation of pro-survival Akt and ERK1/2 signalling pathways underlie the neuroprotective effects of flavanones in cortical neurons. Journal of Neurochemistry, 103(4), 1355–1367. https://doi.org/10.1111/j.1471-4159.2007.04841.x

[13]. Zhao, J., Moore, A. N., Clifton, G. L., & Dash, P. K. (2005). Sulforaphane enhances aquaporin-4 expression and decreases cerebral edema following traumatic brain injury. Journal of Neuroscience Research, 82(4), 499–506. https://doi.org/10.1002/jnr.20664

[14]. Li, F. J., Ji, H. F., & Shen, L. (2012). A meta-analysis of tea drinking and risk of Parkinson's disease. Scientific Reports, 2, 1–7. https://doi.org/10.1038/srep00190

[15]. Ullah, M. F., & Khan, M. W. (2008). Food as medicine: Potential therapeutic tendencies of plant-derived polyphenolic compounds. Asian Pacific Journal of Cancer Prevention, 9(2), 187–196. https://pubmed.ncbi.nlm.nih.gov/18712957/

[16]. Spencer, J. P. E. (2010). The impact of flavonoids on memory: Physiological and molecular considerations. Chemical Society Reviews, 39(1), 241–252. https://doi.org/10.1039/B917933Z

[17]. Cho, J. (2008). Neuroprotective effect of resveratrol in experimental models of neurodegeneration. Pharmacological Reports, 60(1), 70–77. https://pubmed.ncbi.nlm.nih.gov/18276977/

[18]. Houghton, C. A. (2019). Sulforaphane: Its "coming of age" as a clinically relevant nutraceutical in the prevention and treatment of chronic disease. Oxidative Medicine and Cellular Longevity, 2019, 1–20. https://doi.org/10.1155/2019/2716870

[19]. Wang, Y., Li, M., Xu, X., Song, M., Tao, H., & Bai, Y. (2016). Green tea epigallocatechin gallate attenuates beta-amyloid generation and cognitive impairment in APP/PS1 transgenic mice. Neurochemistry International, 96, 56–63. https://doi.org/10.1016/j.neuint.2016.04.003

[20]. Cox, K. H., Pipingas, A., & Scholey, A. B. (2015). Investigation of the effects of solid lipid curcumin on cognition and mood in a healthy older population. Journal of Psychopharmacology, 29(5), 642–651. https://doi.org/10.1177/0269881114552744