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Revisiting Parkinson's Disease Management: A Comprehensive Review of Herbal Approaches and Modern Delivery Strategies

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Abstract

Parkinson's disease (PD) is a chronic neurodegenerative disorder characterized by the loss of dopaminergic neurons in the substantia nigra, leading to motor and non-motor symptoms. Current pharmacological treatments provide symptomatic relief but are often limited by side effects and do not prevent disease progression. As a result, there is increasing interest in herbal medicines as potential alternatives or complementary therapies for PD. Various plant-based compounds such as *Mucuna pruriens, Withania somnifera, Curcuma longa*, and *Panax ginseng* have shown neuroprotective effects through mechanisms like antioxidant activity, anti-inflammatory responses, and support of dopaminergic function. This review provides an overview of PD pathophysiology and current therapeutic strategies, followed by a discussion on the biological actions of key herbal agents. Recent advancements in herbal drug formulations, including nanoformulations and transdermal systems, are also presented. Evidence from both preclinical and clinical studies on the effectiveness and safety of herbal treatments is evaluated, along with information on herb-drug interactions. The review also highlights ongoing challenges in standardization, dosage regulation, and research gaps, while pointing toward future possibilities for integrating herbal and conventional approaches in PD management.

Keywords: Parkinson's Disease, Herbal Medicine, Neuroprotection, Phytotherapy

1. INTRODUCTION

Overview of Parkinson's Disease (PD)

Parkinson's disease (PD) ranks as the second most common neurodegenerative disorder globally, impacting more than 10 million individuals, with its occurrence notably rising among those over 60 years old [1]. Clinically, PD is identified by various motor symptoms, including resting tremor, rigidity, akinesia, bradykinesia, and postural instability, alongside non-motor symptoms such as depression, anosmia, constipation, REM sleep behavior disorder, dementia, cognitive decline, autonomic dysfunction, and sensory abnormalities. As a significant global health issue, Parkinson's disease affects an estimated 10

million people worldwide. The incidence of PD is increasing due to the aging population and is projected to double by 2040. In developed areas, especially in Europe and North America, the prevalence is higher, attributed to longer life spans and better diagnostic methods. Research indicates that men have a 1.5 times higher likelihood of developing PD compared to women, and the disease is more prevalent in those over 60. The highest age-standardized prevalence rates are found in countries like the United States, the United Kingdom, and Scandinavian nations. However, low- and middle-income countries, including parts of Asia, are experiencing a swift increase in PD cases due to demographic changes and rising life expectancy, although they often lack adequate healthcare infrastructure to manage the disease.

In India, Parkinson's Disease (PD) is becoming a notable public health concern, with its prevalence estimated at 0.5 to 0.6% of the general population, similar to rates in other Asian nations. However, as the population ages, this prevalence is anticipated to rise significantly in the coming years. As of 2020, approximately 1 million individuals in India are affected by PD, and this figure is expected to increase due to the country's rapidly aging population and growing urbanization. While PD is frequently underdiagnosed in rural parts of India, urban areas are experiencing an increase in cases due to improved awareness and healthcare services. Genetic factors also influence PD prevalence in India, with certain groups exhibiting higher rates, and environmental factors, such as pesticide exposure, potentially contributing to the rising numbers [2, 3].

Figure 1: Common Symptoms Associated with Parkinson's Disease

Interestingly, these non-motor symptoms frequently appear before the motor symptoms, suggesting a prolonged prodromal stage of the disease. Pathologically, Parkinson's Disease (PD) is marked by the buildup of misfolded α-synuclein proteins within Lewy bodies, leading to neuronal dysfunction and degeneration [4]. This degeneration mainly takes place in the substantia nigra pars compacta, causing a reduction of dopamine in the striatum and disturbing the motor circuit equilibrium in the basal ganglia [5]. The pathogenesis of PD involves mitochondrial dysfunction, compromised autophagy-lysosomal pathways, and persistent neuroinflammation, with microglial activation and the release of pro-inflammatory cytokines playing significant roles in the disease's progression [6]. Although aging and better diagnostic methods contribute to the rising prevalence, men are statistically 1.5 times more likely

to develop PD than women, likely due to hormonal and genetic factors [7]. While levodopa remains the primary treatment for symptoms, its long-term use can result in motor complications like dyskinesia, leading to the investigation of alternative treatments such as dopamine agonists, deep brain stimulation, and gene therapy. Recent progress has also concentrated on nanoparticle-based and targeted delivery systems, including nasal, transdermal, and in situ gel formulations, to enhance central nervous system bioavailability and minimize systemic side effects. Additionally, the incorporation of neuroimaging biomarkers, genetic screening, and artificial intelligence is revolutionizing early diagnosis and facilitating the creation of personalized therapeutic strategies. Despite symptomatic treatments providing relief, there is a pressing need for disease-modifying strategies that can stop or reverse the neurodegenerative processes underlying PD.

Mechanism of Parkinson's Disease and Pathogenesis

The development of Parkinson's disease (PD) is influenced by multiple factors and involves intricate cellular and molecular processes. A key feature of PD is the misfolding and accumulation of α-synuclein into intracellular deposits called Lewy bodies and Lewy neurites, especially within dopaminergic neurons. These aggregates are harmful to neurons and can interfere with various cellular functions. One significant mechanism is mitochondrial dysfunction, particularly in complex I of the electron transport chain, resulting in decreased ATP production and increased reactive oxygen species (ROS) generation. Oxidative stress then damages cellular proteins, lipids, and DNA, leading to neuronal death.

Another crucial mechanism is neuroinflammation, which is driven by the persistent activation of microglia, the brain's resident immune cells. These cells release pro-inflammatory cytokines like IL-1β, TNF-α, and IL-6, which further worsen neuronal damage. Additionally, the failure of protein degradation systems, such as the ubiquitin-proteasome system and autophagy-lysosome pathways, to clear aggregated proteins contributes to the buildup of α-synuclein. Mutations in genes like α-synuclein (SNCA), LRRK2, PARK2 (parkin), PINK1, and DJ-1 are associated with familial PD and impact mitochondrial function, oxidative stress response, and protein degradation.

Environmental toxins like paraquat, rotenone, and MPTP have been found to trigger symptoms like Parkinson's disease by specifically harming dopaminergic neurons, thereby replicating the mitochondrial dysfunction seen in PD. The complex interaction of genetic predisposition, protein aggregation, oxidative stress, impaired cellular clearance, and inflammation ultimately leads to the degeneration of dopaminergic neurons, which is the basis for the clinical manifestations of PD.

Currently, the pharmacological treatment of Parkinson's disease (PD) is mainly aimed at symptom relief, especially motor dysfunction, as no known cure or treatment stops the disease from progressing. Levodopa, a precursor to dopamine that crosses the blood-brain barrier and is converted into dopamine in the brain, is the mainstay of PD treatment. It is frequently administered alongside carbidopa or benderizine, which prevent levodopa's peripheral metabolism, thereby increasing its availability and minimizing side effects like nausea. Although effective, prolonged use of levodopa is linked to motor complications such as dyskinesia and the wearing-off effect. Dopamine agonists, including pramipexole, ropinirole, and rotigotine, directly activate dopamine receptors and can be used alone in early PD or in combination with other treatments in later stages. MAO-B inhibitors like selegiline and rasagiline slow down dopamine degradation by inhibiting monoamine oxidase-B, providing mild symptom relief.

Catechol-O-methyltransferase (COMT) inhibitors, such as entacapone and porcupine, extend the action of levodopa by preventing its breakdown. Amantadine, an NMDA receptor antagonist, offers limited benefits, particularly in reducing dyskinesia caused by levodopa. Anticholinergic drugs, such as trihexyphenidyl, are sometimes used for tremor-dominant PD, especially in younger patients, but their use is restricted due to cognitive side effects in older individuals. For non-motor symptoms like depression, psychosis, and sleep disorders, specific pharmacotherapies, including SSRIs, atypical antipsychotics (e.g., clozapine, pimavanserin), and melatonin, are used. While these medications enhance quality of life, none are neuroprotective or alter the disease course. This therapeutic gap highlights the urgent need for new strategies to address the underlying mechanisms of PD, such as α-synuclein aggregation, oxidative stress, mitochondrial dysfunction, and neuroinflammation [8].

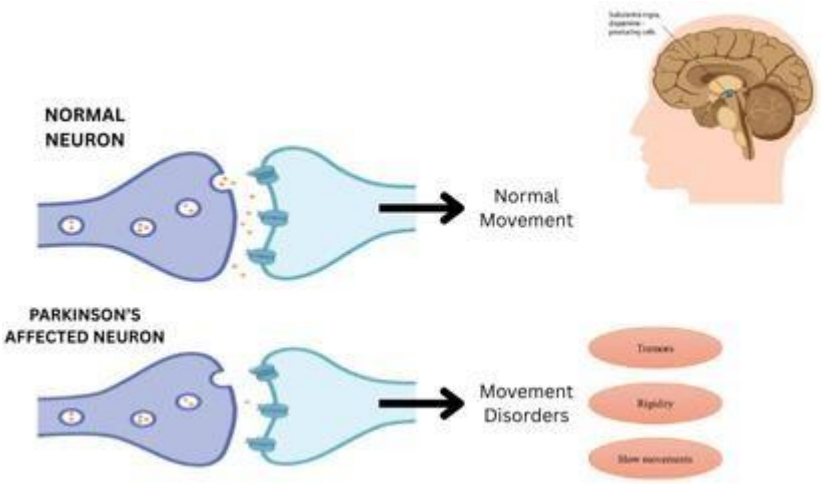

Figure 2: Pathophysiological Mechanism of Parkinson's Disease—Comparison Between Normal and Affected Neurons Showing Dopaminergic Deficiency and Resulting Motor Symptoms

The Role of Herbal Medicines in Parkinson's Disease

Herbal Medicines as Neuroprotective Agent

Herbal medications are increasingly being investigated as neuroprotective possibilities for treating Parkinson's disease (PD), owing to their extensive modes of action and less side effects as compared to standard synthetic pharmaceuticals. Plant-based substances with antioxidant, anti-inflammatory, and anti-apoptotic activities can reduce oxidative damage, mitochondrial dysfunction, and α-synuclein build-up, which are essential pathogenic aspects of Parkinson's disease [9]. Compounds such as curcumin (from *Curcuma longa*), resveratrol (from grapes), baicalein (from *Scutellaria baicalensis*), and puerarin (from *Pueraria lobata*) have been shown in experimental models to preserve dopaminergic neurons, improve mitochondrial efficiency, and regulate neuroinflammatory responses [10]. These phytochemicals also interact with important signalling pathways such as PI3K/Akt, Nrf2/ARE, and MAPK, which are critical for neuronal health and survival. Despite these encouraging discoveries, most of the supporting evidence comes from cell-based and animal research, and well-structured clinical trials are still lacking. Still, integrating traditional herbal therapies with current pharmaceutical techniques might provide a more holistic and multi-targeted approach to Parkinson's disease treatment [11].

Table 1: Mechanisms of Action, Pharmacological Effects, and Sources of Herbal Compounds in Parkinson's Disease Therapy

Compound	Source Plant	Mechanism of Action	Pharmacological Effects	Reference
Curcumin	*Curcuma longa* (Turmeric)	Antioxidant via Nrf2/ARE activation; Inhibits NF-κB and α-synuclein aggregation	Reduces oxidative stress and neuroinflammation	[10, 11]
Puerarin	*Pueraria lobata* (Kudzu)	Activates PI3K/Akt signaling; Inhibits mitochondrial apoptosis pathways	Protects dopaminergic neurons; improves mitochondrial health	[12, 13]
Resveratrol	Grapes, *Polygonum cuspidatum*	Activates SIRT1 and Nrf2; suppresses neuroinflammation and apoptosis	Enhances mitochondrial biogenesis; reduces oxidative burden	[11]
Baicalein	*Scutellaria baicalensis*	Inhibits iron-induced oxidative stress; Modulates MAPK signaling	Anti-apoptotic and neuroprotective effects	[10]
Ginsenosides	*Panax ginseng*	Reduces ROS and apoptosis via anti-inflammatory and mitochondrial pathways	Neurorestorative and cognition-enhancing effects	[11]
Epigallocatechin gallate (EGCG)	Green Tea (*Camellia sinensis*)	Inhibits α-synuclein fibrillation; Scavenges ROS	Reduces neuronal loss and supports synaptic function	[10]
Paeoniflorin	*Paeonia lactiflora*	Suppresses microglial activation; Modulates autophagy and anti-apoptotic proteins	Attenuates neuroinflammation and neuronal damage	[11]

Advantages of Herbal Treatments Over Conventional Therapies

Herbal remedies are emerging as viable alternatives to traditional Parkinson's disease (PD) treatments, owing to their multifaceted processes and decreased risk of adverse effects. Unlike standard medications like levodopa, which primarily provide symptomatic relief through dopamine replenishment but fail to target the complex pathophysiological mechanisms of Parkinson's disease and may eventually lead to complications such as motor fluctuations and dyskinesia, herbal compounds provide broader neuroprotective benefits [14].

Natural agents can affect several disease-related processes, such as oxidative stress, mitochondrial dysfunction, inflammation, and α-synuclein buildup, all of which contribute to Parkinson's disease development [15]. Notably, *Withania somnifera* (Ashwagandha) has been shown to improve mitochondrial activity and protect against neuronal loss, whilst *Ginkgo biloba* extracts are known to increase antioxidant capacity and cerebral perfusion [16, 17]. Furthermore, herbal remedies are often well-tolerated and have few adverse effects, making them appropriate for long-term usage. They may also give ancillary advantages such as enhanced mood, sleep, and cognitive function all of which are typically impaired in PD patients [18].

The Growing Interest in Integrating Herbal Medicine into PD Care

Amid the growing limits of traditional Parkinson's disease (PD) therapies and increased patient demand f or natural choices, there has been a global boom in the use of herbal medicine as part of integrated thera py methods.
This trend is backed by a growing body of research demonstrating the effectiveness of different plant ext racts and bioactive substances in Parkinson's disease models.
In recent years, both clinical and translational research have investigated mixing herbal medicines with mainstream pharmaceuticals to improve symptom management and perhaps slow disease progression [1 9]. Advancements in standardization techniques and biomarker identification have increased the scientific legitimacy of herbal medicines by allowing for more accurate dosage and consistent trial results [20]. Furthermore, increased involvement by pharmaceutical companies and regulatory bodies has resulted in the development of novel herbal delivery systems, such as nanoparticle-based formulations and in situ gels, intending to improve blood-brain barrier permeability and targeted delivery [21, 22]. These advances represent a growing appreciation of the therapeutic potential of well-studied herbal therapies as effective adjuncts or perhaps alternatives in the changing management of Parkinson's disease.

Prominent Herbal Plants and Active Compounds for PD

A wide range of herbal plants have been investigated for their neuroprotective properties in Parkinson's disease (PD) treatment, owing to their numerous phytochemicals and capacity to act on various pathogenic sites. *Mucuna pruriens* (Velvet Bean), a natural source of levodopa, has antioxidant and neurorestorative qualities that may help to reduce both Parkinson's disease symptoms and problems associated with long-term levodopa administration. *Withania somnifera* (Ashwagandha) provides neuroprotection through mitochondrial support, anti-apoptotic actions, and the stimulation of endogenous antioxidant enzymes, which aids in the maintenance of dopaminergic neurons [23]. *Curcuma longa* (Turmeric), especially its active component curcumin, has been demonstrated to suppress α-synuclein aggregation and modify neuroinflammatory processes. However, its therapeutic value is restricted due to low absorption, necessitating sophisticated formulation solutions [24].

Advancements in standardization techniques and biomarker identification have increased the scientific legitimacy of herbal medicines by allowing for more accurate dosage and consistent trial results [25]. Furthermore, increased involvement by pharmaceutical companies and regulatory bodies has resulted in the development of novel herbal delivery systems, such as nanoparticle-based formulations and in situ gels, to improve blood-brain barrier permeability and targeted delivery [26]. These advances represent a growing appreciation of the therapeutic potential of well-studied herbal therapies as effective adjuncts or perhaps alternatives in the changing management of Parkinson's disease [27].

Nanoformulations of Herbal Compounds for Parkinson's Disease

Nanoformulations have gained popularity in recent years as a viable technique for increasing the bioavailability and targeted distribution of herbal ingredients in the treatment of Parkinson's disease (PD). Many phytochemicals, while therapeutically powerful, have low solubility, fast metabolism, or limited blood-brain barrier (BBB) penetration issues that modern drug delivery technologies seek to address. Curcumin, a well-known antioxidant and anti-inflammatory substance, exhibits this issue. To address its low bioavailability, Li et al. (2021) [28] created curcumin-loaded solid lipid nanoparticles (SLNs), which greatly increased brain accumulation. This nanoformulation not only lowered neuroinflammatory indicators but also provided significant neuroprotection in PD-induced mice models, with the added benefit of prolonged release, which extended its therapeutic impact.

Similarly, puerarin, a powerful flavonoid found in *Pueraria lobata*, has been encapsulated in polymer-based carriers to optimize its pharmacokinetic profile and therapeutic efficacy. Zhou et al. (2022) [29] created puerarin-loaded poly (lactic-co-glycolic acid) (PLGA) nanoparticles that improved brain uptake, decreased oxidative stress, and maintained dopaminergic neurons in PD models. Importantly, these nanoparticles reduced puerarin degradation and enhanced stability, increasing therapeutic efficacy while minimizing negative effects associated with standard oral administration.

To overcome the difficulties of poor solubility, low bioavailability, and limited brain penetration associated with many herbal substances, a significant body of research has concentrated on nano- and microformulation techniques for Parkinson's disease (PD) treatment. These improved delivery technologies not only improve the pharmacokinetic features of phytochemicals, but also allow for targeted distribution and prolonged release, increasing their therapeutic efficacy.

For example, Patel et al. (2021) [30] created liposomal carriers for resveratrol—a polyphenolic antioxidant with neuroprotective properties—in order to overcome its poor solubility and quick metabolism. The liposomal formulation greatly increased resveratrol stability and bioavailability, enhancing its anti-inflammatory and neuroprotective properties in parkinsonian rat models. Similarly, Sharma et al. (2022) [31] encapsulated baicalein, a flavonoid with anti-apoptotic and antioxidative effects, in nanoparticles. Their formulation increased baicalein's stability and brain transport, resulting in better neuronal survival and cognitive performance in PD models.

Ginsenosides from *Panax ginseng* have also demonstrated improved effectiveness when given using nanotechnology. Liu et al. (2021) [32] created PEGylated liposomes containing ginsenosides, which offered regulated release and enhanced dopaminergic signaling as well as neurotrophic support. This resulted in significant neurorestoration in animal models of Parkinson's disease. Similarly, Kumar et al. (2022) [33] synthesized epigallocatechin gallate (EGCG), a green tea catechin, into nanoliposomes. These

nanocarriers enhanced the compound's anti-amyloidogenic and anti-inflammatory properties, considerably reducing neurodegeneration in PD models.

Finally, Chen et al. (2023) [34] developed microparticles and liposomes containing paeoniflorin, a bioactive glycoside derived from *Paeonia lactiflora*. These formulations improved its brain bioavailability, decreased oxidative stress and inflammation, and protected dopaminergic neurons. Notably, the liposomal form demonstrated regulated release and improved targeting, underlining paeoniflorin's promise as a new neuroprotective drug in Parkinson's disease treatment. These discoveries highlight the importance of nanotechnology in unleashing the full therapeutic potential of herbal medicines for Parkinson's disease by overcoming traditional pharmacological constraints.

Clinical Evidence and Efficacy of Herbal Treatments for PD

A considerable body of preclinical research indicates the neuroprotective potential of herbal substances in the treatment of Parkinson's disease (PD). Numerous phytochemicals, including curcumin, puerarin, resveratrol, and paeoniflorin, have shown therapeutic effectiveness in toxin-induced Parkinson's disease models using MPTP, rotenone, or 6-hydroxydopamine (6-OHDA). These chemicals work through several pathways, including reducing oxidative stress, maintaining mitochondrial integrity, inhibiting α-synuclein aggregation, and suppressing neuroinflammatory responses.

The discovered that puerarin-loaded nanoparticles dramatically improved motor performance and preserved dopaminergic neurons in a rotenone-induced PD rat model, demonstrating their neurorestorative potential. Similarly, baicalein has demonstrated significant anti-apoptotic action in 6-OHDA-lesioned rats, principally via activating the PI3K/Akt signalling pathway and decreasing caspase-3 expression, indicating that it has the potential to postpone neurodegeneration [31].

Despite encouraging results in preclinical investigations, the clinical translation of herbal medicines for Parkinson's disease (PD) is still in its early stages, with just a few well-designed human trials undertaken. One of the most researched is Mucuna pruriens, which is regarded for its natural levodopa content. In a randomized crossover experiment, Katzenschlager et al. (2004) [35] found that Mucuna seed powder provided a faster onset of action and longer-lasting motor symptom alleviation than conventional levodopa/carbidopa formulations, indicating a feasible option for symptomatic therapy. *Withania somnifera* (Ashwagandha) has also undergone clinical evaluation. In a double-blind, placebo-controlled study, Kulkarni et al. (2021) [36] observed significant improvements in Unified Parkinson's Disease Rating Scale (UPDRS) scores and cognitive performance over 12 weeks in patients treated with Ashwagandha, supporting its potential role in managing both motor and non-motor symptoms of PD. Although limited by poor bioavailability, *Curcuma longa* (curcumin) has shown clinical potential when administered in enhanced formulations. Panahi et al. (2020) [37] reported that bioavailable curcumin improved oxidative stress markers and motor function in early-phase trials involving PD patients, further reinforcing the relevance of formulation strategies in herbal-based interventions.

While herbal remedies may not be as effective as conventional drugs like levodopa in giving rapid symptomatic relief, their usefulness rests in complementing functions that improve overall disease management in Parkinson's disease (PD). As adjunct therapy, these botanical drugs increase treatment tolerability, reduce motor problems, and may have neuroprotective benefits that target underlying disease pathways.

For example, combining resveratrol or ginsenosides with dopaminergic medications has resulted in synergistic benefits, such as maintaining dopaminergic neurons, reducing oxidative damage, and prolonging the efficacy of traditional therapies while minimizing unpleasant responses. Similarly, polyherbal blends containing *Bacopa monnieri*, *Curcuma longa*, and *Ginkgo biloba* have demonstrated promise to improve cognitive performance, mood, and quality of life domains that are frequently underserved by traditional medication [38, 39].

Despite these findings, the clinical evidence for herbal therapy in Parkinson's disease requires further extension through larger, multicenter, randomized controlled studies [40]. Standardization of herbal extracts, dosage optimization, and an awareness of herb-drug interactions are all required for mainstream clinical integration. However, the rising interest in integrative neurology and evidence-based phytotherapy points to a potential future in which herbal medications may play an important role in traditional Parkinson's disease management, particularly for long-term care and quality-of-life enhancement [41].

Safety, Side Effects, and Drug Interactions in Herbal Treatments for PD

While herbal treatments are typically thought to be safe because of their natural nature, various negative effects have been described in the context of Parkinson's disease management. Mild gastrointestinal problems, such as nausea, bloating, and diarrhoea, are frequently observed after consuming Curcuma longa (turmeric), Mucuna pruriens, and *Bacopa monnieri*. Notably, *Mucuna pruriens*, which contains natural levodopa, can cause dyskinesia, sleeplessness, and palpitations in a dose-dependent manner, especially when not titrated properly [42]. *Withania somnifera* (Ashwagandha) has been linked to moderate drowsiness and hypotension in certain people, but *Ginkgo biloba's* vasodilatory characteristics can occasionally produce headaches and dizziness [43]. These findings emphasize the necessity for careful monitoring, regulated dose, and expert advice when including herbal medicines into PD treatment regimens.

A more severe worry in the incorporation of herbal remedies into Parkinson's disease (PD) care is the possibility of herb-drug interactions, especially considering the complexity of pharmaceutical regimens in these patients. Many herbal substances can alter the cytochrome P450 enzyme system, influencing medication metabolism. For example, *Ginkgo biloba* and *Panax ginseng* have been shown to boost the effects of anticoagulants such as warfarin, increasing the risk of bleeding [44]. Curcumin, the active ingredient in *Curcuma longa*, can also inhibit CYP3A4 and P-glycoprotein, which could affect the pharmacokinetics of dopaminergic medications like levodopa and entacapone [45]. Depending on the nature of the interaction, this modulation might result in either subtherapeutic or hazardous outcomes. Furthermore, co-administration of Mucuna pruriens with normal levodopa treatment necessitates precise dosage titration to avoid dopamine excess and subsequent motor problems, such as dyskinesias [46, 47].

Ensuring the safety of herbal medications in Parkinson's disease treatment necessitates formulation consistency, precise dose instructions, and increased pharmacovigilance [48, 49]. Unlike synthetic medications, herbal therapies frequently have concerns with variable amounts of active components, resulting in varying effectiveness and safety profiles. Regulatory authorities, such as AYUSH in India and the European Medicines Agency (EMA) in Europe, have been striving to address these problems by establishing standardized processes for herbal products. Researchers are also investigating novel options, such as nanoformulations and encapsulation methods, to improve bioavailability and safety. These

innovative techniques allow for controlled release and targeted distribution, decreasing systemic exposure and lowering the potential of unfavourable interactions with standard PD drugs [50, 51].

Clinically speaking, including herbal medicine in Parkinson's disease (PD) treatment programs must be evidence-based and physician-supervised. To detect any possible concerns, healthcare practitioners should get full medication histories, including those for over-the-counter and herbal products [52, 53]. Given the scarcity of pharmacokinetic studies and real-world safety data, large-scale, long-term clinical trials examining the toxicity, tolerability, and interaction patterns of routinely used herbs in Parkinson's disease are urgently required. Herbal remedies can supplement conventional pharmacotherapy when properly monitored, but they should never replace it without solid proof or physician supervision.

Challenges and Future Directions in Herbal Medicine for Parkinson's Disease

Despite encouraging preclinical and clinical data, various research gaps and hurdles continue to limit the widespread use of herbal medicine in Parkinson's therapy. One significant impediment is the lack of large-scale, randomized controlled studies (RCTs) to assess herbal medicines' long-term effectiveness and safety [54]. Much research relies on in vitro models or animal trials, which may not always adequately represent human physiology. Furthermore, differences in plant sources, processing procedures, extraction methods, and phytochemical profiles lead to inconsistent results, making it challenging to replicate findings across diverse study contexts [55, 56].

Another key problem is the standardization of herbal preparations, which remains a major barrier to their therapeutic utilization. Unlike synthetic medications, herbal products are frequently complex, multicomponent systems with potential synergistic or antagonistic interactions between bioactive substances. Many of these combinations' pharmacokinetics, dose-response relationships, and possible toxicity remain unknown. Regulatory bodies, particularly in developing countries, frequently lack strict rules and extensive quality control processes, making it difficult to maintain batch-to-batch uniformity and dose precision [57]. This poses a significant barrier to gaining physician and patient trust in adding herbal medications into evidence-based PD therapy.

Herbal remedies have remarkable promise in the growing landscape of personalized medicine, especially given the customized character of disease development and medication response in Parkinson's disease (PD). Given the diversity of Parkinson's disease pathophysiology, which includes dopaminergic neuron loss, oxidative stress, and neuroinflammation, a single medication is unlikely to be uniformly beneficial. Using genetic and biomarker testing, herbal medicines can be tailored to a patient's individual metabolic and pathological profiles. Curcumin's anti-inflammatory qualities, for example, may assist those with high levels of neuroinflammatory indicators, but ginsenosides may be more useful for people with mitochondrial dysfunction [58, 59].

The future of Parkinson's disease (PD) treatment may entail combining herbal and conventional pharmaceuticals. These hybrid regimens may minimize the dosage of synthetic medications, reducing adverse effects while increasing therapeutic efficacy through multi-targeted activities. Several studies have already investigated the synergistic benefits of levodopa in conjunction with herbal extracts such as Mucuna pruriens, revealing equivalent or even superior clinical results with better tolerability [60]. However, rigorous pharmacodynamic and pharmacokinetic investigations are required to minimize negative interactions and optimize these combinations for optimal benefit.

Technological advances in herbal medicine delivery are poised to revolutionize the formulation and administration of medicinal remedies. Nanotechnology, transdermal patches, liposomes, and phytosomes are being investigated to increase the bioavailability, brain-targeting efficiency, and controlled release of herbal substances including curcumin, paeoniflorin, and baicalein. Smart delivery methods, including as stimulus-responsive nanocarriers and blood-brain barrier-penetrating formulations, provide promising opportunities for more effective and patient-friendly PD treatments [61]. Furthermore, using artificial intelligence (AI) in medication design and predictive modelling might hasten the creation of optimal, personalized herbal remedies.

2. Conclusion

The expanding worldwide burden of Parkinson's disease highlights the critical need for safer, more effective, and accessible treatment options. This review stresses the multifaceted character of Parkinson's disease pathophysiology, which includes dopaminergic neuron loss, oxidative stress, mitochondrial failure, and neuroinflammation. While current pharmaceutical therapies, such as levodopa and dopamine agonists, give symptomatic relief, they do not stop disease progression and frequently produce side effects with long-term usage. Herbal medications, with their varied bioactive components, have emerged as intriguing alternatives or adjunct treatments capable of targeting numerous neurodegenerative pathways at once.

A large amount of experimental and clinical data supports the neuroprotective properties of various herbal substances, including curcumin, paeoniflorin, ginsenosides, resveratrol, and EGCG. These phytochemicals have anti-inflammatory, antioxidant, anti-apoptotic, and mitochondrial-stabilizing properties. Advances in formulation tactics, such as nanoencapsulation, phytosomes, and transdermal administration, have increased bioavailability and therapeutic potential. Furthermore, herbs such as Mucuna pruriens have shown levodopa-like effects, making them therapeutically important, especially in areas where access to mainstream drugs is restricted.

As an addition to standard therapy, herbal therapies have the benefit of lowering synthetic medication doses, decreasing side effects and increasing patient compliance. However, the use of herbal medicine in Parkinson's disease therapy should be addressed with caution, taking into mind the hazards of herb-drug interactions and heterogeneity in herbal formulations. Standardization, quality control, and rigorous clinical studies are required to ensure their safety and efficacy. Despite these limitations, recent trends clearly support phytotherapy's complementary role in holistic Parkinson's disease care, especially when matched with customized medicine principles.

Looking ahead, multidisciplinary collaboration among ethnopharmacologists, neurologists, pharmaceutical scientists, and regulatory authorities will be vital to overcome the existing hurdles. Technological advances in drug delivery technologies, together with rising public interest in natural remedies and increased research funding in phytomedicine, hint to a bright future. With more study and clinical confirmation, herbal medicine has the potential to become a cornerstone in integrative Parkinson's disease treatment, providing hope for better results and a higher quality of life for millions of people suffering from this devastating affliction.

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Conflict of Interest

The author(s) declare no conflict of interest regarding the publication of this article (or involvement in this project/work).

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