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THE RAPEUTIC POTENTIAL OF ASHWAGANDHA (WITHANIA SOMNIFERA)

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ABSTRACT

Ashwagandha (Withania somnifera (L.) Dunal) is an important medicinal plant in Ayurvedic practice and an increasingly investigated ingredient in contemporary herbal products. Its chemical profile includes steroidal lactones known as withanolides, withanosides, alkaloids and other constituents whose relative abundance varies by plant part, source and extraction process. Experimental studies report antioxidant, anti-inflammatory, neurobiological, endocrine and stress-response effects, while human research has most consistently examined perceived stress, anxiety-related symptoms and sleep. Randomized trials and evidence syntheses suggest potential benefits for selected stress and sleep outcomes, but findings are constrained by small samples, heterogeneous preparations, differences in outcome measures and generally short treatment periods. Evidence for cognition, physical performance, reproductive outcomes and metabolic health is promising in some studies but remains insufficient to support broad therapeutic claims. Much of the evidence for anticancer, neuroprotective and disease-modifying activity is preclinical and cannot be directly translated into clinical recommendations. Safety assessment is essential because gastrointestinal symptoms and drowsiness are reported, rare cases of clinically apparent liver injury have been described, and potential interactions with thyroid, sedative, immunosuppressive, antihypertensive and glucose-lowering medicines warrant attention. Pregnancy and

breastfeeding are important precautionary contexts, and long-term safety remains uncertain. This narrative review summarizes botanical identity, phytochemistry, proposed mechanisms, therapeutic evidence, formulation and standardization considerations, safety issues and research priorities. Overall, Ashwagandha is a scientifically interesting botanical with a limited but developing clinical evidence base; reproducible product characterization and adequately powered, independently replicated trials are needed before its uses can be defined more confidently.

KEYWORDS: Ashwagandha; Withania somnifera; withanolides; phytochemistry; clinical evidence; herbal safety.

INTRODUCTION

Medicinal plants remain important sources of traditional care, pharmacologically active molecules and leads for drug discovery. Plant-derived products can contain multiple chemical classes that affect biological systems through overlapping or distinct pathways. However, the presence of bioactive constituents does not automatically demonstrate clinical efficacy, and traditional use should be interpreted as a rationale for research rather than a substitute for controlled evidence. For herbal medicines, the identity of the species, plant part, cultivation conditions, extraction method, chemical fingerprint and dose can all influence reproducibility. These requirements are particularly relevant when a plant is marketed as a general wellness supplement for several unrelated outcomes.[1-4]

Ashwagandha, botanically identified as *Withania somnifera* (L.) Dunal, is a member of the Solanaceae family and is widely used in Ayurveda and related South Asian medical traditions. The root is the most familiar medicinal material, although leaves and other parts are also studied and may have substantially different chemical profiles. The Sanskrit-derived common name is often interpreted as referring to the smell of a horse, while the plant is also known as winter cherry and, less precisely, Indian ginseng. Ashwagandha is frequently described as a rasayana or adaptogenic herb, but these traditional concepts do not correspond to a single validated pharmacological mechanism or a specific approved clinical indication.[2,4-6]

Modern investigation has focused on withanolides, a structurally diverse group of C-28 steroidal lactones, as well as withanosides and several alkaloids. Withaferin A and withanolide A are among the better-known compounds investigated in cell and animal models. Reported actions include modulation of inflammatory signaling, oxidative stress

responses, cellular stress pathways and neuronal function. Yet extract-level biological activity may reflect multiple constituents, interactions among constituents, or nonspecific experimental effects; it is not scientifically justified to attribute every effect of a whole-root extract to one molecule without direct comparative testing.[1-3,7,8]

Interest in Ashwagandha has expanded because small randomized controlled trials have evaluated stress, anxiety-related symptoms, sleep, cognition, physical performance and reproductive outcomes. Evidence syntheses have reported benefits for some stress-related measures and sleep outcomes, although they also emphasize heterogeneity in dose, extract composition, duration and study quality. These limitations make it difficult to identify a uniform effective dose or generalize findings from a specific standardized preparation to powders, multi-ingredient products or extracts derived from leaves. The most supportable interpretation is therefore indication-specific and formulation-specific rather than a blanket claim that the plant treats multiple diseases.[9-18]

The safety profile also requires balanced discussion. Short-term trials in selected healthy adults have often reported acceptable tolerability, but these studies have limited ability to identify rare events or risks during prolonged use. Published case reports and case series associate some Ashwagandha supplements with liver injury, and authoritative health information advises precaution in pregnancy, breastfeeding, thyroid conditions, autoimmune disorders and around surgery. Potential interactions with medicines used for diabetes, hypertension, immunosuppression, sedation, seizures and thyroid replacement also matter in real-world use. These concerns reinforce the need to assess benefit and risk together, and to avoid assuming that a product is safe merely because it is plant-derived.[5,6,19-22]

The present review evaluates the therapeutic potential of Ashwagandha from a pharmaceutical-sciences perspective. It summarizes botanical identity and traditional context, major phytochemical groups, proposed mechanisms, findings from preclinical and human studies, formulation and quality-control needs, clinically relevant precautions and research priorities. The review deliberately distinguishes experimental plausibility from human evidence and does not treat Ashwagandha as a replacement for established care. By considering both the opportunities and the uncertainties, the article aims to support a more reproducible and evidence-based approach to future development of *W. somnifera* preparations.[1-3,7,17]

MATERIALS AND METHODS

This manuscript was developed as a narrative review and evidence map rather than a systematic review or meta-analysis. A targeted literature search was undertaken for this draft using PubMed-indexed records, official National Institutes of Health resources, publisher pages and accessible review articles. Search concepts included: “Withania somnifera,”

- Cognition,
- Muscle strength,
- Reproductive health,
- Thyroid,
- Liver injury,
- Herbal quality control.

Landmark pharmacology papers were retained where they provided a foundation for interpreting more recent work. [17,19-27]

Priority was given to randomized controlled trials, systematic reviews and meta-analyses, well-characterized preclinical studies, authoritative safety sources and reports providing relevant botanical or chemical detail. Where a source discussed several extract preparations, the preparation, population and duration were considered when summarizing the result. This approach was intended to prevent direct comparison of dissimilar products as though they were chemically equivalent. The evidence was synthesized by topic: botanical identity, phytochemistry, proposed mechanisms, human therapeutic outcomes, product quality and safety.[1-4,19-27]

Important methodological limitation: Scopus, Web of Science and ScienceDirect were not independently searched as complete databases for this draft, and no dual-reviewer screening, protocol registration, formal risk-of-bias assessment or quantitative meta-analysis was performed. The manuscript must therefore be described as a narrative review. Before submission, the authors should conduct and document any additional database searches they actually perform, confirm reference metadata, and update the literature cut-off date if the submission is delayed. No new laboratory experiments or clinical evaluations were performed for this review. [15,17]

RESULTS AND DISCUSSION

1. BOTANICAL PROFILE AND TRADITIONAL SIGNIFICANCE

1.1 Botanical identity and morphology

Withania somnifera (L.) Dunal is a perennial or short-lived evergreen shrub in the Solanaceae family. It is commonly cultivated in parts of India and also occurs across arid and subtropical regions. The plant typically has ovate leaves, small greenish or yellow-green flowers and orange-red berries enclosed by an inflated calyx. Root material is the principal component of many traditional preparations and commercial root extracts, but leaf extracts also appear in research and commercial products. Accurate botanical authentication is important because similar common names, vernacular substitutions and mixed botanical materials can complicate supply chains and product identity.[1-4]

The phrase “Ashwagandha extract” is not a sufficiently precise description for scientific comparison. A root powder, aqueous extract, hydroalcoholic extract, root-and-leaf blend and isolated withanolide preparation may differ markedly in chemical composition. Even preparations described as “standardized” may use different marker compounds, assays, extraction ratios and specifications. Accordingly, botanical identity should be reported with the accepted scientific name, author citation where appropriate, plant part, geographical origin, extraction solvent, drug-to-extract ratio and analytical standardization details.[1-4,6,10,19]

1.2 Traditional context and current relevance

Ashwagandha has a longstanding place in Ayurvedic practice and is traditionally described as a rejuvenating or restorative medicine used in contexts involving fatigue, vitality, sleep and general wellbeing. Such uses are historically important and helped generate modern hypotheses about stress physiology and neurobiological function. However, traditional use is often based on a whole-system context that includes formulation, diet and practitioner guidance; it cannot be assumed to predict the effects of every isolated commercial capsule. Modern clinical evaluation should therefore specify both the product and the intended outcome.[2,4,9,17]

The modern consumer market commonly presents Ashwagandha as an adaptogen. The term adaptogen is used for substances proposed to improve the ability to adapt to stress, but it is not a precise diagnostic or regulatory category and should not be mistaken for a formally established mechanism. In clinical research, the concept can be operationalized only through defined outcomes, such as validated perceived-stress scales, anxiety ratings, sleep measures

or biomarkers. Improvements in one outcome do not establish equivalent benefit in mood disorders, cognitive decline, metabolic disease or other indications.[5,6,11-15]

2. PHYTOCHEMICAL COMPOSITION OF ASHWAGANDHA

The most characteristic phytochemicals of W. somnifera are withanolides, a family of naturally occurring steroidal lactones built on an ergostane-related skeleton. Their structures differ in oxidation patterns, side-chain features, hydroxylation and other substitutions, producing a broad range of biological properties. Withaferin A, withanolide A, withanolide D and withanone are frequently discussed examples. Withanolide content varies by plant part and may be affected by genetics, growing conditions, maturity, harvesting, storage and extraction. A claim such as “high withanolide content” has limited scientific value unless the assay method and individual or total markers are defined. Historic phytochemical work provides useful context, but its methods and chemical nomenclature should be interpreted in light of modern analytical standards.[1-3,28]

Withanosides are glycosylated withanolide-related compounds reported especially in root material. Glycosylation can influence polarity, solubility, absorption, metabolism and the way compounds interact with biological targets. Sitoindosides and related glycosides have also been described in the plant. These constituents may contribute to the pharmacology of whole extracts, but their pharmacokinetics and roles in human outcomes are not as well characterized as their presence in phytochemical analyses. Analytical identification should use suitably validated chromatographic and spectrometric approaches when specific compounds are claimed.Ashwagandha also contains alkaloids, including compounds historically named withanine, somniferine, anaferine, anahygrine and cuscohygrine in different studies and plant parts. Sterols, phenolic compounds, flavonoids, sugars, amino acids and other primary or secondary metabolites have also been reported. Some of these findings arise from preliminary phytochemical screening, which is less specific than isolation followed by structural confirmation using methods such as nuclear magnetic resonance and mass spectrometry. Broad lists of detected constituents should therefore not be interpreted as proof that each molecule occurs at pharmacologically relevant concentrations in marketed products.[1-3]

The chemical relationship between plant material and activity is an important pharmaceutical question. Root- and leaf-dominant preparations may have different withanolide ratios, and extraction solvents can enrich or deplete selected chemical groups. Botanical processing, drying temperature, storage humidity and light exposure may affect stability. The commercial label may report total withanolides without explaining whether the assay responds equally to

each compound. In research and product development, a multi-marker fingerprint combined with botanical authentication and contaminant testing is more informative than a single non-specific assay alone.[3,4,10,19]

TABLE 1. MAJOR PHYTOCHEMICAL GROUPS REPORTED IN *WITHANIA SOMNIFERA*.

Constituent group	Representative examples	Reported biological areas	Evidence and interpretation
Withanolides	Withaferin A, withanolide A, withanolide D, withanone	Inflammatory signaling, cellular stress, neurobiology and experimental cytotoxicity	Predominantly preclinical; activities vary by compound and model
Withanosides and related glycosides	Withanosides I-VII; other withanolide glycosides	Potential effects on neurobiological and other pathways; influence extract polarity	Chemical isolation and preclinical data; human exposure is incompletely described
Alkaloids	Anaferine, anahygrine, cuscohygrine, withanine and related alkaloids	Reported pharmacological activity; contribution to whole-extract effects remains uncertain	Reported in phytochemical studies; relevance depends on part and concentration
Sterols and related compounds	Beta-sitosterol and other plant sterols	Potential membrane, metabolic and inflammatory relevance	Presence does not establish a clinical effect of Ashwagandha products
Phenolic compounds and flavonoids	Various phenolic acids and flavonoid-like constituents reported in extracts	Antioxidant assays and possible contributions to extract activity	Chemical assays and preclinical evidence; avoid extrapolating directly to clinical benefit
Other primary metabolites	Sugars, amino acids, lipids and minor constituents	Matrix properties and possible indirect effects on extract characterization	Composition can vary widely by tissue, solvent and processing

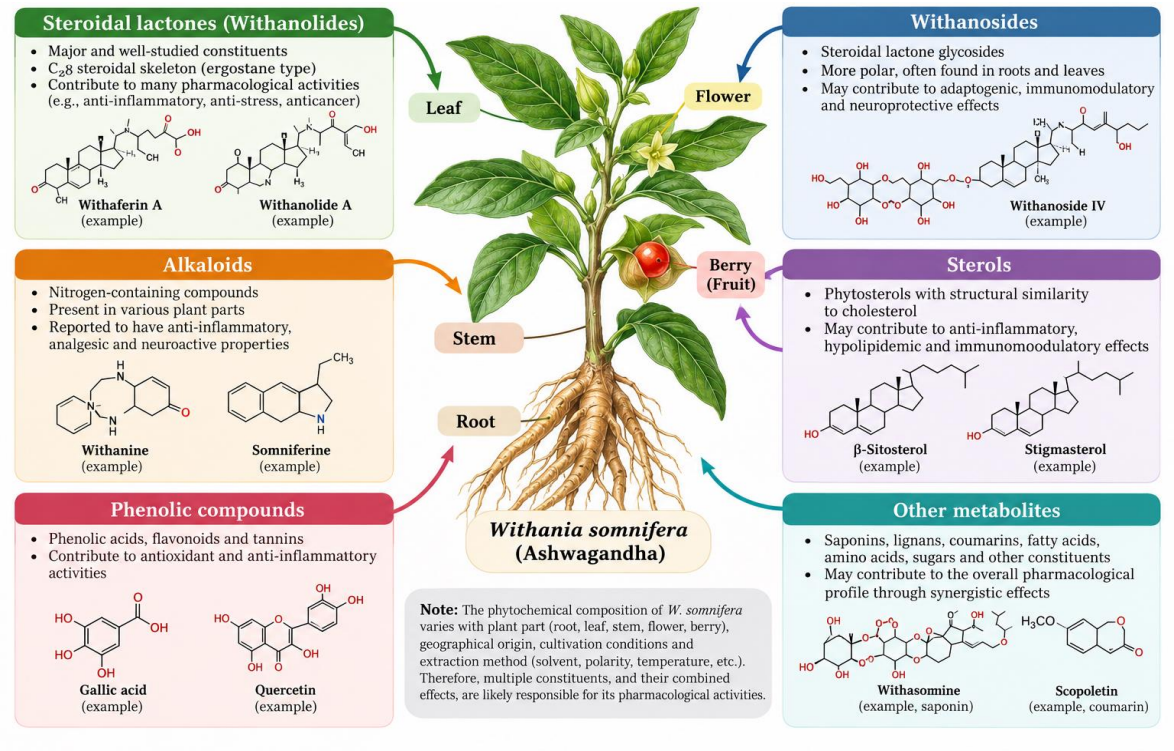


FIGURE 1. BOTANICAL IDENTITY AND MAJOR PHYTOCHEMICAL CONSTITUENTS OF ASHWAGANDHA.

3. PHARMACOLOGICAL MECHANISMS OF ACTION

3.1 Stress physiology and hypothalamic-pituitary-adrenal axis

One frequently proposed mechanism for stress-related outcomes is modulation of the hypothalamic-pituitary-adrenal (HPA) axis, the coordinated endocrine system through which hypothalamic and pituitary signals regulate adrenal glucocorticoid release. Some clinical trials of specific root extracts have reported reductions in perceived stress and serum cortisol relative to placebo. These findings provide a human signal that deserves replication, but they do not prove that every formulation acts through the same pathway or that cortisol changes necessarily mediate a meaningful improvement in functioning. Stress ratings, cortisol concentration and clinical anxiety are related but distinct outcomes.[10-12,17,18]

Preclinical studies also suggest effects on stress adaptation and neurotransmission, but the mechanisms are not fully resolved. Altered HPA-axis feedback, changes in oxidative balance, inflammatory mediators or sleep may contribute in parallel. Since stress symptoms can improve through several behavioral and physiological routes, mechanistic claims should be tested through studies that measure both the proposed mediator and patient-centered outcomes. Cross-sectional correlations or changes in a single biomarker are insufficient to establish a causal pathway.[1,7,17]

3.2 Oxidative stress and antioxidant responses

Oxidative stress occurs when reactive oxygen species production exceeds the capacity of antioxidant defenses and can damage lipids, proteins and nucleic acids. Several Ashwagandha constituents and extracts show radical-scavenging or antioxidant-associated effects in chemical assays and experimental biological systems. Preclinical literature also describes changes in endogenous antioxidant enzymes and lipid peroxidation under selected conditions. These observations provide hypotheses for further study, yet simple in vitro radical-scavenging capacity is not equivalent to improved antioxidant status in humans because digestion, bioavailability, metabolism and tissue exposure intervene between ingestion and target engagement.[1-3,8,30]

An important translational distinction is whether an extract directly scavenges radicals at attainable concentrations or indirectly influences cellular stress responses. The latter could involve transcriptional regulation and stress-response networks, but should not be assumed from chemical antioxidant testing alone. Well-designed human studies would need prespecified oxidative-stress biomarkers, suitable control groups, standardized preparations and assessment of clinically meaningful outcomes. At present, antioxidant activity is best described as a mechanistic area of investigation rather than an independent clinical indication for Ashwagandha.[1-3,7,30]

3.3 Inflammatory signaling and immunomodulation

Experimental work on withaferin A and other withanolides reports modulation of inflammatory mediators and pathways including nuclear factor-kappa B (NF-kB) in selected cell and animal models. These pathways regulate cytokine expression, immune-cell activation and cellular stress responses. Such findings may partly explain reported anti-inflammatory effects, but a biologically active molecule can influence multiple targets, sometimes at concentrations that cannot be safely achieved in humans. Extract-level studies also differ in composition, making pathway attribution difficult. A mechanism described in tumor cells, stimulated immune cells or an animal model should not be represented as an established mechanism in healthy volunteers.[1-3,7,8]

Immunomodulatory activity is not inherently beneficial in every clinical situation. If a botanical changes immune signaling, its effects may differ according to baseline immune state, co-medications and disease context. This is particularly relevant for autoimmune conditions and for people receiving immunosuppressants. The possibility of pathway modulation should therefore be integrated into interaction and safety assessment rather than used only as a marketing advantage.[1,5-7,19]

3.4 Neurobiological pathways, sleep and cognition

Neurobiological hypotheses include modulation of gamma-aminobutyric acid (GABA)-related signaling, effects on stress-associated neurotransmission, and protection against experimental neuronal injury. Some of these hypotheses are supported mainly by animal studies, receptor assays or isolated-compound experiments. Sleep changes in clinical trials might occur indirectly through reduced stress, directly through neurochemical pathways, or through more than one route. However, the available clinical evidence does not establish a single molecular target that explains the reported sleep effects of all products.[1,7,9,15,16,18]

In neuroprotection research, withanolides and extracts have been studied in models of oxidative injury, inflammation and neurodegeneration. A compound may preserve cell viability in an experimental model while failing because of inadequate brain exposure, metabolism, off-target toxicity or disease complexity in humans. Therefore, claims about treating Alzheimer disease, Parkinson disease or other neurodegenerative disorders are premature without robust clinical trials. Current cognitive findings should be framed as preliminary evidence for selected memory or cognitive test outcomes rather than proof of disease prevention or reversal.[1-3,7,8,23]

3.5 Endocrine and metabolic pathways

Ashwagandha has been studied for possible effects on thyroid function, reproductive hormones, glucose regulation and stress-related endocrine markers. These areas require caution because endocrine changes may be beneficial in one defined population and harmful in another. For example, a small trial in adults with subclinical hypothyroidism reported changes in thyroid-related laboratory outcomes, but this does not justify unsupervised use in thyroid disease. People using thyroid medication may face altered hormone control, and they should discuss supplements with their clinician rather than adjust prescribed treatment themselves.[5,6,27]

Metabolic hypotheses include effects on insulin sensitivity, inflammatory pathways, cortisol and exercise-related physiology. Human evidence for glucose regulation remains limited and is complicated by population differences, concurrent lifestyle changes, and the use of different extracts. The metabolic response to a supplement cannot be inferred from changes in oxidative stress in an animal model or from a short-term biomarker trial. Until stronger trials are available, Ashwagandha should not be positioned as a replacement for established diabetes or lipid management. [1-3,5,6,17]

TABLE 2. PROPOSED MECHANISTIC PATHWAYS AND THE STRENGTH OF CURRENT SUPPORT.

Pathway or system	Reported observation	Main evidence base	Interpretive limitation
HPA-axis/stress response	Changes in perceived stress and cortisol in some trials	Human trials plus preclinical studies	Products and populations differ; mediation is not established
Oxidative stress	Radical-scavenging and antioxidant-associated effects	Chemical assays, cells and animal models	Laboratory antioxidant activity is not proof of clinical antioxidant benefit
Inflammatory signaling	Modulation of NF-kB-related or cytokine pathways	Mostly preclinical constituent and extract research	Concentration, target specificity and human relevance remain uncertain
Neurobiological signaling	Possible effects on neurotransmission, sleep and cognitive performance	Animal models and selected human sleep/cognition studies	No single validated mechanism; no proven treatment for neurodegenerative disease
Endocrine activity	Reported changes in cortisol, testosterone or thyroid tests in selected studies	Small human studies and preclinical research	Population-specific effects may not generalize; monitor interactions
Cell survival and cancer pathways	Cytotoxicity or pathway modulation in tumor models	Cell and animal research	Not evidence of anticancer efficacy or safety in patients

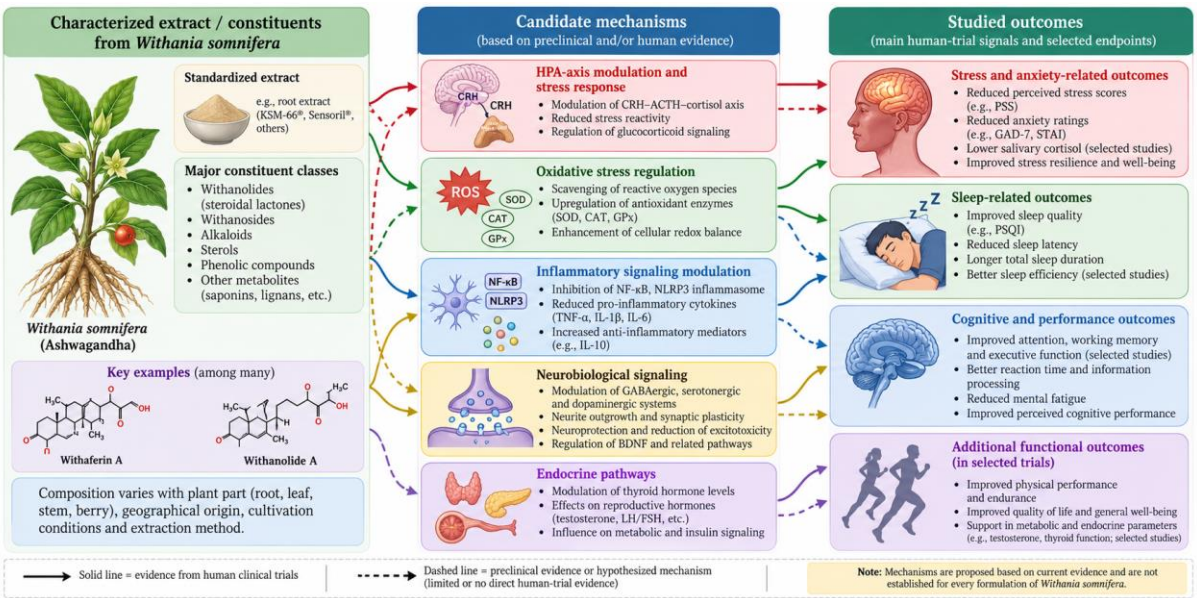


FIGURE 2. PROPOSED PHARMACOLOGICAL MECHANISMS OF ASHWAGANDHA

4. THERAPEUTIC APPLICATIONS OF ASHWAGANDHA

4.1 Stress and anxiety-related symptoms

The most frequently studied contemporary use is the reduction of stress-related symptoms. In a randomized, double-blind, placebo-controlled trial, Chandrasekhar and colleagues evaluated a high-concentration full-spectrum root extract in adults reporting stress and found improvement in stress and anxiety-related measures compared with placebo over the study period. Later trials have examined different formulations and doses. These results suggest a potential benefit for selected adults, but trial size, product-specific composition, recruitment methods and reliance on self-report outcomes limit the certainty of broad conclusions.[10-12]

Meta-analyses have generally reported favorable pooled effects on selected stress or anxiety measures, but the findings must be interpreted alongside between-study heterogeneity, small numbers of trials, variable study quality and possible publication bias. A pooled estimate does not erase differences among extracts, study duration or population. The evidence is not sufficient to conclude that Ashwagandha treats a diagnosed anxiety disorder, replaces psychotherapy or psychiatric medicines, or provides uniform benefit to every user. Further trials should pre-register primary outcomes, report adverse events completely and include appropriate active comparators where clinically meaningful.[12-14,17,18]

For pharmaceutical development, the stress-related signal is a useful starting point because it can be examined using validated scales, sleep measures, cortisol profiles and functioning outcomes. However, biomarker changes should not be substituted for patient benefit. Studies should also characterize concurrent caffeine, alcohol, sleep medication, exercise, psychotherapy and other supplement use, because each can affect stress and sleep endpoints. Independent replication of the same chemically characterized product would strengthen confidence more than repeated trials using incomparable materials.[10-15]

4.2 Sleep and insomnia

Sleep is another area with a comparatively organized clinical literature. Langade and colleagues studied a root extract in adults with insomnia and anxiety in a randomized, double-blind, placebo-controlled design. The study reported improvement in selected sleep measures after ten weeks, including sleep onset and sleep efficiency, although the sample was small and the test product was a particular high-concentration root extract rather than a generic Ashwagandha preparation. The results are encouraging but need replication in larger, independent studies with clear reporting of sleep-diary and actigraphy outcomes.[16]

A systematic review and meta-analysis of five randomized trials involving 400 adults found a modest pooled effect on overall sleep, with greater apparent effects in subgroups with

insomnia, doses at or above 600 mg/day and treatment duration of at least eight weeks. The review also reported heterogeneity and noted the limited available safety data for long-term use. A separate 2024 meta-analysis also reported improvements in several sleep and anxiety outcomes but found substantial heterogeneity for anxiety. These findings support further investigation, not a universal dosing recommendation.[14-16]

Clinically, sleep disturbance can be a symptom of multiple conditions, including depression, sleep apnea, restless legs syndrome, thyroid disease, chronic pain and medication effects. Supplementation should not delay appropriate assessment for persistent or severe insomnia. Better trials would distinguish people with a formal insomnia diagnosis from those with self-reported poor sleep and should assess daytime function, cognition, falls and next-day sedation as well as total sleep time. Safety reporting should include interactions with alcohol, sedatives and other central nervous system depressants.[5,6,14-16]

4.3 Cognitive function and neuroprotective potential

Ashwagandha is widely marketed for memory, focus and cognitive performance, but the clinical evidence is less mature than the evidence related to stress and sleep. A randomized controlled study of a root extract in adults with mild cognitive impairment reported improvements in selected memory and cognitive-function measures. The result is hypothesis-generating, yet it does not establish prevention of dementia, durable benefit after treatment cessation or efficacy in a clinically diagnosed neurodegenerative disease. Larger trials with well-characterized populations and prespecified validated cognitive measures are necessary.[7,17,23,31]

Preclinical research reports neuroprotective effects in selected experimental models, including changes in oxidative stress, inflammation, neuronal signaling and cell survival. These studies can identify candidate mechanisms but are affected by differences in disease model, dose, treatment timing and extract composition. Many experimental models do not reproduce the multifactorial nature of human neurodegenerative disease. Accordingly, the claim that Ashwagandha treats Alzheimer disease, Parkinson disease, epilepsy or other neurological disorders is not supported by current clinical evidence.[1-3,7,8]

If cognition is to become a credible clinical application, future studies should differentiate acute attention or reaction-time effects from learning, memory, daily function and disease progression. Trials should consider whether any cognitive benefit is mediated by improved sleep or reduced stress rather than direct neuroprotection. Pharmacokinetic studies are also needed to show which constituents or metabolites achieve central nervous system exposure at tolerable doses.[1-3,7,23]

4.4 Anti-inflammatory and antioxidant activity

Anti-inflammatory and antioxidant properties are repeatedly described in experimental literature and provide a pharmacological basis for investigating Ashwagandha in conditions involving inflammatory or oxidative pathways. Withaferin A and other withanolides have produced effects in cell systems and animal models, including modulation of inflammatory signaling and cellular stress responses. Nonetheless, a constituent that reduces a marker in an experimental model may have a different effect in a whole person because absorption, metabolism, protein binding and tissue distribution determine the exposure at the target site.[1-3,7,8,30]

Human studies sometimes include inflammatory biomarkers as secondary outcomes, particularly in exercise or stress research, but biomarker observations are not enough to establish a treatment for chronic inflammatory disease. The plant should not be presented as a substitute for proven therapy for rheumatoid arthritis, autoimmune disease or other inflammatory conditions. Trials should define a specific clinical population, relevant validated disease outcomes, concomitant treatments and a standardized extract, and they should examine whether changes in biomarkers correlate with meaningful benefit.[1-3,5,6,17,24]

4.5 Metabolic health and glucose regulation

Preclinical reports have explored possible effects of Ashwagandha on glucose metabolism and metabolic stress, and a small number of human studies have included glucose-related laboratory outcomes. The clinical literature is not sufficiently consistent to establish an antidiabetic indication. Differences in participants, baseline metabolic status, extracts, co-interventions and treatment duration make it difficult to determine whether any observed change is reproducible or clinically meaningful. Herbal supplements may also affect glucose levels in people using antidiabetic medicines, creating a practical need for medication review and monitoring.[1-3,5,6,17]

Future metabolic trials should recruit clearly defined populations, such as adults with prediabetes or type 2 diabetes, and distinguish fasting glucose, HbA1c, insulin sensitivity, body composition and patient-important outcomes. The study product should be chemically characterized, and lifestyle interventions should be balanced across groups. Until robust evidence is available, Ashwagandha should not replace prescribed glucose-lowering medication, dietary care or clinical monitoring.[3-6]

4.6 Musculoskeletal health and physical performance

Physical performance has been assessed in small clinical studies, often among healthy adults beginning resistance training. In an eight-week randomized, double-blind, placebo-controlled trial involving 57 men with limited resistance-training experience, Wankhede and colleagues reported greater improvements in selected strength and muscle-size outcomes in the Ashwagandha group than in placebo. The study provides a defined human signal, but its relatively small sample, short duration, participant characteristics and specific root extract limit generalization to athletes, older adults or people with sarcopenia.[24]

Other trials have explored endurance, recovery, muscle status and biomarkers of inflammation. Such results can be influenced by training programs, diet, sleep, baseline fitness and measurement technique. Improved performance in a controlled exercise program does not establish an anabolic or ergogenic effect across all populations. Studies should report training adherence, dietary intake, adverse effects, product composition and clinically relevant performance measures. Claims about treating muscle disease or preventing age-related functional decline require stronger evidence in the relevant patient groups.[17,24]

4.7 Reproductive health and hormonal effects

Reproductive research has particularly examined male fertility, sperm parameters and testosterone-related outcomes. A controlled clinical study in infertile men reported changes in semen quality and reproductive hormone measures after treatment with a *W. somnifera* preparation. Reviews of the reproductive literature describe possible beneficial effects in selected outcomes, but the studies differ in population, preparation and methodology, and their findings cannot be generalized to all causes of infertility. Fertility is multifactorial, and Ashwagandha should not replace investigation and evidence-based management of infertility.[17,25,26]

Some small studies in men have reported increases in testosterone or vitality measures, although results may depend on age, baseline status, overweight, stress and the specific extract. Hormonal changes are not necessarily beneficial for every person and may be inappropriate in some hormone-sensitive conditions. A small randomized crossover study also examined hormonal and vitality outcomes in aging, overweight men, illustrating that effects may depend on population and preparation. Authoritative health guidance advises people with hormone-sensitive prostate cancer to avoid Ashwagandha because of the possibility of increased testosterone. Reproductive claims in women, effects on fertility outcomes and long-term endocrine consequences remain inadequately established. [5,6,17, ,32]

A key safety boundary is pregnancy and breastfeeding. Ashwagandha should be avoided during pregnancy and not used while breastfeeding according to the National Center for Complementary and Integrative Health. This precaution is not negated by the plant's traditional status or by short clinical trials conducted in unrelated adult populations. Reproductive safety studies would require appropriate ethical safeguards and cannot be replaced by assumptions drawn from traditional use.[5,6]

4.8 Antimicrobial, anticancer and other emerging applications

Antimicrobial, anticancer and other disease-oriented applications are frequently discussed in Ashwagandha reviews, but much of the evidence remains experimental. Withaferin A and related compounds can inhibit growth or alter signaling in some cancer-cell models, and different extracts have shown activity in laboratory assays. Such observations may justify medicinal-chemistry, pharmacokinetic or preclinical investigations, but they do not establish a safe and effective cancer treatment. Direct cytotoxicity at high concentrations may also injure normal cells, and oral supplement exposure may not approach the concentrations used in cell experiments.[1-3,7,8]

Other emerging areas include fatigue, menopausal symptoms, chronic inflammatory conditions and healthy aging. These topics may be scientifically reasonable to explore, but the evidence varies and is usually not sufficient for routine recommendations. A review should avoid an unranked list of alleged benefits because such lists obscure the difference between a small controlled human trial, observational findings and a cell experiment. Each proposed indication needs a dedicated assessment of population, product, comparator, clinical endpoint, adverse events and replication.[1-3,5,6,17]

5. EVIDENCE FROM PRECLINICAL AND CLINICAL STUDIES

The evidence landscape is uneven. Stress-related symptoms and sleep have been examined in multiple randomized studies and systematic reviews, whereas cognition and physical performance are supported by fewer and usually smaller clinical trials. Reproductive findings are suggestive but heterogeneous, and evidence for metabolic disease, chronic inflammatory disorders or cancer remains insufficient for clinical recommendations. A single overall rating for "Ashwagandha efficacy" would therefore be misleading: confidence should be judged separately for each use and for the particular extract investigated.[5,6,9-17,23-26]

Interpretation also depends on commercial and methodological factors. Trials may be small, short and sometimes manufacturer-supported; many use self-reported outcomes or several endpoints, increasing the importance of prespecification and transparent analysis. Different

preparations cannot be assumed to be bioequivalent, and a statistically significant average effect may not imply a noticeable benefit for every participant. The most informative next step is replication of specific findings using independently manufactured, chemically characterized products and clinically meaningful outcomes.[4,6, 24]

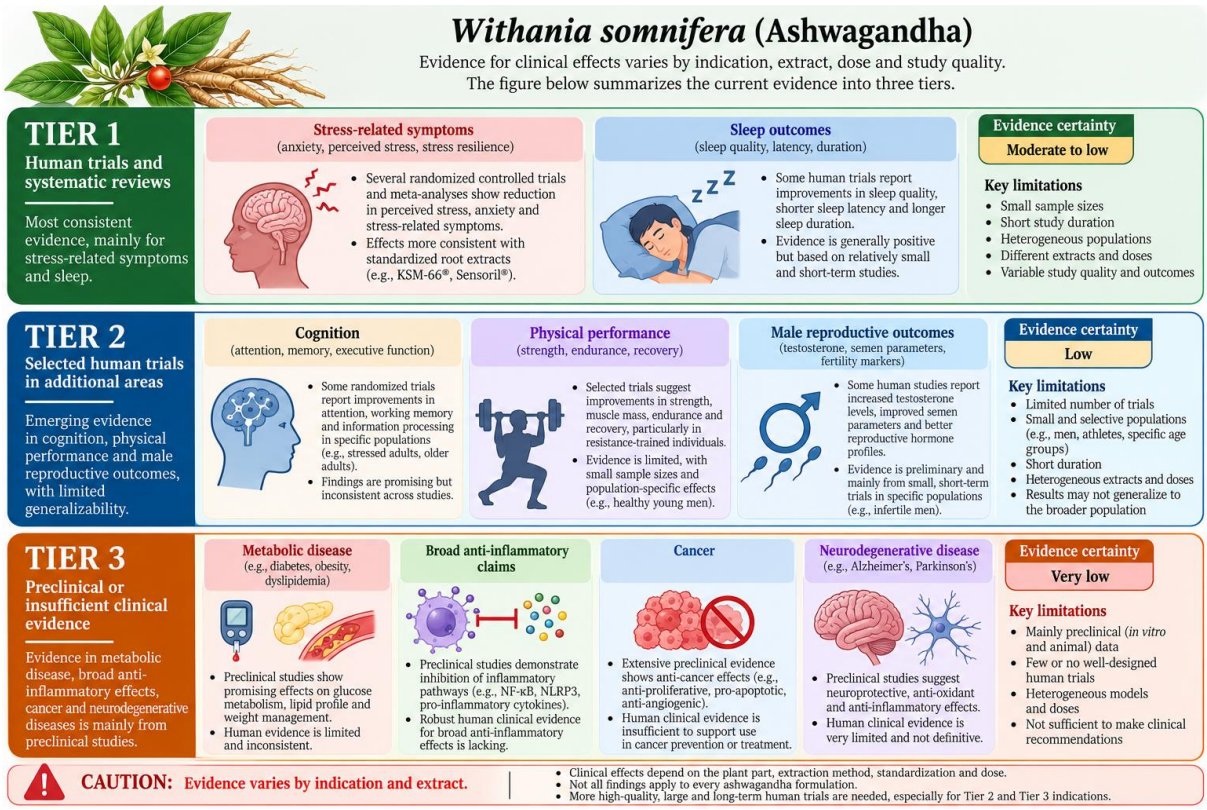


FIGURE 3. EVIDENCE LANDSCAPE FOR THE THERAPEUTIC POTENTIAL OF ASHWAGANDHA.

TABLE 3. SELECTED PRECLINICAL AND CLINICAL EVIDENCE FOR ASHWAGANDHA.

Application	Preparation / study type	Main reported finding	Key limitation
Stress and anxiety	High-concentration root extract; randomized placebo-controlled adult study	Improvement in selected stress and anxiety measures; lower cortisol was reported in the study	Single formulation and limited duration; not proof for anxiety disorders generally
Stress-related outcomes	Meta-analyses of randomized controlled trials	Pooled analyses suggest improvements on some stress/anxiety measures	Heterogeneous products, small trials and variable methods
Sleep	Root extract; randomized placebo-controlled study	Improvements in selected sleep-onset,	Small sample; findings product-

Application	Preparation / study type	Main reported finding	Key limitation
	in adults with insomnia/anxiety	sleep-efficiency and sleep-quality outcomes	specific
Sleep	Systematic review and meta-analysis of five RCTs, 400 adults	Small pooled improvement in overall sleep; stronger effect signals in selected subgroups	Moderate heterogeneity and limited long-term safety data
Cognition	Root extract; randomized controlled study in adults with mild cognitive impairment	Improvement in selected memory/cognitive measures reported	Not evidence of dementia prevention or disease modification
Physical performance	Root extract; 8-week randomized trial, 57 men in resistance training	Greater improvement in selected strength and muscle-size outcomes versus placebo	Small, selected population and short duration
Male reproductive health	Clinical study in infertile men	Reported changes in semen quality, oxidative markers and reproductive hormones	Population and preparation specific; fertility is multifactorial
Thyroid function	Randomized placebo-controlled trial in subclinical hypothyroidism	Changes in thyroid laboratory measures were reported	Small indication-specific trial; thyroid interaction concerns remain
Short-term tolerability	Randomized placebo-controlled safety study; 80 healthy adults for 8 weeks	No major laboratory or adverse-event signals in the study population	Cannot detect rare events or establish long-term safety
Liver safety	Multi-centre case series and published reports	Rare clinically apparent liver injury has been reported after supplement use	Case reports cannot estimate incidence; causality may be complex
Anticancer / neuroprotection	Cell and animal studies of extracts/withanolides	Activity reported across multiple experimental systems	Preclinical activity is not clinical efficacy or proof of safety

6. FORMULATION, STANDARDIZATION AND BIOAVAILABILITY

For a botanical product intended for repeatable research or clinical use, quality begins with authentication of the correct species and plant part. Materials should have traceable sourcing, documented harvesting and processing conditions, and suitable testing for identity, purity and contaminants. WHO guidance on herbal-material quality describes methods for assessing macroscopic and microscopic identity, foreign matter, moisture, ash values, extractives and

contaminants. These tests support material quality but do not by themselves prove therapeutic efficacy. Complementary guidance on good agricultural and collection practices and on contaminants and residues supports a quality system that begins before extraction and continues through finished-product testing.[4,33,34]

Extraction is a critical process variable because water, alcohol mixtures and other solvents recover different sets of constituents. Extraction temperature, time, particle size and solvent-to-material ratio can change the chemical fingerprint. For Ashwagandha, a root-only extract should not be treated as equivalent to a root-and-leaf blend; nor should a preparation standardized to one marker be assumed equivalent to one standardized to a different marker set. Manufacturers and researchers should report the native drug-to-extract ratio, excipients, extraction solvent and marker assay rather than only the total tablet or capsule mass.[1-4,19]

Phytochemical standardization should ideally combine species authentication with chromatographic fingerprinting and quantitative markers. HPLC or UHPLC methods can quantify selected withanolides, while LC-MS or other spectrometric approaches can support characterization of more complex extracts. Reference standards, validation characteristics, sample preparation procedures, limits of quantification and batch-to-batch variation should be reported. A total-withanolide value should be interpreted in light of the method used because assays may not respond equally to all constituents and may not distinguish individual compounds.[1-4]

Formulation innovation may eventually improve consistency or exposure, but enhanced delivery should not be automatically equated with improved clinical benefit. Any formulation change should establish chemical stability, release behavior, pharmacokinetic characteristics, tolerability and, when intended for therapeutic use, relevant clinical outcomes. Products that deliver greater exposure could also increase adverse effects or interactions. Development should therefore proceed as a pharmaceutical quality and benefit-risk question rather than as a marketing exercise based only on novelty. [1-4,17,19]

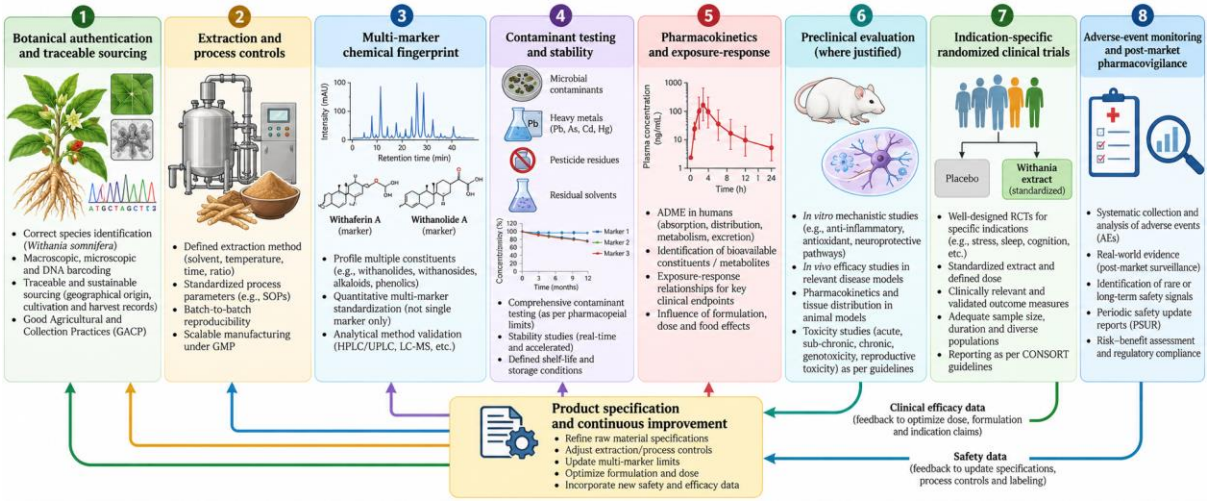


FIGURE 4. TRANSLATIONAL PATHWAY FROM BOTANICAL MATERIAL TO CLINICAL APPLICATION.

7. SAFETY, ADVERSE EFFECTS AND DRUG INTERACTIONS

Short-term randomized trials in selected adult volunteers have often reported acceptable tolerability, with mild gastrointestinal complaints or drowsiness among the commonly described effects in broader safety summaries. However, trials of several weeks or a few months in relatively healthy participants are not designed to establish safety during years of use, in pregnancy, in people with complex comorbidity or in users taking multiple medicines. Absence of adverse events in a small trial should be interpreted as absence of a detected signal under that study's conditions, not proof that clinically important risk is absent.[5,6,17,19]

Rare cases of clinically apparent liver injury have been associated with Ashwagandha-containing supplements. A report from India described a multi-centre case series of liver injury associated with single-ingredient formulations, with cholestatic or mixed patterns among reported presentations and severe outcomes in some patients with pre-existing chronic liver disease. Additional published cases from Iceland and the United States have also raised concern. Case series cannot determine incidence or prove that all products have the same risk, but they show that the possibility should not be dismissed.[20-22]

Potential drug interactions include medicines for diabetes and high blood pressure, immunosuppressants, sedatives, anticonvulsants and thyroid hormone medications. The clinical magnitude of every possible interaction is not equally well characterized, and evidence may range from pharmacological plausibility to limited clinical reports. Nonetheless, pharmacists and prescribers should ask specifically about herbal supplements

and review the patient's full medication list. Risk may be increased by combining several sedating products or by using a poorly characterized multi-ingredient supplement.[5,6,17,19] Product quality and attribution can complicate safety assessment. A supplement may contain multiple herbs, excipients, undeclared substances or contaminants, and different batches may not have the same constituent concentrations. A suspected reaction associated with one preparation does not establish that every preparation has an identical risk, but neither can the safety of one standardized root extract be generalized to every product. Good labeling, lot-level chemical information, prudent supplement use and pharmacovigilance reporting are essential to improve the evidence base.[4,6,35,36]

TABLE 4. SAFETY CONSIDERATIONS AND PRACTICAL PRECAUTIONS.

Issue	What is known / reported	Practical interpretation
Gastrointestinal effects and drowsiness	Mild stomach upset, diarrhea, vomiting or drowsiness may occur	Monitor tolerability; avoid assuming every formulation is equally tolerated
Liver injury	Rare clinically apparent liver injury has been described in case reports and series	Stop and seek clinical assessment if symptoms of liver injury occur; caution with pre-existing liver disease
Pregnancy and breastfeeding	Authoritative safety guidance advises avoidance in pregnancy and non-use during breastfeeding	Do not use as a self-directed supplement in these periods
Thyroid disorders / thyroid medicines	Possible effects on thyroid-related measures and potential interaction concern	Discuss use with a clinician; do not self-treat thyroid disease
Autoimmune disease / immunosuppressants	Potential immunomodulatory effects and possible interaction	Medical review is warranted before use
Sedatives, anticonvulsants and alcohol	Potential additive or medicine-related interactions have been raised	Review all central nervous system-active products and avoid unsupervised combinations
Glucose-lowering or antihypertensive medicines	Potential interaction with glucose or blood-pressure control	Monitor with a qualified clinician; do not replace prescribed therapy
Surgery and hormone-sensitive prostate cancer	Caution/avoidance advised in current safety summaries	Tell the surgical team and treating clinician about use; avoid use in relevant risk settings
Long-term use	Evidence is insufficient to establish long-term safety	Duration and follow-up should not be extrapolated from short trials

8. FUTURE PERSPECTIVES

Future clinical studies should begin with a clearly defined indication rather than an open-ended claim of "general wellbeing." For stress-related symptoms, trials should define the target population, primary outcome, clinically meaningful difference and treatment duration in advance. For insomnia, researchers should distinguish diagnosed insomnia from subjective poor sleep and include daytime functioning and safety outcomes. For physical performance, the training program and nutritional context should be standardized. Replication should use the same well-characterized extract whenever possible, allowing results to be compared across research groups.[10-18,23,24]

Preclinical development should focus on translationally credible questions. For isolated withanolides, investigators should establish exposure, selectivity, metabolism and toxicity before advancing disease-modifying claims. For anticancer or neuroprotective research, the relevant comparator, therapeutic window, tissue distribution and reproducibility across models are essential. Computational predictions or docking results can guide experimental hypotheses but do not demonstrate biological activity. Use of standard assay controls, blinded outcome analysis and independent replication would improve confidence in findings and reduce the risk of overinterpreting exploratory results.[1-3,7,8]

Future product development may also examine stable dosage forms, improved dissolution or delivery systems, and combinations with other botanical or conventional ingredients. These approaches should be justified by a specific quality or exposure problem and evaluated for interactions, dose uniformity, stability and clinical performance. More complex formulations may increase manufacturing cost and introduce new variability; innovation is valuable only if it improves reproducibility, safety or patient-relevant outcomes. A staged development pathway from quality-controlled raw material through pharmacokinetic work and appropriately designed clinical trials is therefore preferable to premature marketing claims.[4,17,19]

CONCLUSION

Ashwagandha (Withania somnifera) is a chemically complex medicinal plant with a long history of traditional use and a growing, but uneven, modern evidence base. Its characteristic withanolides, withanosides, alkaloids and other metabolites provide a rationale for studying stress-related, neurobiological, inflammatory, endocrine and cellular pathways. Of the clinical applications considered, stress-related outcomes and sleep have the clearest body of human research, with selected randomized trials and evidence syntheses reporting favorable

effects. Even in these areas, the certainty of evidence is limited by small trials, heterogeneous preparations, short follow-up and inconsistent methods. Findings related to cognition, physical performance and reproductive health are promising but require independent replication, while claims involving metabolic disease, chronic inflammatory disorders, cancer or neurodegenerative disease remain insufficiently supported for clinical use. Safety should be considered alongside possible benefit. Mild gastrointestinal symptoms and drowsiness can occur, rare cases of liver injury have been reported, long-term safety is not established, and precautions are warranted during pregnancy, breastfeeding, around surgery, in thyroid or autoimmune disorders and with several classes of medicines. The composition of commercial preparations varies, so findings from one standardized extract should not be generalized to all powders, blends or supplements. Future progress depends on authenticated botanical material, transparent multi-marker standardization, better pharmacokinetic characterization, fit-for-purpose quality testing, independent and adequately powered clinical trials, complete adverse-event reporting and indication-specific evaluation of clinically meaningful outcomes. Ashwagandha should therefore be regarded as a promising subject for careful pharmaceutical and clinical research rather than as a universally proven treatment. A balanced evidence-based approach can preserve its research potential while reducing unsupported claims and avoidable safety risks.

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REFERENCES

1. Mirjalili MH, Moyano E, Bonfill M, Cusido RM, Palazon J. Steroidal lactones from *Withania somnifera*, an ancient plant for novel medicine. Molecules. 2009;14(7):2373-2393. doi:10.3390/molecules14072373.
2. Saleem S, Muhammad G, Hussain MA, Altaf M, Bukhari SNA. *Withania somnifera* L.: insights into the phytochemical profile, therapeutic potential, clinical trials, and future

prospective. Iran J Basic Med Sci. 2020;23(12):1501-1526. doi:10.22038/IJBMS.2020.44254.10378.

3. Bashir A, Nabi M, Tabassum N, Afzal S, Ayoub M. An updated review on phytochemistry and molecular targets of *Withania somnifera* (L.) Dunal (Ashwagandha). Front Pharmacol. 2023;14:1049334. doi:10.3389/fphar.2023.1049334.
4. World Health Organization. Quality control methods for herbal materials. Geneva: World Health Organization; 2011. Available from: https://www.who.int/publications-detail-redirect/9789241500739.
5. National Center for Complementary and Integrative Health. Ashwagandha: usefulness and safety [Internet]. Bethesda (MD): National Institutes of Health; updated 2023 [cited 2026 Oct 14]. Available from: https://www.nccih.nih.gov/health/ashwagandha.
6. National Institutes of Health, Office of Dietary Supplements. Ashwagandha: is it helpful for stress, anxiety, or sleep? Health Professional Fact Sheet [Internet]. Bethesda (MD): NIH; updated 2025 May 2 [cited 2026 Oct 14]. Available from: https://ods.od.nih.gov/factsheets/Ashwagandha-HealthProfessional/.
7. Speers AB, Cabey KA, Soumyanath A, et al. Effects of *Withania somnifera* (Ashwagandha) on stress and the stress-related neuropsychiatric disorders anxiety, depression, and insomnia. Curr Neuropharmacol. 2021;19(9):1468-1495.
8. White PT, Subramanian C, Motiwala HF, et al. Natural withanolides in the treatment of chronic diseases. Adv Exp Med Biol. 2016;928:329-373.
9. Kulkarni SK, Dhir A. *Withania somnifera*: an Indian ginseng. Prog Neuropsychopharmacol Biol Psychiatry. 2008;32(5):1093-1105. doi:10.1016/j.pnpbp.2007.09.011.
10. Chandrasekhar K, Kapoor J, Anishetty S. A prospective, randomized double-blind, placebo-controlled study of safety and efficacy of a high-concentration full-spectrum extract of Ashwagandha root in reducing stress and anxiety in adults. Indian J Psychol Med. 2012;34(3):255-262. doi:10.4103/0253-7176.106022.
11. Lopresti AL, Smith SJ, Malvi H, Kodgule R. An investigation into the stress-relieving and pharmacological actions of an Ashwagandha (*Withania somnifera*) extract: a randomized, double-blind, placebo-controlled study. Medicine (Baltimore). 2019;98(37):e17186. doi:10.1097/MD.0000000000017186.
12. Akhgarjand C, Asoudeh F, Bagheri A, Kalantar Z, Vahabi Z, Shab-Bidar S, et al. Does Ashwagandha supplementation have a beneficial effect on the management of anxiety

and stress? A systematic review and meta-analysis of randomized controlled trials. Phytother Res. 2022;36(11):4115-4124. doi:10.1002/ptr.7598.

13. Fatima K, Malik J, Muskan F, Raza G, Waseem A, Shahid H, et al. Safety and efficacy of *Withania somnifera* for anxiety and insomnia: systematic review and meta-analysis. Hum Psychopharmacol. 2024;39(6):e2911. doi:10.1002/hup.2911.
14. Cheah KL, Norhayati MN, Yaacob LH, Abdul Rahman R. Effect of Ashwagandha (*Withania somnifera*) extract on sleep: a systematic review and meta-analysis. PLoS One. 2021;16(9):e0257843. doi: 10.1371/journal.pone.0257843.
15. Pratte MA, Nanadatkar S, Dondapati A, Nadkarni S. An alternative treatment for anxiety: a systematic review of human trial results reported for Ashwagandha (*Withania somnifera*). J Altern Complement Med. 2014;20(12):901-908. doi:10.1089/acm.2014.0177.
16. Langade D, Kanchi S, Salve J, Debnath K, Ambegaokar D. Efficacy and safety of Ashwagandha (*Withania somnifera*) root extract in insomnia and anxiety: a double-blind, randomized, placebo-controlled study. Cureus. 2019;11(9):e5797. doi:10.7759/cureus.5797.
17. Tandon N, Yadav SS. Safety and clinical effectiveness of *Withania somnifera* (Linn.) Dunal root in human ailments. J Ethnopharmacol. 2020; 255:112768.
18. Smith SJ, Lopresti AL, Teo SYM, et al. Examining the effects of herbs on testosterone concentrations in men: a systematic review. Adv Nutr. 2021;12(3):744-765.
19. Verma N, Gupta SK, Tiwari S, Mishra AK. Safety of Ashwagandha root extract: a randomized, placebo-controlled study in healthy volunteers. Complement Ther Med. 2021;57:102642. doi:10.1016/j.ctim.2020.102642.
20. Philips CA, Valsan A, Theruvath AH, Ravindran R, Oommen TT, Rajesh S, et al. Ashwagandha-induced liver injury-a case series from India and literature review. Hepatol Commun. 2023;7(10):e0270. doi:10.1097/HC9.0000000000000270.
21. Björnsson HK, Björnsson ES, Avula B, Khan IA, Jonasson JG, Einarsson JG, et al. Ashwagandha-induced liver injury: a case series from Iceland and the US Drug-Induced Liver Injury Network. Liver Int. 2020;40(4):825-829. doi:10.1111/liv.14393.
22. National Institute of Diabetes and Digestive and Kidney Diseases. Ashwagandha. In: LiverTox: Clinical and Research Information on Drug-Induced Liver Injury [Internet]. Bethesda (MD): NIDDK; updated 2024 Dec 3 [cited 2026 Oct 14]. Available from: https://www.ncbi.nlm.nih.gov/books/NBK548536/.

23. Choudhary D, Bhattacharyya S, Bose S. Efficacy and safety of Ashwagandha (*Withania somnifera* (L.) Dunal) root extract in improving memory and cognitive functions. J Diet Suppl. 2017;14(6):599-612. doi:10.1080/19390211.2017.1284970.
24. Wankhede S, Langade D, Joshi K, Sinha SR, Bhattacharyya S. Examining the effect of *Withania somnifera* supplementation on muscle strength and recovery: a randomized controlled trial. J Int Soc Sports Nutr. 2015;12:43. doi:10.1186/s12970-015-0104-9.
25. Ahmad MK, Mahdi AA, Shukla KK, Islam N, Rajender S, Madhukar D, et al. *Withania somnifera* improves semen quality by regulating reproductive hormone levels and oxidative stress in seminal plasma of infertile males. Fertil Steril. 2010;94(3):989-996. doi:10.1016/j.fertnstert.2009.04.046.
26. Nasimi Doost Azgomi R, Zomorrodi A, Nazemyieh H, Fazly Bazzaz BS, Mohsen tenani M, et al. Effects of *Withania somnifera* on reproductive system: a systematic review of the available evidence. Biomed Res Int. 2018;2018:4076430. doi:10.1155/2018/4076430.
27. Sharma AK, Basu I, Singh S. Efficacy and safety of Ashwagandha root extract in subclinical hypothyroid patients: a double-blind, randomized placebo-controlled trial. J Altern Complement Med. 2018;24(3):243-248. doi:10.1089/acm.2017.0183.
28. Power FB, Salway AH. LIX. The constituents of *Withania somnifera*. J Chem Soc Trans. 1911;99:490-507. doi:10.1039/CT9119900490.
29. Matsuda H, Murakami T, Kishi A, Yoshikawa M. Structures of withanosides I, II, III, IV, V, VI, and VII, new withanolide glycosides, from the roots of Indian *Withania somnifera* Dunal, and inhibitory activity for tachyphylaxis to clonidine in isolated guinea-pig ileum. Bioorg Med Chem. 2001;9(6):1499-1507. doi:10.1016/S0968-0896(01)00024-4.
30. Shukla SD, Bhatnagar M, Khurana S. Critical evaluation of Ayurvedic plants for stimulating intrinsic antioxidant response. Front Neurosci. 2012;6:112. doi:10.3389/fnins.2012.00112.
31. D'Cruz M, Andrade C. Potential clinical applications of Ashwagandha (*Withania somnifera*) in medicine and neuropsychiatry. Expert Rev Clin Pharmacol. 2022;15:1067-1080.
32. Lopresti AL, Drummond PD, Smith SJ. A randomized, double-blind, placebo-controlled, crossover study examining the hormonal and vitality effects of Ashwagandha (*Withania somnifera*) in aging, overweight males. Am J Mens Health. 2019;13:1557988319835985. doi:10.1177/1557988319835985.

33. World Health Organization. WHO guidelines on good agricultural and collection practices (GACP) for medicinal plants. Geneva: World Health Organization; 2003.
34. World Health Organization. WHO guidelines for assessing quality of herbal medicines with reference to contaminants and residues. Geneva: World Health Organization; 2007.
35. National Center for Complementary and Integrative Health. Using dietary supplements wisely [Internet]. Bethesda (MD): National Institutes of Health [cited 2026 Oct 14]. Available from: https://www.nccih.nih.gov/health/using-dietary-supplements-wisely.
36. National Institutes of Health, Office of Dietary Supplements. Dietary supplements: what you need to know [Internet]. Bethesda (MD): NIH [cited 2026 Oct 14]. Available from: https://ods.od.nih.gov/factsheets/WYNTK-Consumer/.