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Review Article:

A Comprehensive Review on Recent Trends in Ayurveda Nutraceuticals: From Multi-Target Pharmacology to Personalised Precision Nutrition

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Abstract :

Background: Healthcare is rapidly shifting toward disease prevention, driving a booming nutraceutical market that is redefining global wellness. At the forefront of this movement, ancient Ayurvedic traditions are merging with modern science, treating food as medicine to maintain bodily balance. While traditional herbal formulas have long struggled with low bioavailability and poor absorption, recent breakthroughs in drug delivery systems and computational biology are finally bridging that gap. This review explores how a decade of multidisciplinary research has successfully transformed traditional remedies into standardized, globally recognized therapeutics. **Materials and methods:** This study synthesises peer-reviewed literature from 2015 to 2026 across major databases to find out this changing landscape. **Result:** Bibliometric and thematic analyses reveal that current research evolves around four core pillars, such as phytochemical standardisation, advanced delivery systems, multi-target pharmacology and clinical validation. Despite this progress, the sector faces significant hurdles, including heavy metal contamination, microbial adulteration, inconsistent raw material quality, and fragmented global regulations across the FDA, EFSA, and FSSAI. Looking forward, the integration of Artificial Intelligence (AI) and machine learning offers a promising frontier for optimising polyherbal synergies and predicting drug-nutraceutical interactions. **Conclusion:** This review demonstrates that a decade of scientific studies has successfully transformed Ayurvedic nutraceuticals into a standardised, evidence-based opportunity for global integrative medicine.

Keywords: Ayurvedic nutraceuticals, phytochemical standardisation, advanced delivery systems, multi-target pharmacology, clinical validation, and regulatory harmonisation.

Introduction

The global healthcare strategy is moving toward proactively preventing the illness that is treating them. This change is making the fast-growing nutraceutical market, which is expected to clear 600 billion USD globally over the next ten years. [1]. Over the last ten years (2015–2026), there has been an upward growth in integration of traditional medical knowledge systems with modern food science and pharmacological technologies [2]. Among these traditional systems, Ayurveda stands out due to its concepts regarding

nutrition (*Ahara*) as the ultimate therapeutic modality for maintaining physiological equilibrium and preventing chronic diseases [3].

In classical Ayurvedic texts like the *Charaka Samhita* [4] and *Sushruta Samhita* [5], the categories of food and medicines are well mentioned. Dietary raw materials are categorised according to their *Vipaka* (Post-digestive effect), *Virya* (Potency), *Prabhava* (Specific action). [6] Modern functional food scientists developed their complex architecture by isolating bioactive secondary metabolites to create targeted supplements. However, raw herbal matrices often suffer from poor gastrointestinal absorption, low systemic bioavailability, thermal instability, and rapid phase-II hepatic metabolism, which limits their clinical translation in contemporary medicine [7, 8].

To address these limitations, multidisciplinary research from 2015 to 2026 has searched for advanced engineering and computational technologies to bridge the gap between traditional wisdom and scientific validation. This review systematically focuses the major milestones of this decade, examining how high-throughput screening, advanced drug delivery systems, and systems biology platforms have transformed ancient polyherbal recipes into standardised and globally accepted nutraceutical agents.

Methodology

To build a highly accurate dataset tracking the modern evolution of Ayurvedic nutraceuticals, a comprehensive systematic literature search was executed covering the period from January 2015 to June 2026.

Search Strategy and Indexing Databases

Primary literature data collection was conducted across five major academic repositories: Web of Science (WoS), PubMed, Google Scholar, and ResearchGate. The following terms were considered for the search:

- "Ayurveda" OR "Ayurvedic" OR "Rasayana" AND "Nutraceutical" OR "Functional Food" OR "Dietary Supplement" OR "Phytochemical" OR Clinical Trial"

Inclusion and Exclusion Criteria

To ensure high-quality articles were selected against strict criteria:

Inclusion: Peer-reviewed original research papers, systematic reviews, meta-analyses, and book chapters exploring chemical characterisation, nanotechnology, in vitro/ in vivo/ in silico mechanistic pathways, clinical trials, and regulatory aspects of Ayurvedic botanicals utilised as food supplements.

Exclusion: Informal studies, articles lacking definitive botanical identification, papers published outside the 2015–2026 window, and non-peer-reviewed conference abstracts.

After a multi-stage screening of titles, abstracts, and full texts, we finalised a selection of definitive studies to anchor the thematic framework of this review.

Result and Discussion

Phytochemical Standardisation and Fingerprinting Methodologies

A major barrier to the global acceptance of herbal products has been the inherent chemical variability of raw plant materials, which is influenced by geographical origin, soil quality, seasonal harvesting fluctuations, and post-harvest handling [9]. Over the past decade, research has prioritised shifting from crude extracts to precision-standardised herbal profiles.

Modern analytical chemistry is now equipped with multi-dimensional separation and spectroscopic techniques to ensure batch-to-batch consistency. Rather than tracking single active ingredients. [10] For example, standardisation protocols for *Withania somnifera* (*Ashwagandha*) extracts focus on establishing exact ratios of major withanolides (such as Withaferin A, Withanolide A, and Withanolide D) . This process ensures therapeutic efficacy while minimising potential toxicity from variable concentrations of withaferin A[11]. Similarly, *Curcuma longa* (Turmeric) formulations are standardised to preserve the exact proportion of three main curcuminoids: curcumin, demethoxycurcumin, and bisdemethoxycurcumin [12].

Additionally, Gas Chromatography-Mass Spectrometry (GC-MS) has been widely applied to map the volatile oil profiles of aromatic Ayurvedic herbs like *Zingiber officinale* (Ginger) and *Ocimum sanctum* (*Tulsi*) [13]. Genetic identity validation via DNA barcoding and ISSR (Inter Simple Sequence Repeat) molecular markers has further eliminated the risk of cryptic botanical substitutions in multi-component formulations [14]. This rigorous multi-tiered approach ensures that volatile and non-volatile bioactives are consistently preserved during commercial functional food production.

Novel Delivery Systems: Enhancing Pharmacokinetic Bioavailability

The therapeutic efficacy of many premium Ayurvedic secondary metabolites such as polyphenols, flavonoids, and lipophilic triterpenoids is frequently compromised by their physical and chemical limitations . Many of these compounds exhibit poor aqueous solubility, and they are unstable in the highly acidic gastric environment, experience rapid enzymatic breakdown in the intestinal lumen, or undergo extensive first-pass metabolism in the liver [15]. To overcome these pharmacokinetic difficulties, the period between 2015 and 2026 has seen a major surge in adapting advanced nanotechnological delivery systems for Ayurvedic

ingredients [16].

Table no. 1 shows the works that were taken part in in the Neutraceutical area

Delivery System Architecture	Mechanism of Action	Target Bioactive Compounds	Enhanced Pharmacokinetic Outcome
Phytosomes (Lipid Complexes)	Phospholipids bind molecularly to polyphenols, forming stable, amphiphilic complexes that readily cross lipid bilayers. [17]	Curcuminoids [18], Epigallocatechin gallate (EGCG), Silymarin	4- to 6-fold increase in systemic plasma concentrations; improved lymphatic absorption.
Nano-emulsions [19]	Isotropic mixtures of oil, water, and surfactants that generate droplet sizes under 200 nm, by passing initial hepatic clearance.	Essential oils of *Zingiber officinale* [20], *Piper nigrum* oleoresins [21]	Enhanced intestinal permeability; rapid absorption and rapid onset of therapeutic action.
Solid Lipid Nanoparticles (SLNs) [22]	Bioactives are trapped within a biocompatible solid lipid core matrix, shielding them from chemical and enzymatic breakdown [23].	Withanolides [24], Bacosides, Gymnemic Acids	Sustained-release profiles over 24 hours; protected from stomach acid breakdown.
Polymeric Nanoparticles [25]	Biodegradable polymers (e.g., PLGA, Chitosan) encapsulate the herbs to target specific tissues or organs [26].	*Centella asiatica* saponins, Resveratrol	Crosses the blood-brain barrier (BBB); provides targeted delivery for neuroprotective benefits.

Furthermore, physical micro-encapsulation methods have been optimised not only to prolong shelf stability but also to mask the naturally intense bitterness characteristic of many *Rasayana* herbs, vastly improving compliance in functional food and commercial beverage systems [27]. By enclosing fragile Ayurvedic extracts inside these specialised lipidic and polymeric structures, modern nutraceutical formulators have successfully transformed unstable traditional extracts into highly bioavailable, shelf-stable, and reproducible therapeutic agents [28].

Reverse Pharmacology and Systems Biology Approaches

Historically, conventional western drug discovery relies on a forward target-driven methodology: identifying a specific biological target, conducting high-throughput screening of synthetic chemical libraries, and evaluating safety in animals before moving to human trials. This process is lengthy and frequently suffers from high attrition rates during clinical phases.

Conversely, Ayurvedic nutraceutical development has increasingly embraced the paradigm of **Reverse pharmacology,** often described as the "clinic-to-lab" approach [29]. Because Ayurvedic formulations have a documented history of safe human consumption spanning centuries, the discovery workflow is reversed. Researchers begin with validated clinical observations of efficacy [30], then transition back to laboratory settings via *in vitro* and *in vivo* models to discover underlying molecular mechanisms and identify active compounds.

Complementing reverse pharmacology, the rise of network pharmacology has revolutionized our understanding of polyherbal formulations [31]. Traditional Western pharmacology generally adheres to a "one drug, one target, one disease" model. This approach is ill-suited for Ayurvedic philosophy, which utilizes multi-herb formulations (*Yoga*) to restore full-body homeostasis.

Network pharmacology uses computer models to map how the complex mixture of chemicals in an Ayurvedic herb interacts across a web of biological pathways. Instead of searching for a single chemical in *Triphala* (a mixture of three fruits: *Terminalia chebula*, *Terminalia*

bellirica, and *Phyllanthus emblica*) [32], network models and *in silico* molecular docking show that its diverse polyphenols act simultaneously on multiple points within the gut inflammation pathway [33]. They simultaneously inhibit pro-inflammatory cytokines, regulate the gut microbiome [34], and upregulate endogenous antioxidant enzymes like Superoxide Dismutase (SOD) and Catalase [35]. This network-based approach provides an empirical, multi-targeted explanation for the holistic, synergistic effects that characterize Ayurvedic medicine.

Mainstream Therapeutic Areas and Clinical Evidence

The clinical validation of Ayurvedic nutraceuticals between 2015 and 2026 has focused primarily on managing non-communicable diseases (NCDs), age-related metabolic decline, and chronic stress.

Neuroprotective and Adaptogenic Agents

Withania somnifera (Ashwagandha) has emerged as a premier global adaptogen [36]. Extensive clinical trials and meta-analyses published over the past decade confirm that standardised root extracts significantly reduce human anxiety and stress scores by lowering serum cortisol levels and modulating the hypothalamic-pituitary-adrenal (HPA) axis [37]. At the molecular level, its withanolides interact with GABAergic and glucocorticoid receptors, supporting neuroplasticity, reducing oxidative damage in the brain, and improving sleep architecture in patients suffering from chronic insomnia [38].

Similarly, *Bacopa monnieri* (Brahmi) has undergone rigorous validation, demonstrating an ability to enhance memory retention, attention span, and cognitive processing speeds in both young adults and ageing populations [39]. This effect is driven by bacosides, which upregulate brain-derived neurotrophic factor (BDNF) and repair damaged synaptic connections [40].

Metabolic and Cardiovascular Homeostasis

Managing metabolic syndrome, including type 2 diabetes mellitus, obesity, and atherogenic dyslipidaemia, represents another key therapeutic cluster [41]. Standardised supplements containing *Gymnema sylvestre* (Gurmar) have demonstrated clear clinical efficacy in lowering HbA1c levels. The gymnemic acids work via a dual mechanism: blocking sweet taste receptors on the tongue and inhibiting glucose absorption pathways across the intestinal brush border membrane. [42]

Furthermore, the complex interaction between glucose and lipid metabolism is increasingly managed using Ayurvedic options. Research shows that regulating key metabolic enzymes like HMG-CoA reductase can help address both obesity, cellular energy balance, and elevated fasting glucose [43]. Botanicals such as *Commiphora mukul* (*Guggulu*) [44], *Terminalia arjuna* [45], and *Phyllanthus emblica* (*Amalaki*) [46] are frequently utilised as safe, long-term options to optimise lipid profiles, enhance bioaccessibility of trace minerals [47], and mitigate systemic, low-grade vascular inflammation [48]. Clinical exploratory trials have also shown their efficacy in resolving advanced metabolic dysfunction-associated steatotic liver disease (MASLD) [49].

Adjuvant Therapeutics and Special Populations

The application of Ayurvedic nutraceuticals has expanded into oncology and paediatrics. Clinical evaluations have established the role of traditional *Rasayana* therapies as valid adjuvants to mitigate cachexia and oxidative depletion during post-chemotherapy recovery [50]. In paediatric functional nutrition, standardised polyherbal matrices incorporated into everyday food formats (e.g., fortified herbal cookies) have demonstrated success in restoring biochemical markers in cohorts experiencing chronic malnutrition [51]. Furthermore, high-potency antioxidant formulations like *Amrit Kalash* have been validated for broad immunomodulatory defence [52], while specific botanical extracts are deployed to maintain systemic oral mucosal health [53].

Safety, Quality Control, and Regulatory Harmonisation Challenges

Along with these scientific advancements, the global integration of Ayurvedic nutraceuticals faces several persistent quality control issues and regulatory fragmentation challenges.

Toxicological Contamination and Adulteration

A primary challenge to the reputation of Ayurvedic supplements is the recurring issue is contamination [54]. Because many medicinal herbs are hyper-accumulators of soil elements, they can absorb toxic heavy metals (such as Lead, Cadmium, Arsenic, and Mercury) if cultivated in unmonitored or industrially contaminated soil [55]. Advanced toxicological screening frameworks now mandate the use of Inductively Coupled Plasma Mass Spectrometry (ICP-MS) to ensure that heavy metal concentrations remain well below international safety thresholds [56].

Furthermore, industrial processing plants must strictly monitor for organochlorine and organophosphorus pesticide residues accumulated during agricultural cultivation [57], mycotoxins (specifically aflatoxins produced by *Aspergillus* fungi during improper drying or storage phases) [58], and microbial loads, requiring gentle sterilisation strategies like gamma irradiation to ensure compliance with standard colony-forming unit (CFU) safety limits without altering volatile compositions [59].

Fragmented International Regulatory Frameworks

The global commercialisation of Ayurvedic products is hindered by a lack of unified regulatory standards [60] Different international jurisdictions categorise and evaluate these products under vastly different legal frameworks:

- **India (FSSAI & AYUSH):** The Food Safety and Standards Authority of India [61], in coordination with the Ministry of AYUSH, provides a structured regulatory framework that recognises "Ayurveda Aahar" [62]. This designation allows traditional formulations to be legally marketed as functional foods and dietary supplements, provided they adhere to established safety guidelines and traditional preparation texts.
- **United States (US FDA):** The FDA regulates imported Ayurvedic formulations under the Dietary Supplement Health and Education Act (DSHEA) of 1994. Under this law, these products cannot claim to diagnose, treat, cure, or prevent any specific disease. They are restricted to structural or functional health claims, and the burden of safety verification rests primarily on the manufacturer. [63]
- **Europe (EFSA):** The European Food Safety Authority applies rigorous Traditional Herbal Medicinal Products Directives (THMPD). EFSA requires extensive documentation demonstrating safe historical use within the European Union for at least 15 years, creating a demanding market entry barrier for authentic polyherbal Ayurvedic formulations. [64]

Future Horizons: Artificial Intelligence and Precision Ayurveda

As the field looks beyond 2026, the next major evolutionary step for Ayurvedic nutraceuticals lies in integrating Artificial Intelligence (AI) and machine learning algorithms with traditional knowledge. [65] Machine learning models are currently being trained on massive ethnopharmacological databases to predict ideal synergistic ratios for multi-herb formulations. This helps optimise complex botanical mixtures far more quickly than traditional trial-and-error laboratory experiments.

Additionally, AI-driven platforms are being deployed to evaluate the complex personal health categories of Ayurveda (the three *Doshas*: *Vata*, *Pitta*, and *Kapha*) alongside modern genetic and gut microbiome data [66]. This convergence give a way for precision Ayurvedic nutraceuticals and supplements modified to fit an individual's unique metabolic, genetic, and epigenetic profiles [67]. This dual approach respects traditional personalised medicine while satisfying the empirical standards required by modern healthcare systems.

Conclusion

The 2015–2026 decade transformed Ayurvedic nutraceuticals into a scientifically validated global industry. Advanced analytical techniques (HPTLC, LC-MS/MS) and nanotechnology have resolved standardisation and bioavailability hurdles, while network and reverse pharmacology have validated polyherbal synergy. Despite regulatory fragmentation and quality control challenges, sufficient clinical evidence confirms their safety and efficacy. Moving forward, AI and personalised technologies position evidence-based Ayurveda at the forefront of global integrative medicine.

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