



## **NEW VISTAS FOR BETTER HEALTHCARE SYSTEM TO HUMAN BEINGS CAN BE OPENED BY THE INTEGRATION OF BIOTECHNOLOGY AND AYURVEDA**

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### **ABSTRACT**

This study explores the multidisciplinary fusion of Ayurveda and biotechnology as a convergent paradigm for healthcare systems. While biotechnology offers the cutting edge tools and techniques for molecular characterization, quality assurance and therapeutic innovation, Ayurveda, an ancient Indian medical tradition of healthcare, places an emphasis on personalized, preventive and holistic health practices. The study methodically investigates the biotechnological validation of Ayurvedic ideas including the use of genomes for Prakriti-based phenotyping, the clinical standardization of herbal formulations and the improvement of bioavailability. To find areas of agreement and integration issues, a qualitative review methodology was used to examine clinical research, peer-reviewed literature and regulatory frameworks. The results imply that the use of biotechnological methods can improve the safety, effectiveness, clinical efficacy and scientific legitimacy of Ayurvedic treatments. However, legal discrepancies, standardization challenges and ethical issues limit the convergence process. In the direction of changing needs for global public health, we have, through this article, endeavoured to present a systematic but evidence-based framework for combining biotechnology and Ayurvedic principles with immense potential to produce even more individualised, preventive and sustainable healthcare models.

**Keywords:** Biotechnological tools and techniques, Ayurvedic system of healthcare, Modernization of Ayurvedic therapy, Human health.

### **INTRODUCTION**

The movement towards integrative and personalized medicine, where cutting-edge scientific innovation meets time-tested traditional wisdom, is becoming an increasingly dominant trend in global healthcare. Among the most promising intersections lies the convergence of biotechnology and Ayurveda, the ancient Indian medical system with roots stretching back over 3,000 to 5,000 years (Jagtap, 2020; Patwardhan et al. 2005). While biotechnology offers precision tools for molecular diagnostics, therapeutic interventions and drug development, Ayurveda contributes a holistic, individualised framework for understanding aetiology, human physiology, maintaining health and preventing disease through natural remedies based on lifestyle interventions (Patwardhan et al. 2005). At first glance, biotechnology and Ayurveda may seem to represent opposite paradigms: one reductionist, analytical and experimental while the another holistic, qualitative and evidence-based respectively. However, this contrast is, upto some extent, increasingly viewed as complementary rather than contradictory. Ayurveda provides a rich

system of biology perspective rooted in concepts like Prakriti (individual composition), Dhātu (the upholding and maintaining components of the body) and their interplay between body, mind and the environment (Jagtap, 2020). These principles align naturally with modern pursuits in genomics, metabolomics and bioinformatics and together offer the tools to investigate the biological underpinnings of such traditional concepts (Mukerji, 2023).

Recent advancements have provided better opportunities for validating and enhancing Ayurvedic knowledge using biotechnological approaches. Genomic studies, to name a few, have unveiled significant correlations between the classification of Ayurvedic Prakriti and gene expression patterns which together lay down the foundation of the groundwork for personalized medicine (Ubale, 2011; Singh, 2011). Such studies suggest that traditional diagnostics could be supported and even refined through molecular profiling. This not only strengthens the credibility of Ayurveda in scientific circles but also provides a framework for customised treatment strategies that combine ancient diagnostics

with modern therapeutics. In the field of pharmacognosy and herbal medicine, biotechnology has played a transformative role. Tools such as DNA barcoding, high-performance liquid chromatography (HPLC) and other advanced analytical techniques are now routinely used to authenticate herbal ingredients, ensure product consistency and meet modern safety and efficacy standards (Mukherjee et al. 2015). These developments have improved the global acceptability of Ayurvedic products by addressing longstanding concerns about quality control and standardization. Moreover, the integration of biotechnology facilitates more targeted drug discovery from Ayurvedic pharmacopoeia. Using molecular screening, bioinformatics and cell-based assays, researchers can isolate bioactive compounds from traditional formulations, assess their pharmacokinetics and pharmacodynamics, and optimize their therapeutic applications. This approach allows for the scientific refinement of age-old remedies, turning traditional herbal formulations into globally marketable and clinically effective therapies (Mukerji, 2023). Beyond pharmacology, this integrative approach also promotes a broader rethinking of healthcare systems. The convergence of Ayurveda and biotechnology exemplifies a shift towards evidence-based traditional medicine, culturally rooted healthcare models and sustainable wellness strategies. It responds to the global demand for natural, safe and effective therapies, especially in the context of chronic lifestyle diseases, mental health conditions and the need for personalized care (Patwardhan et al. 2005).

In conclusion, the collaboration between biotechnology and Ayurveda is more than a scientific exercise, it represents a paradigm shift in how we approach health and healing. This synergy offers a balanced path forward that is scientifically rigorous, culturally respectful and clinically effective. By combining the diagnostic precision and therapeutic capabilities of biotechnology with the personalized and holistic wisdom of Ayurveda, the future of healthcare can be both innovative and integrative.

#### **LITERATURE REVIEW**

The scientific researches, to develop clinically efficacious ayurvedic herbal drugs as better and futuristic drugs of choice, have not been widely started, however, our group made significant contributions in this area (Agarwal et al. 1997; Abbas et al. 1997; Tripathi et al., 1999 Tripathi and Semwal 2022) of giardial diarrhea treatment with Pippali rasayana-an ayurvedic herbal drug with miraculous revitalizing property for in built immunity. These research findings strongly supported rationalizing and scientifically developing herbal formulations as futuristic better drugs of choice for use

in diarrheal diseases. Recent studies highlight how biotechnology and Ayurveda are increasingly being combined as a revolutionary step toward evidence-based and individualized healthcare. In order to support the scientific validity of traditional Ayurvedic classifications (Prakriti types), the new field of Ayurgenomics aims to correlate them with genomic and molecular markers. According to a recent study, prakriti based classification is consistent with variations in immune response and gene expression, providing a basis for tailored treatments (Majumder et al. 2023). Additionally, it has been demonstrated that nanotechnology can improve the effectiveness of Ayurvedic formulations. Research indicates that the bioavailability, stability and therapeutic potential of herbal extracts are enhanced when they are transformed into nanoparticles (Tajne et al., 2025; Sharma, 2024). This is consistent with long-standing customs like Bhasma, (Chatterjee et al., 2024) which have been shown by science to involve nanoparticles. Due to their inherent limits, contemporary and traditional medicine must be integrated as health systems evolve. Although both seek to address medical conditions, traditional medicine is less widely accepted worldwide than contemporary medicine because it lacks adequate scientific support of data and observational facts. Emerging diseases provide difficulties for all medical professionals and may be related to environmental changes. Therefore, interdisciplinary research that integrates traditional, modern and biomedical disciplines, is essential to create successful treatment plans. With this evaluation concentrating on Ayurvedic remedies and possible biotechnological support, biotechnology can make a substantial contribution to diagnostics and therapy regimens (Chauhan et al. 2023). Despite being frequently seen as a contemporary scientific discipline, biotechnology has its roots in natural processes and old customs that predate human civilization. The historical development of biotechnology is traced in this overview, from fermentation and early microbial uses to the emergence of molecular biotechnology characterized by advances in recombinant DNA, genetic engineering and hybridoma technology (Abhishek, 2024). It draws attention as to how biotechnology is revolutionizing human health, especially in the areas of diagnosis, treatment and the preparation of new medications. However, there is now more interest in natural, plant-based therapies due to the drawbacks and negative consequences of synthetic medications (Jha et al. 2025). Ayurvedic knowledge combined with contemporary biotechnological instruments is showing promise, particularly in preparation of herbal medications for persistent and antibiotic resistant illnesses including bacterial and giardial diarrhoea. The critical need for worldwide standardization and scientific validation of Ayurvedic



herbal formulations, including *Pippali rasayana*, as safe, accessible and efficient substitutes for allopathic therapies, is emphasized in this article (Ghisalberti, 1994; Agarwal et al. 1994; Gandhi et al. 2022 Tripathi, and Semwal 2022). Herbal biomedical technology holds great potential for promoting environmental sustainability through the preservation of endangered medicinal plants and the development of eco-friendly pharmaceuticals (Singh, 2017).

### THE GROWTH AND IMPACT OF MODERN BIOTECHNOLOGY

Early biotechnology was rooted in the discovery and use of yeast in the production of wine and beer, marking the beginning of applied biological processes in human civilization. As scientific understanding evolved, research persisted despite initial uncertainties, eventually leading to the identification of pathogenic microorganisms as the causative agents of disease. By the mid-twentieth century, biotechnology had begun to flourish, spurred by political acknowledgment of its potential and supported by economic growth. This period also saw the convergence of various biological sciences through foundational research in molecular biology and biochemistry, which laid the groundwork for future innovations (Buchholz and Collins, 2013). In recent decades, biotechnology has experienced exponential growth, becoming a critical driver of innovation across multiple sectors including healthcare, agriculture, industry and environmental sustainability. Breakthroughs in molecular biology, genomics and bioinformatics have paved the path for advanced technologies such as next-generation sequencing (NGS), synthetic biology platforms and precision gene-editing tools like CRISPR- Cas9 (Doudna and Charpentier, 2014; Shendure et al. 2017). The global biotechnology industry is witnessing remarkable expansion, with projections estimating a compound annual growth rate (CAGR) of 13.96%, rising from approximately USD 1.55 trillion in 2023 to USD 3.88 trillion by 2030 (Size GH. Share and Trends Report, 2024). In the healthcare domain, biotechnology has led to the development of over 260 biologic medications that address more than 230 diseases, generating over USD 175 billion in global sales (Pisano, 2006). Advances in gene-editing have also significantly enhanced crop resilience, productivity and nutritional quality, thereby contributing to improved global food security (Mijena et al. 2022). Industrial biotechnology is facilitating a transition toward a bio-based economy, promoting the sustainable production of biofuels, enzymes and biodegradable materials (Wei et

al. 2022). Nevertheless, the widespread application of biotechnology is accompanied by ongoing challenges, including biosafety concerns, the need for harmonized international regulations and inequitable access to technologies, particularly in low and middle income countries (Santos et al. 2024). Despite these issues, the continued integration of artificial intelligence, nanotechnology and high-throughput data analytics is expected to accelerate biotechnological advancements and their global impact in the decades ahead. As one of the most transformative scientific revolutions of the 21st century, modern biotechnology is reshaping industries, redefining healthcare systems and addressing urgent global challenges in agriculture, environmental conservation and energy sustainability. Defined by the use of biological systems, organisms or their components to develop or modify products and processes for specific applications, biotechnology encompasses a multidisciplinary framework involving molecular biology, genetics, bioinformatics and biochemical engineering (Trigo et al. 2023).

Since the discovery of restriction enzymes and the development of recombinant DNA technology in the 1970s, the field has progressed rapidly, culminating in the current era of synthetic biology and Clustered Regularly Interspaced Short Palindromic Repeats (CRISPR) based gene editing (Berg et al. 1975; Doudna and Charpentier, 2014). Aligning with sustainable health practices, CRISPR-based diagnostic techniques have also enhanced the quick identification of infections, while agricultural applications have concentrated on creating hardy crop types (Gulati, 2021). By providing genetic validation of individual constitutions (prakriti) and guaranteeing quality control of herbal medications through molecular authentication, this potent technology also shows potential for integration with traditional medical systems like Ayurveda (Dudeja et al. 2025). The healthcare sector, in particular, has experienced profound benefits, with biopharmaceuticals such as monoclonal antibodies, recombinant proteins and nucleic acid-based therapies revolutionizing the treatment of various cancers, autoimmune disorders and genetic diseases (Walsh, 2018). Furthermore, biotechnology enabled the swift development of diagnostics and vaccine technologies, as demonstrated by the use of RT-PCR and mRNA platforms during the COVID-19 pandemic (Krammer, 2020). In agriculture, genetically modified crops have made substantial improvements in yield, pest and disease resistance and nutritional enhancement (James, 2015). Simultaneously, environmental biotechnology contributes to global sustainability efforts

by generating biofuels, biodegradable alternatives to plastics and microbial solutions for waste management and pollution mitigation (Prajapati et al. 2025). However, the rapid pace of biotechnological development also raises complex ethical, legal and social questions. Concerns surrounding genetic privacy, the ethical implications of human genome editing, intellectual property rights and fair access to biotechnology-based interventions underscore the necessity for robust governance frameworks and international cooperation (NASEM, 2017).

#### **MOLECULAR BIOTECHNOLOGY AND THE REVIVAL OF AYURVEDIC THERAPEUTICS**

The integration of molecular biotechnology with Ayurvedic therapeutics represents a promising frontier in modern healthcare, offering the potential to scientifically validate and enhance traditional remedies. Advances in molecular biology techniques such as genomics, proteomics, metabolomics and bioinformatics are now being employed to understand the molecular mechanisms of Ayurvedic formulations and individual herbs, allowing for the identification of bioactive compounds, their targets and pathways of action (Patwardhan et al. 2005). Better quality health and disease free life are the real ventures targeted and achieved to a greater extent by the infusions of our modern research (Thacharodi et al. 2024). Diagnosis and subsequent therapy are the pillars that support a healthy life, allowing individuals to enjoy the pleasures of nature without a doubt.

Undoubtedly, the contributions of modern synthetic drugs in enhancing life span, reducing mortality rate and adding vigor and vitality to life, by their effective and proper administration in several infections and diseases, are worth considering. However, the type of antibiotic treatment to be continued, with a sufficient degree of clinical efficacy and safety, becomes a controversial issue due to inherent drawbacks of modern synthetic antidiarrheal drugs, including antibacterial diarrhea drugs, like severe side toxic effects, chronicity, withdrawal effects, relapses and reinfections, drug /antibiotic resistance, disturbance of micro flora and microbial eco-biodiversity of bowel, nausea, abdominal cramps, furry tongue, metallic and unpleasant taste, unavailability in far flung regions, cost factor and IPR, GATT *etc.*, (Tripathi, 2020, Ramirez et al. 2020). Moreover, these adverse effects discourage their prompt and repeated use as clinically effective and safe drugs. The seriousness of global scientific and medical communities can be envisaged from the fact that even faecal matter of a healthy person was introduced in the gut of the severe antibiotics non

responsive bacterial diarrhea patients and amazing and promising positive results, in terms of cure, were found. Being otherwise so beneficial, it is an embarrassing psychoethical issue for many people worldwide including Indians. It is known as the prebiotic concept of treatment (Wang et al. 2024).

In such situations of trauma and complications, it becomes mandatory to develop clinically efficacious ayurvedic herbal drugs with amazing properties of innocuous nature, anti relapse, easy availability in far flung areas, economic, free from IPR constrains, without drug resistance, specially the “Rasayana” class known for rejuvenating the host immunity (Agarwal et al. 1997, Abbas et al. 1997, Tripathi, et al. 1999). Further, the cell mediated immunological protective roles were confirmed in the treatment of Salmonella and Shigella caused diseases (Erica, 2009, Pont, 2009, www.squidoo.com/ natural medicine). Non-immunological defense mechanisms provide the first line of defense against pathogenic organisms that might otherwise colonize the gastrointestinal tract. Gram-negative bacteria may be found in the upper gut of patients with pernicious anaemia thereby making them prone to infectious diarrhea. The leads to develop herbal formulations, as ayurvedic drugs, were taken from the studies conducted for Krimi Roga (Shastri and Chaturvedi, 1986 and Atrideo, 1978). Consequently, we worked on anti giardial diarrhea herbal drugs and observed a profound degree of revitalizing quality to host immunity (Agarwal et al. 1994, Agarwal et al. 1997, Abbas et al. 1997, Tripathi et al. 1999). Clinical trials conducted by us with these drugs in giardiasis patients have shown high curative value.

#### **HERBAL BIOTECHNOLOGY FOR DIARRHEAL DISEASES**

Herbal biotechnology offers promising avenues for the prevention and treatment of diarrheal diseases, especially in regions where access to modern pharmaceuticals or safe water remains limited. Traditional medicine across many cultures has long been used the plant extracts and decoctions showing antidiarrheal effects. Recently researches have been started for validating many of these plant products through phytochemical, in vivo and even clinical studies. Key bioactive compounds such as tannins, flavonoids, alkaloids, saponins and terpenes have been implicated in mechanisms including inhibition of gut motility, decreasing intestinal secretion, increasing fluid and electrolyte reabsorption, antimicrobial activity and modulation of intestinal flora (Palombo, 2006). The role of herbal biotechnology can be seen in the form developing the polyherbal formulations that combine several plant species to produce additive or synergistic effects. A recent study of a polyherbal formulation



combining *Punica granatum*, *Acacia arabica*, *Andrographis paniculata*, *Holarrhena antidysenterica* and *Terminalia bellerica* showed strong antidiarrheal activity in rats: inhibition of diarrheal episode frequency (dose-dependency up to ~60%), delay in intestinal transit, reduced enteropooling (intestinal fluid accumulation) and suppression of cAMP-dependent secretion in vitro (Sharma et al. 2020). Fermentation is another biotechnological approach being explored. A fermented polyherbal preparation was shown to reverse ricinoleic acid-induced diarrhea in rats and also inhibited multiple antibiotic-resistant gastrointestinal pathogens in vitro. This suggests that combining traditional herbal knowledge with biotech processes like fermentation can enhance efficacy and help counter antimicrobial resistance (Kandhare et al. 2023).

Ethnobotanical surveys, serving as the foundation for herbal biotechnology, reveal the use of large numbers of plant species to clinically treat and manage the diarrheal diseases. Researches conducted in Sub-Saharan Africa alone demonstrated that over 500 plant species were identified, many from the Fabaceae family, with strong antimicrobial activity in species such as *Punica granatum* and *Indigofera daleoides* (Nondo et al., 2024). Likewise, studies in Assam, India, identified close to 39 species from 36 families used in traditional remedies against diarrhea and dysentery (Kakati et al. 2016). There are many in vivo animal-model studies have been carried out, however, relatively very few human clinical trials and clinical standardizations of these herbal remedies have been performed. Safety profiles, optimal dosages, standardization of extracts and quality control remain key challenges for scientifically developing these herbal preparations as suitable drugs for the common people. Further, it is mandatory to give special attention, on risks of microbial contamination or heavy metal content, while developing these natural products through good manufacturing practices and biotech-based standardization techniques (Jahan et al. 2024)

In order to confer the global reproducibility, credibility and acceptability to the Ayurvedic herbal drug including Pippali Rasayana (PR), it is imperative to conduct detailed scientific research evaluating the therapeutic efficacy, particularly in the clinical management of bacterial diarrhea, which accounts for nearly 85% of all diarrheal cases worldwide. Given its potential to provide effective treatment and clinical cure for over 95% of global diarrheal patients—both giardial and bacterial—PR holds significant promise as a future therapeutic

option. This highlights the urgent need for further investigation and validation through rigorous biomedical and biotechnological researches. Herbal biotechnology, as a multidisciplinary field, has evolved historically and continues to expand through various branches that contribute not only to human health but also to environmental sustainability. Its overarching aim has always been to enhance human life through improved diagnosis, therapy and prevention of diseases. While modern synthetic drugs have undoubtedly expanded the life expectancy and reduced mortality, their adverse effects, high costs and issues like antibiotic resistance necessitate a re-evaluation of traditional health systems. Ayurvedic medicine, one of the oldest known healthcare systems, offers a vast repository of knowledge focused on holistic healing and immunity enhancement. There is a pressing need to scientifically validate and modernize Ayurvedic formulations using contemporary biotechnological tools and parameters. This approach would facilitate the development of eco-friendly, innocuous and highly effective herbal drugs with strong therapeutic value, positioning these natural products as viable alternatives or complements to modern synthetic drugs.

#### INNOVATIONS IN HERBAL BIOMEDICAL SCIENCE

Biomedical science, particularly herbal biotechnology, has diversified into various specialized disciplines as a result of extensive global research aimed at improving human health and quality life (Hefferon, 2012). This field has made significant contributions by developing safer and more innocuous drugs, especially for chronic conditions, thereby minimizing drug-related side effects and trauma. Additionally, herbal biotechnology supports sustainable environmental development through the conservation and propagation of endangered, rare and threatened medicinal plants using advanced techniques such as agro-biotechnology and tissue culture (Nalawade and Tsay, 2004). These efforts contribute to expanding greenbelt areas, reclaiming barren lands and promoting healthier seasons and agroclimates. Collectively, these multipronged initiatives strive to enhance the overall success and sustainability of life on Earth, which remains the most complex and vital living system known to humanity. The drugs produced through these methods offer unique therapeutic benefits, underscoring the need to integrate traditional knowledge with modern biotechnological advancements for better health outcomes (Rahal et al. 2012).

In recent years, herbal biomedical science has undergone impressive and extensive innovations that integrate traditional plant-based knowledge with modern scientific techniques to improve safety, efficacy and therapeutic potential. Advanced extraction methods like ultrasound-assisted green technologies have been shown to increase yields of bioactive compounds while preserving their structure and reducing environmental impact (Gouda et.al. 2021). Similarly, nanotechnology-based delivery systems (e.g. nanoparticles, nanoemulsions, liposomes) and functional biomaterials like hydrogels and microneedles are being used to overcome limitations of herbal medicines such as low bioavailability, poor stability and weak targeting. Furthermore, rigorous clinical research and standardization efforts are being pursued, including quality control of plant materials, phytochemical characterization and evidence from randomized controlled clinical trials, bridging the gap between ethnopharmacology and modern medicine (Fabricant and Farnsworth, 2001).

**Conclusion:** The integration of biotechnology and traditional Ayurvedic herbal expertise may be concluded as a viable avenue for the development of safer, more efficient and sustainable healthcare solutions. The development of biomedical research, especially herbal biotechnology, highlights how plant-based medicines might be used to treat urgent global health issues like chronic and infectious diseases. The validation, improvement and large-scale manufacturing of these herbal remedies are made easier by contemporary biotechnological methods with ensured guarantee of efficacy, sustainability in the environment and reproducibility. Furthermore, the drawbacks and side effects of synthetic pharmaceuticals emphasize how vital it is to investigate and popularize the herbal drugs as better substitutes mainly in the environment with little resources. For complete use of therapeutic potential of Ayurvedic and herbal biotechnology, more multidisciplinary studies, thorough clinical evaluation and international cooperation, are warranted. This will enhance health outcomes and advance eco-friendly medical practices. Thus, it can be understood that there exists a great potential to promote the holistic well-being and sustainable development in healthcare sector through this fusion of traditional knowledge and contemporary research.

#### **FUTURE PROSPECTIVE OF THE RESEARCH**

Future studies must concentrate on a few crucial areas in order to fully grasp and extract the full potential of herbal biotechnology in improving world health. First, to confirm the safety, effectiveness and repeatability of Ayurvedic herbal compositions across a range of

populations, comprehensive clinical trials using strict scientific procedures are necessary. Precision medicine techniques should be promoted by utilizing developments in molecular biology and bioinformatics to clarify the mechanisms of action of herbal substances at the proteomic and genomic levels. Furthermore, the cultivation and yield of rare and endangered medicinal plants can be improved by incorporating biotechnological tools and techniques like tissue culture, genetic engineering and metabolomics. For herbal drugs to be accepted and commercialized globally, consistent procedures of formulation, quality assurance and regulatory frameworks must be developed. Additionally, the translation of research discoveries into workable healthcare solutions will be accelerated by interdisciplinary collaboration involving biotechnologists, pharmacologists, traditional practitioners, basic biomedical scientists and policymakers. In order to attain comprehensive and long-lasting health results, the prudent use of herbal remedies must be encouraged by public awareness and education campaigns that strike a balance between the advantages of contemporary synthetic medications and the depth of traditional knowledge.

#### **CONFLICTS OF INTEREST**

Authors have no conflict of interest in this manuscript.

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