A review of traditional and modern science convergence in Indian phytopharmaceuticals


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Abstract

Phytopharmaceuticals are a distinct category of plant-based medicines that combine the rich heritage of traditional knowledge with the rigor of modern science. With their standardized production, scientific validation, and adherence to quality and safety standards, phytopharmaceuticals bridge the gap between traditional herbal medicine and modern pharmaceuticals, offering effective, reliable, and safe treatment options. The search for bioactive molecules in medicinal plants can be guided by traditional knowledge, which could result in the discovery of novel phytochemicals. A strong basis for the development of phytopharmaceuticals is provided by unique position of India as a leader in both traditional medicine and modern pharmaceutical innovation. The fast expanding pharmaceutical industry in India that ranks among the world's largest in terms of both production and export, supplements the centuries-old traditional medical culture of India, including Ayurveda, Siddha, and Unani. Because of these two advantages, India is able to create a thriving ecosystem for the development of plant-based medicines by bridging the gap between traditional knowledge and modern science.

Keywords: Ayurveda, Modern science, Phytopharmaceuticals, Traditional knowledge

1. Introduction

Phytopharmaceuticals refer to the bioactive compounds that have been isolated from plant sources which exhibit pharmacological activity. Herbal medicines containing single or multiple phytoconstituents having biological activities are also considered as Phytopharmaceuticals. Indian culture is well versed with several medical treatments developed from plants or parts of plants based on ancient knowledge. India is also known as botanical garden of the world as it is one of the large scale producers of medicinal plants. Along with supporting the maintenance of all the physiological functions in the human body, phytopharmaceuticals exhibit pharmacological actions like specific targeting of biological receptors, blocking of disease related pathways, and the breaking of life cycles of pathogens. Even though the herbal remedies are very much popular in the society, only few medicinal plants have been identified through scientific evaluation for their pharmacological potential. But, these herbal drugs are not regulated properly and many times they are not registered or not even controlled by health authorities. There is an urgent need to discover more Phytopharmaceuticals, identify their sources, evaluate their pharmacological activities and prepare their standardised formulations.

2. Definition of phytopharmaceuticals

Central Drugs Standard Control Organization (CDSCO) has designed the Guidelines for Phytopharmaceuticals in India. According to these guidelines, phytopharmaceuticals are defined as "the purified and standardized fractions with a defined minimum percentage of a bioactive or phytochemical compound, prepared from medicinal plant materials using appropriate processes and marketed for a specific indication or therapeutic use". This gives exact idea of how the phytopharmaceuticals are different from conventional herbal medicines and synthetic drugs and it also sets standards for reproducibility, consistency, and quality of the phytopharmaceutical product (1). As per D and C act 1940, Phytopharmaceutical drugs include purified and standardized fraction with defined minimum four bioactive or phytochemical compounds (qualitatively and quantitatively assessed) of an extract of a medicinal plant or its part, for internal or external use of human beings or animals for diagnosis, treatment, mitigation or prevention of any disease or disorder but does not include administration by parenteral route (2).

3. Key characteristics of phytopharmaceuticals

3.1. Standardization and quality control

Phytopharmaceuticals are standardized in a manner to get a specific percentage of bioactive components (e.g., flavonoids, alkaloids, or terpenes), in contrast to traditional herbal remedies, which might vary in effectiveness due to factors including plant growth circumstances and extraction processes. Analytical testing, the application of proven extraction and purification methods, and the selection of premium raw materials are the steps in this process. For example, Liu et al. (2021) reported that standardized *Ginkgo biloba* extracts contain nine biginkgosides, a new type of flavonol glycosides, six new flavonol glycosides, a new sesquiterpene, and three new nor-sesquiterpenoids (3).

3.2.Purity and safety

To ensure that the finished phytopharmaceutical product is safe for consumption, the impurities and potentially hazardous substances (such as pesticides, heavy metals, and microbiological contamination) are eliminated during processing. Considering the variation in plant components, which can compromise safety if unchecked, this purification procedure is especially crucial. According to a study by Klein-Junior et al. (2021), the contaminants in raw plant materials can lead to adverse health effects and, if left unchecked, can reduce the therapeutic effectiveness of phytopharmaceuticals. This emphasizes the significance of purification and quality inspections (4).

3.3. Scientific validation and clinical trials

Phytopharmaceuticals, in contrast to many conventional herbal remedies, undergo thorough scientific testing, including *in vitro* (lab) and *in vivo* (animal and human) investigations. For example, *curcumin,* a phytoconstituent obtained from *Curcuma longa*, has been the subject of extensive research, and clinical trials have demonstrated its effectiveness in lowering inflammation and curing a number of illnesses. Due to their proven safety and effectiveness characteristics, products with standardized *curcumin* extracts are now often used as phytopharmaceuticals (5). The anti-malarial medication, artemisinin, which is made from *Artemisia annua* (sweet wormwood) is a well-known example of herbal medicine. Modern malaria treatment procedures now heavily rely on artemisinin-based medicines due to this understanding of its mechanism (6).

3.4. Regulatory compliance and good manufacturing practices (GMP)

Strict regulatory standards, such as good manufacturing practices (GMP), are followed during the production of phytopharmaceuticals to guarantee their consistency, superior quality, and consumer safety. To be marketed as pharmaceutical-grade, phytopharmaceuticals must adhere to strict production, labeling, and quality criteria set by regulatory bodies like the U.S. FDA and the CDSCO in India. The stability and quality of plant-based products can be affected by variables like temperature, humidity, and cleanliness. Regulatory compliance, which guarantees the safety and effectiveness of phytopharmaceuticals, has helped to increase their adoption in mainstream healthcare (7).

3.5. Bioavailability and novel formulations

Novel formulations including liposomes, nanoparticles, and encapsulation can greatly increase the bioavailability of certain plant-based substances, such as curcumin, which makes them more effective as medicines. The therapeutic potential of plant-based medications is increased by these

sophisticated formulations, which allow for targeted distribution and regulated release of active ingredients. For example, nano-curcumin is a more powerful antioxidant and anti-inflammatory due to its enhanced absorption and bioactivity (8).

4. Historical context of phytopharmaceuticals

With deep roots in the history of medicine, plants have been the primary source of healing. Based on the curative qualities of plants, traditional medical systems including Western herbalism, Ayurveda in India, Traditional Chinese Medicine (TCM), and Unani all evolved complex procedures and vast materia medica.

4.1. Ancient beginning

Use of plants for the treatment of various diseases has been initiated since ancient ages. The evidences for this have been found in various texts, records, pharmacopoeias and books written by sages and scientists in different ages (Figure 1) (9).

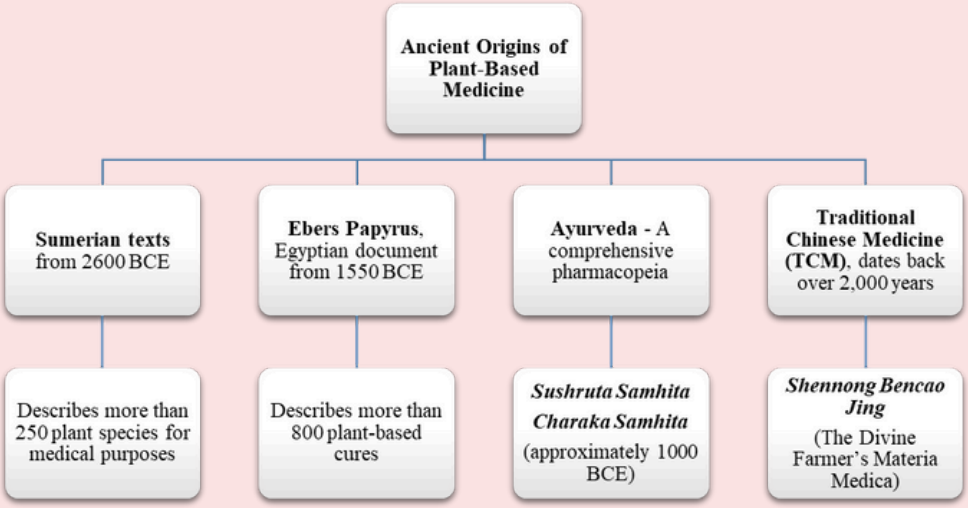

Figure 1. Evidences of use of plants in ancient ages

4.2. 18th to 20th century

In-depth treatises like *The Canon of Medicine* were written in 18th century. When botanists and early chemists started separating active ingredients from plants in the 18th and 19th centuries, empirical knowledge gave way to more methodical scientific investigation (Figure 2) (10). The government agencies in India, such as the Ministry of AYUSH, were created to encourage the incorporation of conventional plant-based remedies with scientific verification, setting standards for quality assurance and research (11).

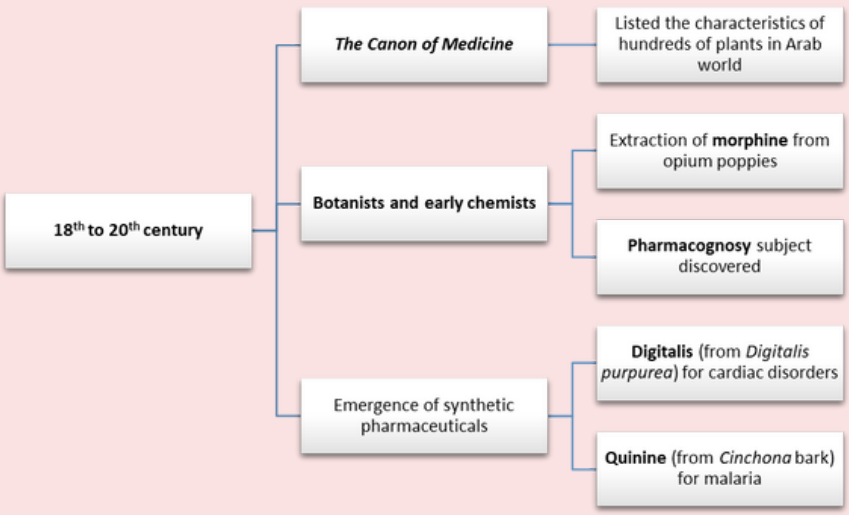

Figure 2. Advancements in herbal knowledge in 18th to 20th century

4.3. 21st century developments

Researchers are now able to discover and separate bioactive chemicals from plants, confirm their mechanisms of action, and create standardized formulations that satisfy global quality and safety requirements; which have been possible due to developments in biotechnology, molecular biology, and analytical chemistry (Table 1). The World Health Organization has acknowledged the importance of traditional plant-based remedies and has pushed for their inclusion in national healthcare systems as safe, scientifically proven alternatives (12).

Table 1. Isolated bioactive compounds from plants

Bioactive Compound	Plant Source
Alkaloid	
Piperine	*Piper sylvaticum* Roxb.
Berberine	*Berberis lycium* Royle
Lysergol	*Convolvulaceae* Juss.
Reserpine	*Rauvolfia serpentina* (L.) Benth. ex Kurz
Maculine	*Teclea afzelii* (Engl.)
Sanguinarine	*Chelidonium majus* L., *Sanguinaria canadensis* L., *Macleaya cordata* (Willd.) R. Br.
Chanoclavine	*Ipomoea muricata* (L.) Jacq.
Caffeine	*Camellia sinensis* (L.) Kuntze
Caranine	*Clivia miniata* (Lindl.) Verschaff.,*Crinum bulbispermum* (Burm.f.) Milne-Redh. & Schweick.
Evodiamine	*Evodia aromatica* (Sonn.) Pers.
Thalicfoetine	Roots of *Thalictrum foetidum* L.
Terpenes	
Eugenol	*Syzygium aromaticum* (L.), *Cinnamomum zeylanicum* Blume.
Cinnamaldehyde	*Cinnamomum verum* J. Presl.
Ursolic acid	*Salvia rosmarinus* Spenn., *Salvia officinalis* L.
Farnesol	*Vachellia farnesiana* (L.) Wight & Arn.
Carvacrol	*Thymus capitatus* (L.), *Thymus vulgaris* L.
Nerolidol	*Cannabis sativa* L.
Thymol	*Thymus capitatus* (L.)

Phenols	
Myricetin	*Myricaceae* Rich. ex Kunth., *Anacardiaceae* R.Br.,*Polygonaceae* Juss., *Pinaceae* Spreng. ex F.Rudolphi., *Primulaceae* Batsch ex Borkh.
Baicalein	*Thymus vulgaris* L., *Scutellaria baicalensis* Georgi,*Scutellaria lateriflora* L.
Epigallocatechin gallate	*Camellia sinensis* (L.) Kuntze
Chebulinic acid	*Terminalia chebula* Retz.
Emodin	*Rheum palmatum* L.
Curcumin	*Curcuma longa* L.
Quercetin	*Vitaceae* Juss., *Brassicaceae* Burnett,*Amaryllidaceae* J.St.-Hil., *Rutaceae* Juss.
Kaempferol	*Alpinia calcarata*
Resveratrol	*Vitis vinifera* L.
Apigenin	*Matricaria chamomilla* L.
Genistein	*Glycine max* (L.)
Organosulfur/isothiocyanate	
Allicin	*Allium sativum* L.
Ajoene	*Allium sativum* L.
Allyl isothiocyanates	*Armoracia rusticana*
Benzyl isothiocyanate	*Alliaria petiolata*
Berteroin	*Brassica oleracea* L.
Cheirolin	*Cheiranthus cheiri* L.
Alyssin	*Alyssum* L. sp.

5. Importance of integrating traditional and modern science

The development of phytopharmaceuticals as a reliable, efficient, and scientifically supported medical treatment depends significantly on the integration of ancient knowledge and modern science. Many advantages, such as improved efficacy, safety, and innovation in drug development, result from this synergy, which integrates the empirical knowledge of traditional methods with the accuracy of modern research. Knowing the importance of this integration helps to clarify how modern and traditional methods can work in collaboration to produce a more comprehensive healthcare paradigm.

5.1. Enhanced efficacy and safety

Evidence-based medicine is made possible by the application of modern scientific methods like pharmacology and bioassays, which enable researchers to verify and measure the effects of traditionally used botanicals. For example, research demonstrating the adaptogenic and anxiolytic properties of *Withania somnifera* (Ashwagandha) through the modulation of stress hormones like cortisol has confirmed its historic use in Ayurveda for stress reduction (13). Modern science can assure the constant quality of phytopharmaceuticals by combining traditional knowledge with regulated manufacturing procedures like GMP and verified extraction techniques. This is demonstrated by research on standardized *Panax ginseng* extracts, since stable ginsenoside levels in standardized products have been linked to dependable therapeutic effects in stress reduction, physical performance, immunological and cognitive processes, blood glucose and lipid management, and chronic obstructive pulmonary disease (14).

5.2. Improved understanding of mechanisms of action

The specific biological mechanisms of plants or their isolated compounds on particular health disorders are verified by current science, while traditional wisdom offers useful hints about which plants are effective for various ailments. For example, action of *curcumin* on particular inflammatory pathways has been linked to the anti-inflammatory properties of *Curcuma longa* which has long been used to treat digestive problems and joint pain because it suppresses nuclear factor-kappa B (NF-κB), a crucial regulator of inflammation (15).

5.3. Innovation in drug development

The extensive plant-based knowledge for isolation of bioactive compounds can serve as a basis for novel drug development breakthroughs. For instance, the discovery of the antimalarial medicine artemisinin, which is derived from *Artemisia annua* and it resulted in one of the most successful therapies for malaria and earned Dr. Tu Youyou a Nobel Prize in 2015 (16). More potent and bioavailable phytopharmaceuticals have been produced by combining conventional methods with cutting-edge formulation technologies. When taken in their raw form, turmeric and its active constituent *curcumin* are poorly absorbed; however, their bioavailability and therapeutic efficiency have been greatly enhanced by new formulations including liposomal curcumin and curcumin nanoparticles (17).

5.4. Sustainability and biodiversity conservation

To avoid overexploitation, traditional knowledge systems support ethical and sustainable harvesting methods like selective collecting and alternating harvest cycles. The Convention on Biological Diversity (CBD) and the World Health Organization (WHO) both acknowledge that incorporating traditional practices into conservation plans can be extremely important for preserving biodiversity and enhancing the phytopharmaceutical sector. Research and development partnerships with indigenous communities give these groups the chance to preserve their cultural tradition while gaining economic benefits (2).

5.5. Addressing global health challenges

Phytopharmaceuticals provide beneficial remedies that can supplement traditional treatments in facing the challenges of growing global health difficulties such antibiotic resistance, chronic illnesses, and mental health disorders. Certain phytopharmaceuticals have demonstrated potential as substitutes for traditional antibiotics, which are becoming more and more problematic because of germ resistance. Phytopharmaceuticals may offer new ways to treat resistant bacterial strains, according to research on plant-derived antimicrobials, such as the usage of neem and tea tree oil extracts. Plant-based substances that have shown promise in treating inflammatory ailments, cardiovascular diseases, and metabolic disorders include resveratrol, berberine, and gingerol (18).

The modern phytopharmaceutical sector demonstrates the applicability and flexibility of traditional medicine in contemporary healthcare by integrating ancient knowledge with state-of-the-art science. This forms the basis of how phytopharmaceuticals may promote sustainability and cultural preservation while addressing urgent global health concerns like chronic illnesses, antibiotic resistance, and mental health disorders.

6. Conclusion

In conclusion, India is well positioned to lead the global phytopharmaceutical market due to its sophisticated pharmaceutical sector and plenty of traditional medical expertise. India can produce safe, standardized plant-based medications that satisfy international standards by integrating traditional knowledge with modern science. India has more opportunity to innovate in this area with the help of supportive legislation, a robust export network, and growing demand for alternative medicines. This evolution of phytopharmaceuticals from traditional roots to a scientifically grounded industry not only drives economic growth but also reinforces India's position as a central player in advancing global health through natural and plant-based solutions. Regulatory compliance guarantees the safety and effectiveness of phytopharmaceuticals, which increases their adoption in mainstream healthcare

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