

CHAPTER 01

Natural Products in Medicine: Historical and Modern Perspectives



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ABSTRACT: The traditional and alternative therapeutic practices by using natural products serve as the standard therapeutic approach. The primary source of natural product-based new chemical entities (NCEs) originates from four natural groups, including plants, animals, microbial and minerals. Origin of herbal medicine follows traditional Chinese, Ayurveda, kampo, African, Korean and Egyptian medicine, explaining the ethnopharmacological application. According to FDA-approved drugs, the integration of medications with modern medical practice is hindered by inadequate pharmacological assessment. Different modern strategies include genomics, metabolomics, big data, proteomics, computer-aided automation and artificial intelligence with multidisciplinary approaches that optimize therapeutic use of natural products. Moreover, this chapter delves into regulatory and ethical challenges, especially the protection of Intellectual property, equitable sharing, traditional knowledge, and universal standards of compliance. By integrating traditional and modern technologies, natural products serve as a promising avenue for drug development.

Keywords: Bioactive, Traditional medicine, Herbal products, Genomic analysis, Metabolomics.

Natural products (NPs) with wide-ranging biological activity leads to applications in human and veterinary medicine, as well as their function in agricultural applications. Researchers do not consider natural macromolecules, DNA, RNA, and protein (their precursors and primary metabolic intermediates) to fit within the NP classification. The identification of NPs results from evidence showing their effectiveness as essential components, such as pharmaceuticals and herbicides, in addition to insecticides. More than 23,000 naturally produced compounds have been identified since penicillin discovery about 75 years ago (Katz & Baltz 2016).

NPs serve as essential resources for the development of therapeutic sources, and used in the treatment of chronic disorders (Atanasov et al., 2021). Traditional synthetic drugs differ from NPs due to unique characteristics that challenge drug implementation (Harvey et al., 2015). NPs are essential in medicines and the foundation for most historic medical treatments. Research highlighted

that natural substances possess potent compounds against medical problems. Since ancient times, nature has provided top-tier drug candidates through which medical chemists as well as researchers obtain unmatched potential for compounds. Human beings used natural compounds and their derived molecules to treat diseases for nearly 60,000 years (Chaachouay & Zidane 2024; Ahmed et al., 2025).

According to WHO report, 65% of worldwide human population starts treatment with natural bioactive compounds as their primary defensive weapons. The traditional medicine practices of China and India, along with other countries, have continuously used various NPs (Yuan et al., 2016). The pharmaceutical industry continues to use NPs as primary source for drug development, as described by David et al. (2015). Research demonstrates that traditional medicine from NPs combat multidrug-resistant infectious diseases because they provide new promising therapy targets via activating novel pathways (Chopra & Dhingra 2021). There has been a remarkable renaissance of

interest in natural product research over the last decade, and it gained more attention to provide novel and interesting scaffolds with improved physicochemical and pharmacodynamic properties.

Scientists use numerous diverse techniques, which include GC–MS, LC-MS, LCNMR, together with isolation, analysis and biological assays for their investigations (Chopra & Dhingra 2021). Medicinal chemists use molecular targets as their primary focus in the drug design process. New molecular analogs created from natural compounds exhibit higher efficacy and lower side effects (Dangi et al., 2021).

The main source for new chemical entities (NCEs) exists in four natural classes: plants, animals, microbial and minerals resources. It is reported that ethnopharmacological compounds from plants make up 80% reported compounds (Fabricant & Farnsworth 2001). The purpose of this chapter is to present an overview of NPs in medicine, their historical background, and their importance in modern drug research and development. Moreover, the technological progress that is applied in the research of NPs as well as the strategic planning required to succeed in addressing developmental issues is described. This chapter is a combination of historic knowledge and modern scientific innovation highlighting the necessity of the NPs role in the future of pharmacotherapy.

HISTORICAL OVERVIEW OF NPS

Herbal medicine's historical significance serves as an example of the long-standing connection between people and nature in the quest for health and well-being. Many societies throughout the world have recognized and utilized the medicinal properties of plants throughout history. Archaeological discoveries indicate that the use of medical herbs dates back to the Palaeolithic period, almost 60,000 years ago, demonstrating the lengthy traditional usage of herbal treatments. Consequently, the usage of plants has fluctuated in favor in the medical field; in the past, for medical purposes, ancient societies such as the Greeks, Romans, and Egyptians mainly used botanical remedies (Pereira, 2019).

Traditional Medicine: The oldest type of healthcare in the world, traditional medicine (TM), is used to cure and prevent both mental and physical ailments. NPs are the primary source of the medications utilized in TM. "Clinical trials" in TM have been carried out since antiquity. Over thousands of years, significant experience and advancements have been gained in the field of Traditional Chinese Medicine (TCM) regarding methods of preparation, plant selection, medicinal material recognition, and the optimal time to harvest different herbs (Morimoto et al., 2021).

Ancient Egyptian Therapies: The ancient Egyptians are highly respected for their inventive use of medicinal herbs. Their civilization's records existed 1500 BCE ago having extensive documentation of herbal therapies. Comprehensive study of various botanicals employed for therapeutic purposes can be gained from these records. Their methods and experience form the foundation of many modern herbal remedies and medical operations. A medical data from ancient Egypt, called the Ebers Papyrus contains a wealth of knowledge on herbal remedies and other therapeutic approaches (Canales et al., 2020).

Unani: Unani is a 2500-year-old holistic medicinal practice that originated in ancient Greece. Unani has garnered significant interest worldwide when the WHO started to give TM more attention in the middle of the 1970s, particularly in India, where it was successfully included into the country's healthcare system (Bhusare et al., 2018).

Kampo: The Japanese TM is Kampo. China brought TCM to Japan in the middle of the 5th-6th century. Since then, Japanese practitioners have made substantial changes to TCM to suit their unique situations, and it has eventually evolved into Kampo. According to a recent study, some Japanese practitioners prescribe Kampo medications regularly, sometimes as their initial preference (Yang et al., 2020).

Ayurveda: In India, ayurvedic herbal therapy has a rich history that dates back to pre-Vedic times and has been utilized carefully for thousands of years (4000 BC–1500 BC). India has around 400,000 recognized Ayurvedic practitioners. An official

agency of the Indian government oversees the quality, practice, and educational initiatives of Ayurveda. Thus, it is becoming more widely acknowledged that Ayurvedic medicine's pharmacologically active ingredients and their therapeutic efficacy. Many Ayurvedic remedies combine several plants in a unique ratio to reduce toxicity and produce the best possible medicinal impact. Ayurveda restores equilibrium by using natural components and eliminate the primary cause of disease (Verma et al., 2024).

Traditional Korean medicine (TKM): In Korea, TKM is also referred to as Sasang constitutional medicine (SCM). Korean traditional medicine has a branch called SCM. 86% of individuals in Korea still use SCM, although traditional healthcare organizations are rather effective. In both public and private hospitals, traditional medicine practitioners can provide Korean SCM. Korean SCM services are covered by private insurance as well as public medical insurance. SCM divides people into four Sasang kinds based on their innate characteristics: Tae-Yang, So-Yang, Tae-Eum, and So-Eum. SCM provides customized, constitution-specific solutions for a range of issues. In terms of genetic research, constitution-specific medical risks, and constitution-diagnostic methods, SCM has now made numerous noteworthy advancements (Lee & Lee 2021).

Traditional medicine in Africa (TMA): TMA originated in Africa, which is also its developing country. In Africa, 80 percent of people use traditional medicine, either alone or in conjunction with conventional therapy. For their primary medical needs, up to 80% of Ethiopians and Ghanaians rely on traditional medicine. Ghana's traditional medical system is quite well-organized because it has been included into the country's health care system. One of the main factors contributing to the widespread use of traditional medicine in Africa is its accessibility. Traditional medicine is an excellent example of cultural heritage. Studies on the African ethnomedical plant *Hydnora africana* have shown that natural compounds have antibacterial and antioxidant properties (Okaiyeto & Oguntibeju 2021).

Transition from folklore to empirical pharmacology

Medicinal and aromatic plants are excellent sources of ingredients for creating novel drugs and promoting physical and mental well-being. The use of plants, aromatherapy, unrefined drugs, and other forms of treatment has gained popularity in modern medicine as well as in hospitals and homes. Research on plant-derived NPs still provides a special model for important chemical innovations in the biopharmaceutical sector. Novel pharmaceutical therapeutic agents have been and will continue to be derived from natural materials. Synthetic drug-derived drug metabolites have negative side effects and less therapeutic advantages (Chaachouay & Zidane 2024). Apart from the active compounds mentioned above, many plant-based phytochemical substances are being researched for potential health benefits (Table 1). For example, the therapeutically active substances vitamin E, the pigment beta-car and ellagic acid, are currently being evaluated for their potential use as antimutagenic and cancer-preventive prototypes (Dhoundiyal & Alam 2023).

EVOLUTION OF NATURAL PRODUCT-BASED DRUG DISCOVERY

Developments in science by well-designed analytical methods, which enable better isolation and purification of complex compounds and their more precise characterization through high-resolution spectroscopy as well as chromatography. Natural molecule screening and modification processes have become more efficient due to synthetic biology integrating with computational tools. The combination of modern innovations has both quickened the discoveries of new drug candidates while opening new possibilities for NPs in disease treatment (Benkhniue et al., 2022).

MODERN APPROACHES

Isolation and purification techniques

The advancement of natural product research is possible due to improved isolation and purification methods, which allow investigators to obtain more

Table 1. The primary NPs from plants and their medicinal application

Plant Origin	Drugs or Compounds	Medicinal Application	References
<i>Atropa belladonna L.</i>	Atropine	Anticholinergic	Bailly, 2022
<i>Berberis vulgaris L.</i>	Berberine	Bacillary dysentery	Bhusare et al., 2018
<i>Camptotheca acuminata</i>	Camptothecin	Anticancer	Chaachouay et al., 2023
<i>Erythroxylum coca</i>	Cocaine	Anesthetic	Cantele et al., 2020
<i>Colchicum autumnale</i>	Colchicine	Antigout, antitumor	Ahn et al., 2021
<i>Convallaria majalis</i>	Convallatoxin	Cardiotonic	Miller et al., 2020
<i>Digitalis purpurea</i>	Digitoxin	Cardiotonic	Beaufils et al., 2021
<i>Digitalis lanata</i>	Digoxin	Cardiotonic	Vinci et al., 2023
<i>Ephedra sinica</i>	Ephedrine	Sympathomimetic	Lefevre et al., 2020
<i>Glaucium flavum</i>	Glaucine	Antitussive	Lautié et al., 2020
<i>Papaver somniferum</i>	Morphine	Analgesic	Packard, 2021
<i>Strophanthus gratus</i>	Ouabain	Cardiotonic	Pereira, 2019
<i>Cinchona officinalis</i>	Quinine	Antimalarial	Chaachouay et al., 2023
<i>Rauwolfia serpentina</i>	Reserpine	Antihypertensive	Chaachouay et al., 2023
<i>Salix alba</i>	Salicin	Analgesic	Chaachouay & Zidane, 2024
<i>Datura metel</i>	Scopolamine	Sedative	Thirumurugan et al., 2018
<i>Silybum marianum</i>	Silymarin	Antihepatotoxic	David & Forshaw, 2023
<i>Taxus brevifolia</i>	Taxol	Anticancer	Sam, 2019
<i>Theobroma cacao</i>	Theophylline	Diuretic	Benkhniqeu et al., 2022
<i>Thymus vulgaris</i>	Thymol	Topical antifungal	Chaachouay et al., 2021
<i>Catharanthus roseus</i>	Vinblastine	Anticancer	Vinci et al., 2023

precise bioactive compound identifications and separations as shown in Fig. 1 (Banday et al., 2024). HPLC and vacuum liquid chromatography (VLC) are the primary chromatographic procedures used in labs to effectively separate and purify natural chemicals obtained from plants. The Reversed phase-18 and hydrophilic interaction liquid chromatography variations deliver high-resolution separation performance and outstanding reproducibility (Ahmad et al., 2025).

The analytical technique of thin-layer chromatography (TLC), together with its advanced version, high-performance thin-layer chromatography (HPTLC), serves to perform qualitative and quantitative analysis. NMR and MS now receive additional support from X-ray crystallography and two-dimensional NMR for structural analysis. X-ray crystallography reveals complete three-dimensional information about compound structures required to assess their biological target interactions. Computational tools now revolutionize the process used for structure elucidation. Scientific models of molecular docking, together with computational chemistry methods, enable researchers to anticipate natural

compound interactions with particular biological targets, thus revealing their biological mechanisms (Chen et al., 2024).

High-Throughput Screening and NPs

The application of high-throughput screening (HTS) technologies has transformed bioactive NPs discovery because these technologies enable fast screening of thousands of samples against biological targets. Machine-assisted plate techniques employing 96- or 384-well formations enable parallel testing during this process that works best for *in vitro* bioassays because these tests need small amounts of samples and deliver quick results. The reliability of *in vitro* assays within early-stage drug discovery decreases compared to *in vivo* results because of biological complexity (Ahmad et al., 2025).

NPs and applications

NPs have an essential role in pharmaceutical innovation because they have transformed from ancient medicines into leading modern pharmaceutical compounds (Thomford et al., 2018). Through developments in genomics and

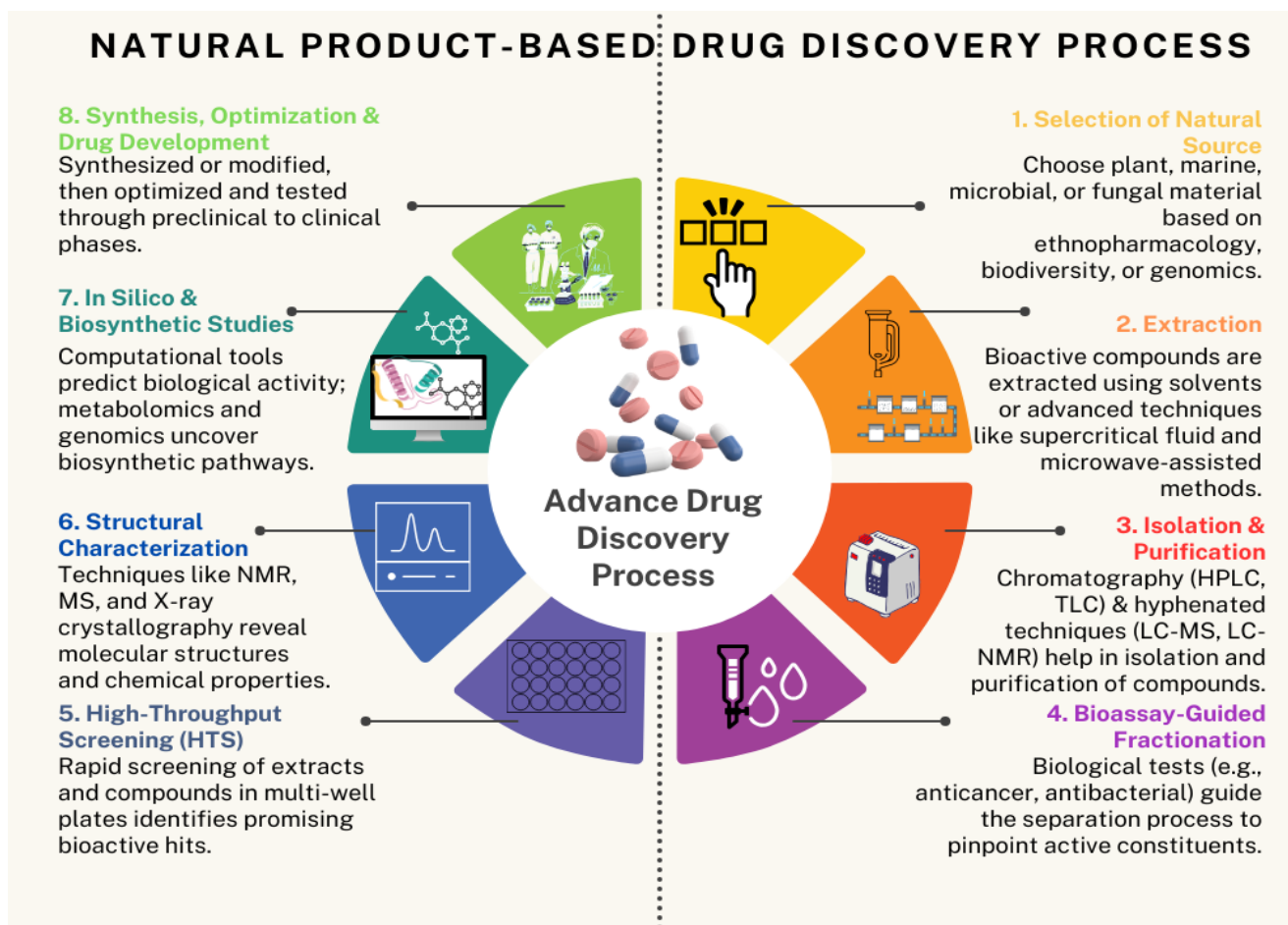


Fig 1. The current graphic representation shows systematic drug development procedures from NPs via using advanced purification methods, structural analysis, screening techniques and computational tools

bioinformatics along with innovations in extraction techniques, researchers can now identify biologically active secondary metabolites with greater precision (Thomford et al., 2018). There are different examples of NPs in modern drug discovery as described in table 2.

Paclitaxel (Taxol) for cancer treatment: Paclitaxel (Taxol) represents a premier natural product that scientists developed into an active anticancer substance. Scientists first extracted paclitaxel from the Pacific yew tree bark (*Taxus brevifolia*), which proved to be a diterpenoid compound that causes cell division interruption due to its ability to stabilize microtubules. The mechanism of paclitaxel differs from standard anticancer drugs as it prevents microtubules break down, which causes cell blockage during mitosis and leads to apoptosis in proliferating cancer cells (Chen et al., 2024; Yang & Horwitz 2017).

Lovastatin for cholesterol reduction: The clinically used drug Lovastatin originates from natural sources and is used to manage hypercholesterolemia by decreasing blood lipid levels. Through its mechanism, lovastatin stops the action of 3-hydroxy-3-methyl-glutaryl Coenzyme A (HMG-CoA) reductase and control cholesterol biosynthesis. Lovastatin exhibits comparable molecular structure to HMG-CoA which allows it to occupy the enzyme active site where it blocks the natural substrate-substrate interaction needed for HMG-CoA to transform into important mevalonate (Peng et al., 2024).

CONTRIBUTION OF TRADITIONAL MEDICINE TO MODERN PHARMACOLOGY

Traditional medicine: Traditional medicine refers to indigenous medicine, unorthodox medicine,

natural medicine, or alternative medicine because traditional medicine uses a natural approach. The term traditional includes many ideas, approaches, and practices passed from generation to generation by communities and between individuals. Traditional medicine is also considered the origin of modern medicine as many of the ancient techniques and remedies made their way into pharmacology and even modern surgical practices. In modern medicine, plants play an important role as the raw materials for essential drugs, as there are estimated 70000 plant species that are used for medicinal purposes (WHO, 2020). Herbal medicines are an interesting convergence point between traditional medicine and modern pharmacology, connecting traditional remedies with the cutting edge of scientific investigation (Gupta et al., 2023).

CASE STUDIES

Artemisinin: According to the WHO, 3.3 billion people live in the areas prone to transmission of malaria (regional area or locality) in 106 countries and territories of the world, with around 216 million malaria cases and an estimated 655,000 deaths each year. In 2010, an estimated 91% of deaths from malaria in Africa were due to *P. falciparum* (one of the most common parasites causing malaria in sub-Saharan Africa). The main mode of treatment of malaria, either through the use of antimalarial drugs or traditional herbal therapy, is current antibiotics (Huang et al., 2023; Ranasinghe et al., 2023; Timothy & de la Fuente, 2023).

The most effective modern drugs against malaria are Artemisinin-based Combination Therapies. In the family Compositae, there are over 300 species of herbs and shrubs; at the time, malaria was considered as a deadly invasion. In 1971, attempts were made to isolate the active compounds from the plant, using diethyl ether at the proper temperature under special conditions. In 1972, Chinese scientists discovered that Qinghaosu (artemisinin), a crystalline compound, could be isolated from the plant by boiling it in acid and removing some or all of its crystalline compounds. In 1977, when artemisinin was isolated from Qinghaosu, it was shown to be effective against *P. berghei* in mice. Artemisinin derived from dihydroartemisinin, artesunate, artrmrther and arteether and different

artemisinin-based combination therapies have been explained in Fig. 2.

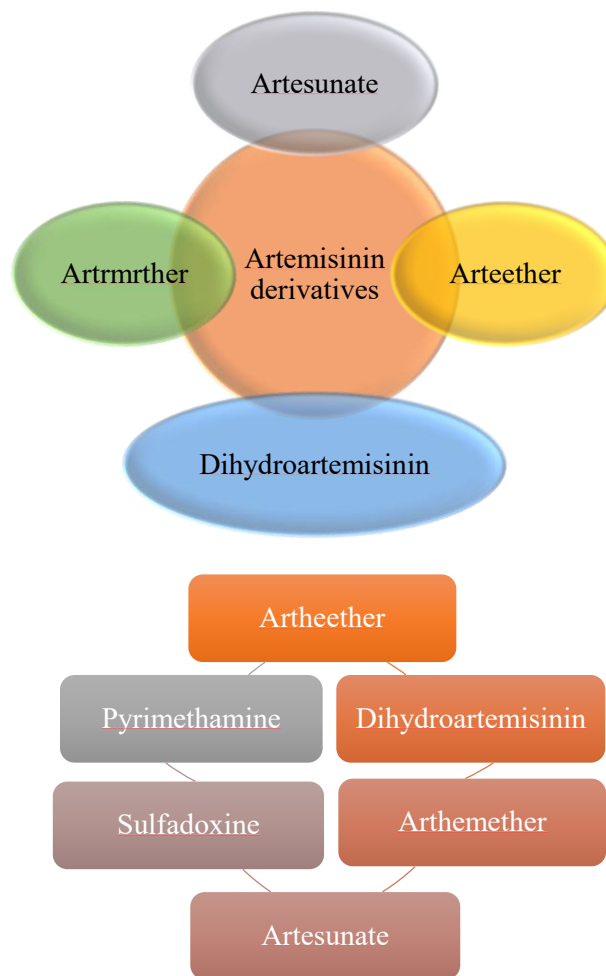


Fig 2. Artemisinin and derivatives as drug

Reserpine: Reserpine is present at the root of *R. serpentina* is an indole alkaloid. It is also a secondary metabolite that affects the central nervous system. Different *Rauwolfia* species are rich in reserpine, which are antipsychotic. Two categories of antipsychotic medications (neuroleptics) exist: atypical neuroleptics, which regulate both positive and negative symptoms in patients, and typical, traditional, or classic neuroleptics, which exclusively regulate positive symptoms.

Integration of Traditional Medicine with Modern Science

Throughout the ages, natural ingredients have been essential for the development of new drugs. These bioactive compounds, derived from plants, microorganisms, marine life, and other natural sources, have been used to treat a wide range of ailments. Biological relevance and chemical variation make NPs extremely important templates for the synthesis of new therapeutic medications. Recent advances in genomics, metabolomics, and biotechnological technologies have significantly enhanced the ability to identify and modify natural substances. Despite synthetic and computational drug design approaches, NPs still dominate the pharmaceutical sector due to their complex structures and unique ways of interacting with biological targets (Anand et al., 2019; Ouedraogo et al., 2023).

TECHNOLOGICAL ADVANCES IN NP RESEARCH

In modern drug discovery research, the chemistry of NPs is a crucial field that has made significant advances. Today, plant-based remedies and science-based approaches focus on identifying and improving bioactive chemicals present in natural substances. Organizations and researchers remain focused on using microorganisms, plants, and marine organisms to search for new therapeutic drugs because they derive many current drugs from NPs (Najmi et al., 2022).

Role of Genomics

The identification of target species remains an essential requirement for pharmaceutical research. Future research recommended the integrative approach for the identification of correct plant species and the collection site to verify the therapeutic effects of compounds. Multiple plants contain different compounds at varying concentrations. Genomic techniques have helped to develop precise identification systems for both plant samples and other NPs. DNA barcoding is a precise method for identifying various plant species along with other natural product sources. Plant identification emerges as an advantage of DNA barcoding as a modern identification technique. Due

to its accuracy and speed, DNA barcoding serves as an essential tool in biodiversity inventories to identify NPs along with their sources and allows rapid herbal product identification (Mishra et al., 2016).

Organizations must now establish reliable NP source lines to verify their compound content. Bio-farming emerged as a new agricultural approach that grows plants under identical conditions, all the way from the beginning to the end, i.e. extraction of NPs. The confirmation of compounds or molecules extracted from NPs is done through DNA barcoding, following extraction. Genomic technologies enable developers to build marker-derived multiple plants that function within genomic chips for highly efficient NPs authentication and genotyping processes (Dzobo, 2022).

Role of metabolomics

The identification and evaluation of compounds through metabolomics represents a fascinating new drug discovery in global health. The identification as well as quantification of specific NP metabolites is carried out by metabolomics profiling (Loskill et al., 2017). However, metabolomics is a technique to quantify evolving metabolic changes in response to biological changes. According to Perez-Pinera et al. (2012), metabolomes have been used in drug research to find and assess metabolites derived from natural sources. Metabolomics uses a stem-based biology method to study how a biological system works and is altered by pharmaceutical stimuli.

The role of big data

The generation of big and complex datasets from "omics" analysis requires bioinformatics and computational tools for interpretation, while statistical analysis provides proper identification of NP pathophysiological effects from such complex data. Omics technologies provide a method to evaluate both NP pharmacodynamic testing and their compositional components alongside associated pharmacological testing. Recently developed machine learning algorithms and advanced techniques allow virtual screening of millions of NPs and their significant role in drug discovery.

The availability of numerous public and private databases with millions of drug candidate possibilities enables natural product and their compounds screening for medicinal purposes. The connectivity map (CMap) is responsible for the evaluation of molecular mechanisms of diseases, allowing greater connection between compounds and disease genes (Brum et al., 2015).

Computer-aided drug design

Scientists have utilized NPs to develop synthetic compounds that resemble the parent structures for a potential drug candidate. These new synthetic compounds derived from NPs often present inappropriate designs for drugs while failing virtual screening tests. These specific drug selection standards enable easy assessment of synthetic compound quality. Two main screening rules, called "rule of three" and "rule of five," exist when selecting compounds for future drug discovery phases. The rule of three and rule of five criteria show high strictness by failing multiple compounds in the evaluation process. Drug designing usually utilizes human-derived guidelines, which contrast with the automated approach in compound-aided compound selection. This method decreases the practical applications and power of NPs in the discovery process. Many compounds have received selection and development through computer-made designs in recent years (Dzobo, 2022). The Scaffold Hunter software achieved success in both design selection and virtual creation of compounds with attractive properties comparable to the original compounds. Scaffold Hunter software has succeeded in identifying different types of pyruvate kinase regulators as inhibitors and activators. The synthetically derived compounds of natural substances show minimal biological effectiveness than their original compounds (Rodrigues et al., 2016).

Role of Automation in NP

Automation faces a negative perception across the globe because machines threaten employment positions, while some people worry about their dominance over human beings. Through automated processes, modern society has accomplished unprecedented accomplishments that were considered impossible a short time ago. Drug

discovery became faster due to automation, which allowed analysis of thousands of NPs and other compounds. All pharmaceutical companies utilize high-throughput screening procedures combined with assays because they expedite the chemical compounds. The implementation of computational software enables scientists to design multiple synthetic compounds in addition to synthesizing them. The drug targets and potential drug candidates can be identified through the use of programming tools such as ADAM and EVE (Sparkes et al., 2010).

Role of proteomics

The identification and clarification of NP mechanisms of action can now be achieved through proteomic analysis as an additional research method to genomic and transcriptomic approaches. The analytical techniques of proteomics reveal both functional mechanisms of NPs and their expression patterns while contributing to product quality documentation. Mass spectrometry achieves protein profile detection through isotope tagging and electrophoresis to obtain similar genomic data, like profiles of NPs. According to Thomford et al. (2016), mass spectrometry successfully distinguished the Chinese herbal species *Vanar gimmung* from *Panax quinquefolium*. Mass spectrometry enables the identification of biological pathways linked to NP chemistry alongside metabolic and biosynthetic mechanisms of a specific substance. Many NPs and plant extract compounds reveal their multitarget effects through proteomics analysis (Lao et al., 2014).

Artificial intelligence (AI)

The pharmaceutical organization dealt with technical barriers as well as economic challenges during drug development before AI intervention sped up their process. Scientists use AI-based techniques to measure drug-target interactions while simultaneously accelerating drug target identification and enhancing drug structural improvement (Khan et al., 2021). The drug development process now receives increased artificial intelligence implementation from numerous firms. The development of start-up companies within the field of AI-assisted drug discovery has surpassed traditional pharmaceutical

industry development. Start-up pharmaceutical enterprises maintain an ongoing production of new medications, thus accelerating drug development at a high pace.

REGULATORY AND ETHICAL CONSIDERATIONS

Evolution of the NPs in development and commercialization is threatened with various regulatory and ethical issues, especially, protection of Intellectual property, equitable sharing, traditional knowledge, and universal standards of compliance.

Intellectual property rights (IPR) and Access and benefit-sharing (ABS) frameworks

Natural product research has been carried out using traditional knowledge and indigenous plants. ABS systems are invented to uphold the right of the indigenous groups and practices that are ethically accepted in carrying research. These ensure that the gains which will arise as a result of the exploitation of biological resources are fairly shared to the nation or society and include monetary compensation, technology transfer or research cooperation. Copyrights, patents, and IPR play an important role in the protection of the novel discovery. However, applying IPR to the naturally occurring substances presents an issue since living organisms and traditional knowledge have not always been patentable. Thus, a moderate solution that will foster innovation and take into account the role of the indigenous people (Xia, 2025).

The Nagoya Protocol and Conventional knowledge protection

The Nagoya Protocol (2010) to the Convention on Biological Diversity (CBD) is one of the most significant legal documents that attempts to regulate the ABS mechanisms internationally. It also ensures that genetic resources, especially those acquired beyond the biodiversity-rich developing countries, are accessed with the arrangement of informed consent and that gains are equally shared. The protection of the traditional knowledge that accompanied the natural resources has also been considered in the protocol and it implies that the knowledge should be accessed after permission.

This legal framework encourages ethical bioprospecting and aids in negating the exploitation or what is often termed as biopiracy of indigenous heritage (Wadekar et al., 2024).

Quality control and standardization in herbal/natural medicine

Consistency, safety, and efficacy are one of the major regulatory challenges in the development of NPs. Herbal preparations usually have several active constituents unlike synthetic preparations; thus, they cannot be standardized easily. The quality control deals with the authentication of raw materials, Good Agricultural and Collection Practices (GACP), and validation of bioactive constituents determined using chromatographic and spectroscopic procedures. Standardization is important to deliver batch-to-batch consistency and essential to successful regulatory approval and consumer acceptance (Hlatshwayo et al., 2025).

Regulatory differences: FDA (USA), EMA (Europe), TCM (China)

NPs are regulated by FDA in the United States as Dietary Supplement Health and Education Act (DSHEA); unlike the other foodstuffs, manufacturers are not required to subject the supplement products to a pre-market approval although they must prove that the supplement is safe. As an alternative, the European Medicines Agency (EMA) provides the pathway to Herbal Medicinal Products Committee (HMPC), through which the traditional and well-established herbal medicines will be evaluated with regards to evidence regarding the efficacy and safety. In China, the Traditional Chinese Medicine (TCM) is completely assimilated into medical practice, and their products are stringently tested by the country authorities (Xia, 2025).

CONCLUSION

The pharmaceutical industry depends on NPs for reliable drug development. Developing appropriate methods for pharmaceutical drug production from biological materials represents a crucial step. Academic research confirms the widespread understanding that researchers began exploring therapeutic chemicals extracted from herbal

medicines. Traditional medicine is less effective, and indigenous knowledge about plants and pharmacological support for NP drug development is easier but produces slower results with lower production effectiveness. Plant-based novel therapeutics assist researchers in creating new medications through modern approaches. New methodologies in biomedical research have facilitated pharmaceutical development by

Modern technical solutions enable researchers to analyze complex chemical properties, resulting in the production and synthesis of medicinal drugs for pharmacological application. Evolution of the NPs for development and commercialization is advanced through various regulatory and ethical issues, especially, protection of Intellectual property, equitable sharing, traditional knowledge, and universal standards of compliance.

Table 2. Pharmaceutical compounds originating from natural resources and their mechanism of action, therapeutic use as well as challenges/innovations.

converting pharmaceutical compounds into drugs.

Drug Name	Source	Mechanism of Action	Therapeutic Use	Challenges/Innovations	References
Paclitaxel	Pacific yew tree (<i>Taxus brevifolia</i>)	Binds to and stabilizes microtubules, preventing their disassembly, thus blocking mitosis and inducing apoptosis in cancer cells.	Ovarian, breast, non-small cell lung cancer, Kaposi's sarcoma.	Low solubility and toxicity; overcome by semi-synthetic derivatives and advanced drug delivery systems using nanotechnology.	Sati et al., 2024
Lovastatin	<i>Aspergillus terreus</i> (fungus)	Inhibits HMG-CoA reductase, reducing cholesterol biosynthesis and lowering LDL cholesterol.	Hypercholesterolemia, prevention of cardiovascular diseases.	Development of synthetic derivatives; issues related to long-term usage in managing lipid profiles.	Peng et al., 2024
Bryostatin-1	Marine bryozoan (<i>Bugula neritina</i>)	Modulates protein kinase C to promote synaptic growth, showing potential for treating cancer, Alzheimer's disease, and HIV-associated cognitive disorders.	Cancer, Alzheimer's disease, HIV-associated cognitive disorders.	Limited clinical use; ongoing research into its full therapeutic potential.	Figuerola & Avila, 2019
Artemisinin	<i>Artemisia annua</i> (sweet wormwood)	Produces reactive oxygen species that damage <i>Plasmodium</i> parasites, leading to their death.	Malaria treatment, part of ACTs (artemisinin-based combination therapies).	Semi-synthetic production to meet global demand and resistance management.	Rai et al., 2021
Camptothecin	<i>Camptotheca acuminata</i> (tree)	Inhibits DNA topoisomerase I, preventing DNA replication and leading to cancer cell death.	Colorectal cancer treatment; derivatives like irinotecan.	Solubility and toxicity issues, overcome by developing more stable and effective analogs.	Fan et al., 2022

Resveratrol	Grapes, Polygonum cuspidatum (knotweed)	Modulates multiple molecular pathways, including sirtuins, NF-κB, and COX enzymes, exhibiting antioxidant, anti-inflammatory, and anticancer properties.	Antioxidant, anti-inflammatory, cardioprotective; potential anticancer agent.	Not yet a drug; ongoing research into its therapeutic applications and synthetic analogs.	Zhang et al., 2024
Avermectin	Streptomyces avermitilis (bacterium)	Targets glutamate-gated chloride channels in parasites, leading to paralysis and death.	Used as ivermectin for parasitic infections like onchocerciasis, lymphatic filariasis.	Potential antiviral and anti-inflammatory effects; ongoing research into broader applications.	Fong et al., 2021
Quinine	Cinchona tree bark	Interferes with Plasmodium parasite's ability to digest hemoglobin, causing toxic heme accumulation and parasite death.	Malaria treatment, particularly for drug-resistant strains.	Largely replaced by modern antimalarials, but still vital for severe malaria cases.	Mohammadi et al., 2020
Vincristine	Catharanthus roseus (Madagascar periwinkle)	Binds to tubulin, disrupting microtubule formation and inhibiting mitosis, leading to cancer cell death.	Leukemia, lymphoma, neuroblastoma treatment.	Neurotoxicity at higher doses; derivatives like vinblastine have been developed to improve efficacy and reduce side effects.	Dhyani et al., 2022
Etoposide	Mayapple (<i>Podophyllum peltatum</i>)	Inhibits topoisomerase II, inducing DNA strand breaks and apoptosis in rapidly dividing cells.	Testicular cancer, small-cell lung cancer, and other malignancies.	Semi-synthetic production from podophyllotoxin; improvements in formulation to reduce side effects.	Singh & Agrawal, 2024
Galantamine	Snowdrop (<i>Galanthus</i> species)	Inhibits acetylcholinesterase, enhancing cholinergic neurotransmission and improving cognitive function.	Alzheimer's disease treatment.	Ongoing research into expanding applications in neurology.	Arumugam, 2024

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