Modern American Journal of Biological and Environmental Sciences
ISSN (E): 3067-7920
Volume 01, Issue 06, September, 2025
Website: usajournals.org

ECO-FRIENDLY MANUFACTURING TECHNOLOGIES IN PHARMACY

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Abstract
This article provides a comprehensive analysis of the technological processes involved in the production of environmentally friendly pharmaceutical products derived from medicinal plants. Special attention is given to advanced methods of raw material processing, innovative extraction techniques, and the principles of standardization that ensure product quality and safety. Furthermore, the study highlights the development and optimization of finished dosage forms, emphasizing their ecological sustainability and therapeutic effectiveness.

Keywords: Medicinal plants, phytopreparations, ecological purity, extraction, technology, standardization, bioactivity.

Introduction

Medicinal plants existing in nature have developed over millions of years and are considered a source of biologically active compounds adapted to the human body. Plants widely used in phytotherapy contain alkaloids, flavonoids, glycosides, saponins, essential oils, vitamins, and microelements. They possess properties such as strengthening the immune system, anti-inflammatory, antiseptic, antiallergic, and other therapeutic effects. Today, the pharmaceutical industry is one of the most important sectors in ensuring human health. However, during the production of medicinal products, the use of various chemical substances, energy, and raw materials can negatively affect the environment. Therefore, in recent years, the introduction of environmentally friendly production technologies in the pharmaceutical industry has become an urgent issue. The concept of “green pharmacy” was developed in this regard, with its main objective being the

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creation of pharmaceutical products through ecologically safe, sustainable, and energy-efficient methods [1].

Drugs created on the basis of chemical synthesis often have adverse effects on the liver, kidneys, and gastrointestinal functions. Environmentally friendly herbal medicines, on the other hand, consist of natural compounds and are distinguished by the absence of harmful side effects on the human body. Due to their high biological compatibility, such preparations are well absorbed and metabolized. There are some useful principles of environmentally friendly production. In the pharmaceutical industry, environmentally friendly technologies are implemented based on the following key principles:

1. Selection of safe raw materials. In chemical synthesis processes, harmful substances should be minimized as much as possible or replaced with biotechnological alternatives.
2. Rational use of resources. Efficiency in production is achieved by minimizing the use of water, energy, and raw materials.
3. Reduction of waste. Industrial by-products should be recycled or reused as secondary raw materials.
4. Application of biotechnologies. The use of microorganisms, enzymes, and cell cultures in drug production is considered safer compared to chemical synthesis.
5. Utilization of nanotechnologies. With the help of nanoparticles, active pharmaceutical ingredients can be delivered precisely to the body, which reduces dosage requirements and minimizes waste [2].

In order to produce high-quality and safe medicines from medicinal plants, first of all, the raw materials must be properly collected, dried, stored, and processed. The plant parts richest in biologically active substances — leaves, roots, bark, seeds, fruits, and flowers — are harvested in compliance with collection regulations. The collected raw materials are dried in places protected from sunlight, free from moisture and contamination. During storage, temperature and humidity must be kept under constant control [3].

The medicinal compounds of plants are mainly extracted through the process of extraction. This method involves isolating bioactive substances from plants using

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solvents. The most commonly used solvents are water, ethanol, methanol, ether, glycerin, and carbon dioxide. Extraction can be performed through various methods: cold extraction, decoction (boiling), infusion (steeping), Soxhlet extraction, ultrasound-assisted extraction, or microwave-assisted extraction. The extraction conditions (temperature, duration, amount of solvent) must be optimized to maximize the yield of active substances.

One of the most important stages in the production of environmentally friendly medicines is the standardization of the final product. Each preparation is evaluated according to the quantity of active compounds it contains, purity, toxicity, microbiological indicators, and moisture content. In this process, chromatography, spectrophotometry, titration, microscopic analysis, and biological tests are applied.

Plant-based medicines are produced in various pharmaceutical forms such as extracts, tinctures, syrups, teas, tablets, capsules, ointments, and balms. In these preparations, the plant extract serves as the main active component. The dosage, storage conditions, and usage instructions of the finished product are determined in accordance with established standards [4].

In modern pharmacy, advanced technologies are being introduced for the isolation and identification of biologically active substances. Approaches such as microencapsulation, nanotechnology, supercritical extraction, and fermentation play a significant role in enhancing the effectiveness and bioavailability of herbal preparations. For example, nanoencapsulated plant extracts are rapidly absorbed by the body and demonstrate high biological activity [5].

One of the key aspects in producing environmentally friendly medicines from plants is cultivating them without pesticides and artificial fertilizers, and avoiding the use of chemical additives during harvesting and processing. In addition, manufacturing enterprises should minimize waste emissions and prevent environmental pollution. The application of energy-efficient methods in processing, proper waste disposal, and the introduction of recycling systems ensure ecological sustainability.

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In the Republic of Uzbekistan, positive experiences are being developed in the cultivation and processing of medicinal plants. In particular, plants such as black cumin, couch grass, licorice, and harmala are being cultivated on large areas in the Surkhandarya, Kashkadarya, Tashkent, and Fergana regions. Work is being carried out to involve them in the industrial-scale production of medicinal preparations. Phytomedicines produced from local raw materials are being certified in accordance with market requirements [6].

In the pharmaceutical industry, the widespread introduction of environmentally friendly production technologies faces a number of challenges that slow down the development of this sector.

Firstly, the implementation of modern ecological technologies requires very high **financial costs.** Large investments are necessary to establish energy-efficient equipment, waste recycling systems, modern extraction processes, and biotechnological laboratories. This remains a serious economic barrier for many pharmaceutical enterprises [7].

Secondly, the effective organization of environmentally friendly production processes requires **highly qualified specialists**. The shortage of experts with deep knowledge in biotechnology, nanopharmacy, chemistry, and ecology makes the implementation of modern technologies in production more complicated.

Thirdly, there are significant issues related to the **supply of raw materials,** which are the primary resource for the production of environmentally friendly medicines. Cultivating medicinal plants without pesticides and synthetic fertilizers requires considerable labor, time, and specific agro-ecological conditions. Moreover, ensuring ecological standards during the collection, drying, storage, and transportation of raw materials is also a challenging process [8].

Therefore, the development of environmentally friendly production in the pharmaceutical industry requires strong **governmental support**, the expansion of scientific research, the introduction of international experience, and the training of qualified specialists.

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The technology of producing environmentally friendly medicines from medicinal plants is one of the most promising directions in pharmacy. Such preparations are safe and effective for human health and contribute to maintaining ecological balance. By integrating scientifically grounded approaches, modern equipment, and ecological principles into technological processes, it is possible to produce high-quality phytopreparations. In this field, scientific research, scientific-technical innovations, agroecological monitoring, and the use of international experience are of great importance. Through deep processing of local raw materials, diversification of production, and strengthening export potential, Uzbekistan's phytopharmacology can be elevated to a new stage of development [9].

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