Int. J. Sci. R. Tech., 2026 3(4)
A Multidisciplinary peer-reviewed Journal
www.ijsrtjournal.com [ISSN: 2394-7063]

Original Article

A Review on Plant Growth Promoters from Pharmaceutical Waste Management

Siddhivinayak Jadhav*, Amruta Jamale, Shravani Jadhav, Sachin Gorad, Bhagyesh Janugade

Krishna foundation Jaywant institute of pharmacy wathar Maharashtra, India

ABSTRACT

Pharmaceutical waste has emerged as a significant environmental concern due to the rapid expansion of the pharmaceutical industry and increased consumption of medicinal products. This waste originates from manufacturing units, healthcare facilities, and households, containing active pharmaceutical ingredients, excipients, solvents, and packaging materials that may persist in the environment. Improper disposal practices such as landfilling and discharge into water bodies lead to soil degradation, water contamination, and adverse effects on living organisms. In recent years, the concept of waste valorization has gained attention as a sustainable strategy to convert pharmaceutical waste into valuable products. One promising approach involves transforming pharmaceutical residues into plant growth promoters, which can enhance agricultural productivity while reducing environmental burden. Plant growth promoters derived from such waste may contain essential nutrients, organic compounds, and bioactive molecules that stimulate plant growth and improve soil health. Various biological, chemical, and physical methods have been explored for this conversion, including composting, microbial degradation, and extraction techniques. This review highlights the potential of pharmaceutical waste as an alternative resource for plant growth promotion, discusses its environmental implications, and evaluates current technologies for its safe utilization. The integration of waste management with agricultural applications offers a dual benefit of pollution control and sustainable farming. The study emphasizes the need for regulatory frameworks and advanced research to ensure safe and efficient implementation of this innovative approach.

Keywords: Pharmaceutical waste, Plant growth promoters, Waste valorization, Sustainable agriculture, Environmental management, Bioactive compounds, Resource recovery

INTRODUCTION

Pharmaceutical waste refers to any unused, expired, or contaminated medicinal product and its associated materials generated during production, distribution, and consumption processes. It includes a wide range of substances such as active pharmaceutical ingredients, intermediates, solvents, packaging materials, and personal care products. These wastes are broadly categorized based on their origin and composition, which significantly influence their environmental impact and disposal requirements. The major sources of pharmaceutical waste include manufacturing industries, hospitals, research laboratories, and households, each contributing differently to the overall waste burden. Industrial waste is often generated in large quantities and may contain high concentrations of chemical residues, whereas hospital and household waste typically consist of expired drugs and unused medications (1,2). The environmental impact of pharmaceutical waste is a growing concern due to its persistence and bioactive nature. Many pharmaceutical compounds are designed to resist metabolic degradation, which allows them to remain stable in the environment for extended periods. When improperly disposed of, these substances can contaminate soil and water systems, affecting microbial communities, aquatic organisms, and even human health through the food chain. One of the most alarming consequences is the development of antimicrobial resistance, which poses a serious threat to global public health (3,4). To address these challenges, sustainable waste management strategies are being explored, focusing on reducing, reusing, and recycling pharmaceutical

Relevant conflicts of interest/financial disclosures: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

waste. Among these approaches, the concept of utilizing waste as a resource has gained considerable attention. Plant growth promoters are substances that enhance plant growth by improving nutrient availability, stimulating hormonal activity, and increasing resistance to environmental stress. Integrating pharmaceutical waste management with the production of plant growth promoters represents an innovative and eco-friendly solution, aligning with the principles of sustainable agriculture and circular economy (5,6).

Figure 1. Sources and environmental impacts of pharmaceutical waste.

This schematic diagram illustrates the major sources of pharmaceutical waste, including manufacturing industries, hospitals and clinics, research laboratories, and households. Waste generated from these sources converges into a common waste stream, which, when improperly managed, leads to significant environmental consequences. The figure highlights key impacts such as water contamination, soil pollution, ecological disruption, and the development of antimicrobial resistance. This conceptual representation emphasizes the pathway from waste generation to environmental exposure, underscoring the need for sustainable waste management strategies.

2. Classification Of Pharmaceutical Waste

Pharmaceutical waste can be classified into several categories based on its physical state, chemical composition, and potential hazard. This classification is essential for determining appropriate handling, treatment, and disposal methods, as well as for identifying opportunities for reuse and valorization. One of the primary classifications is based on physical form, which includes solid and liquid pharmaceutical waste. Solid waste comprises expired tablets, capsules, powders, packaging materials, and contaminated personal protective equipment, while liquid waste includes syrups, injectable solutions, solvents, and effluents generated during drug manufacturing processes. Liquid pharmaceutical waste is particularly concerning due to its high potential for environmental dispersion and contamination of water bodies (7,8). Another important classification distinguishes between hazardous and non-hazardous pharmaceutical waste. Hazardous waste includes substances that are toxic, flammable, corrosive, or reactive, such as cytotoxic drugs, antibiotics, and certain chemical intermediates. These compounds require specialized treatment and disposal methods due to their potential to cause serious harm to human health and the environment. Non-hazardous waste, on the other hand, consists of materials that pose minimal risk under normal conditions, such as saline solutions and some over the counter medications. However, even non-hazardous waste can become problematic when accumulated in large quantities or improperly managed (9,10). Pharmaceutical waste can also be categorized as biodegradable and non-biodegradable. Biodegradable waste includes organic materials that can be decomposed by microorganisms into simpler, non toxic substances. Examples include certain plant-based excipients and natural compounds used in drug formulations. Non-biodegradable waste includes synthetic chemicals and plastics that persist in the environment for long periods and may accumulate in ecosystems. This distinction is particularly relevant in the context of waste valorization, as biodegradable components are more amenable to biological conversion processes such as composting and microbial degradation (11). Understanding the classification of pharmaceutical waste provides a foundation for developing effective strategies for its management and conversion into useful products such as plant growth promoters. Proper segregation and identification of waste types enable the selection of suitable treatment technologies and minimize the risks associated with environmental contamination (12).

3. Environmental Impact Of Pharmaceutical Waste

The environmental impact of pharmaceutical waste has become a critical issue due to its continuous release into ecosystems and its biologically active nature. One of the major consequences is soil contamination, where pharmaceutical residues accumulate and alter the physicochemical properties of soil. These compounds can interfere with soil microbial communities, which play a vital role in nutrient cycling and organic matter decomposition. The presence of antibiotics and other bioactive substances in soil can inhibit beneficial microorganisms, thereby reducing soil fertility and affecting plant growth (13). Water pollution is another significant concern associated with pharmaceutical waste. Improper disposal practices such as direct discharge into sewage systems or water bodies allow pharmaceutical compounds to enter surface water and groundwater. Conventional wastewater treatment plants are often not designed to completely remove these complex chemicals, resulting in their persistence in aquatic environments. This contamination can negatively affect aquatic organisms, causing physiological and reproductive disturbances, and may also enter the human food chain through drinking water sources (14). Pharmaceutical waste also exhibits toxic effects on plants and microorganisms. Certain drug residues can inhibit seed germination, reduce root elongation, and impair photosynthesis in plants. Additionally, these substances may disrupt microbial enzyme activity and metabolic pathways, leading to ecological imbalance. The toxicity is often dose dependent and varies with the type of pharmaceutical compound present in the environment (15). One of the most alarming impacts is the development of antimicrobial resistance. Continuous exposure of microorganisms to sublethal concentrations of antibiotics in the environment promotes the selection of resistant strains. These resistant microorganisms can spread through soil, water, and food systems, posing a significant threat to global health. The emergence of antimicrobial resistance due to environmental contamination highlights the urgent need for proper pharmaceutical waste management and innovative solutions such as waste valorization (16). Overall, the environmental impact of pharmaceutical waste underscores the importance of adopting sustainable strategies to minimize pollution and convert harmful residues into beneficial products, thereby protecting both ecosystems and human health (17).

4. Concept Of Waste Valorization

Waste valorization refers to the process of converting waste materials into useful products, thereby adding value and reducing environmental burden. In the context of pharmaceutical waste, valorization involves transforming discarded drugs, chemical residues, and byproducts into beneficial substances such as plant growth promoters, biofertilizers, or other value-added materials. This approach not only minimizes waste accumulation but also contributes to resource efficiency and sustainability. The growing interest in waste valorization is driven by the need to address environmental pollution while simultaneously meeting the increasing demand for agricultural inputs (18,19). The concept of waste valorization is closely aligned with the principles of the circular economy, which emphasizes the continuous use of resources through recycling, reuse, and recovery. Unlike the traditional linear model of take make dispose, the circular economy aims to create a closed loop system where waste is treated as a resource rather than a burden. In pharmaceutical industries, implementing circular economy strategies can significantly reduce waste generation and promote the recovery of valuable compounds. This transition is essential for achieving sustainable development goals and reducing the ecological footprint of industrial activities (20,21). Conversion of pharmaceutical waste into value added products involves various technological approaches, including biological, chemical, and physical processes. These methods enable the extraction of useful compounds, degradation of harmful substances, and transformation into forms that can be utilized in agriculture. For instance, organic residues and biodegradable components can be processed into nutrient rich materials that support plant growth, while certain bioactive compounds can stimulate physiological processes in plants. The success of these conversion processes depends on the nature of the waste and the efficiency of the treatment methods employed (22,23). Waste valorization also offers economic benefits by reducing disposal costs and generating new revenue streams from waste derived products. In addition, it supports environmental protection by decreasing pollution levels and conserving natural resources. In the agricultural sector, the use of valorized products such as plant growth promoters can enhance soil health, improve crop productivity, and reduce dependence on synthetic fertilizers. Therefore, integrating waste valorization into pharmaceutical waste management represents a promising strategy for achieving both environmental sustainability and agricultural advancement (24).

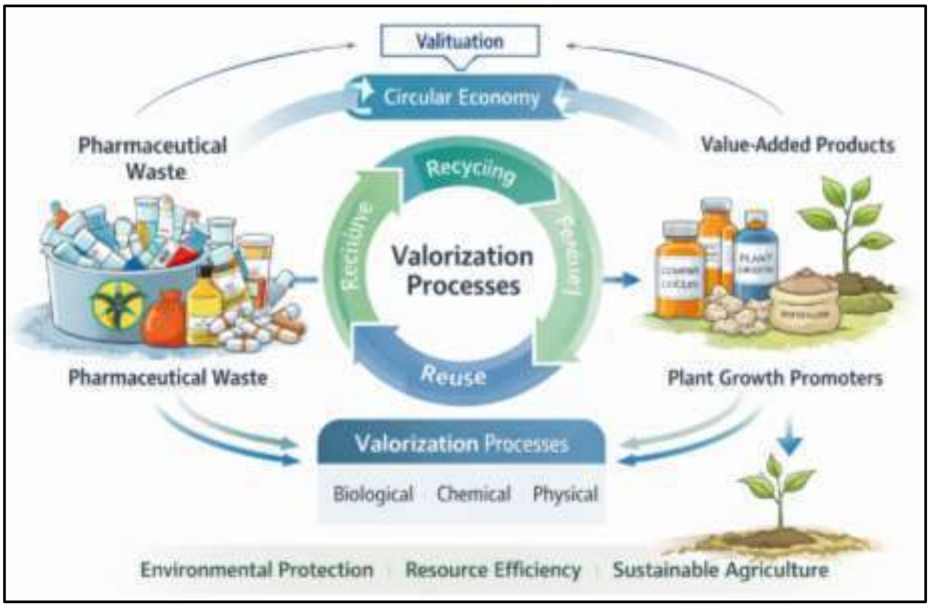

Figure 2. Waste valorization in pharmaceutical waste management.

5. Plant Growth Promoters (PGPS)

Plant growth promoters are substances or microorganisms that enhance plant development, productivity, and overall health through various biological and biochemical mechanisms. These agents improve nutrient availability, stimulate physiological processes, and help plants tolerate environmental stress conditions. In recent years, plant growth promoters have gained considerable attention as sustainable alternatives to conventional fertilizers and chemical growth regulators. Their application in agriculture supports improved crop performance while maintaining soil quality and ecological balance. With the increasing interest in sustainable farming, plant growth promoters derived from alternative sources, including waste materials, are being explored for their potential agricultural benefits (25).

6. Definition and Types

Plant growth promoters can be broadly categorized based on their origin and composition into organic, inorganic, and microbial based promoters. Organic plant growth promoters include natural substances such as compost derived materials, humic substances, amino acids, and plant-based extracts that enhance plant metabolism and nutrient uptake. These materials often improve soil structure and microbial activity, which are essential for healthy plant growth. Inorganic plant growth promoters include mineral nutrients and chemical compounds that directly support plant development by supplying essential elements such as nitrogen, phosphorus, potassium, and micronutrients required for metabolic functions (26,27). Microbial based plant growth promoters consist of beneficial microorganisms such as bacteria, fungi, and actinomycetes that interact with plant roots and soil ecosystems. These microorganisms play a significant role in enhancing nutrient availability through processes such as nitrogen fixation and phosphate solubilization. They also produce growth regulating substances that stimulate plant development and improve resistance to environmental stress. The use of microbial plant growth promoters is considered an eco-friendly approach because it supports natural biological processes within the soil environment (28,29).

6.1 Mechanism of Action

Plant growth promoters function through several mechanisms that collectively enhance plant productivity and resilience. One of the primary mechanisms is nutrient solubilization, where certain compounds or microorganisms convert insoluble nutrients in the soil into forms that can be easily absorbed by plant roots. This process significantly improves nutrient efficiency and reduces the need for excessive fertilizer application (30). Another important mechanism involves the production of plant growth hormones such as auxins and gibberellins. These hormones regulate various aspects of plant development, including cell division, elongation, and differentiation. The presence of such hormones stimulates root formation and improves overall plant vigor, which ultimately contributes to better crop yield (31). Enhancement of root growth is also a key function of plant growth promoters. Improved root systems enable plants to access water and nutrients more effectively, thereby supporting stronger growth and development. In addition, plant growth promoters can increase plant tolerance to environmental stresses such as drought, salinity, and pathogen attack. This stress resistance is achieved through the activation of defense mechanisms and improved metabolic activity within plant tissues (32,33). The diverse mechanisms of plant growth promoters highlight their importance in modern agriculture and support their potential integration with innovative waste management approaches, including the utilization of pharmaceutical waste as a resource for agricultural development (34).

7. Pharmaceutical Waste As A Source Of Plant Growth Promoters

Pharmaceutical waste represents a complex mixture of organic and inorganic compounds, many of which possess significant biological activity. These wastes often contain residual active pharmaceutical ingredients, excipients, solvents, and intermediate compounds that can be repurposed under controlled conditions. The presence of such bioactive compounds provides an opportunity to explore pharmaceutical waste as a potential source of plant growth promoters. When appropriately treated and detoxified, certain components can contribute positively to plant growth and soil health (35,36). One of the key aspects supporting the reuse potential of pharmaceutical waste is its nutrient content. Some pharmaceutical formulations include minerals, organic acids, and other compounds that can serve as nutrient sources for plants. For example, residues containing calcium, magnesium, and trace elements may enhance soil fertility when processed correctly. Additionally, organic compounds present in pharmaceutical waste can improve soil structure and support microbial activity, which are essential for nutrient cycling and plant growth (37,38). Pharmaceutical waste may also contain compounds that exhibit growth stimulating properties. Certain bioactive molecules, even in low concentrations, can influence plant physiological processes such as germination, root development, and stress response. For instance, some antibiotic residues at controlled levels have been reported to induce beneficial stress responses in plants, although their application requires careful regulation to avoid toxicity and environmental risks. Similarly, vitamins and amino acids present in pharmaceutical waste can act as metabolic enhancers, supporting plant growth and development (39,40). Examples of reusable compounds from pharmaceutical waste include fermentation by products, nutrient rich excipients, and biodegradable organic materials that can be converted into soil amendments. These materials can be integrated into agricultural systems after appropriate treatment processes to ensure safety and effectiveness. However, it is essential to eliminate or neutralize harmful components before application, as untreated pharmaceutical waste may contain toxic substances that could adversely affect plants, soil microorganisms, and human health (41,42). The utilization of pharmaceutical waste as a source of plant growth promoters highlights the potential of integrating waste management with sustainable agriculture. This approach not only reduces environmental pollution but also contributes to resource recovery and efficient utilization of industrial byproducts (43).

8. Methods for Converting Pharmaceutical Waste Into Plant Growth Promoters

The conversion of pharmaceutical waste into plant growth promoters involves a range of treatment technologies designed to detoxify harmful substances and recover beneficial components. These methods are broadly categorized into biological, chemical, and physical approaches, each offering specific advantages depending on the nature of the waste. The selection of an appropriate method is crucial to ensure that the final product is safe, effective, and environmentally sustainable. Integrating multiple techniques often enhances the efficiency of the conversion process and improves the quality of the resulting plant growth promoting materials (44).

8.1 Biological Methods

Biological methods are widely regarded as eco-friendly and sustainable approaches for the transformation of pharmaceutical waste. Composting is one of the most commonly used techniques, where organic pharmaceutical residues are decomposed by microorganisms under controlled aerobic conditions. This process results in the formation of nutrient rich compost that can be used to improve soil fertility and support plant growth. Composting also helps in reducing the toxicity of certain pharmaceutical compounds through microbial degradation (45). Vermicomposting is another effective biological method that involves the use of earthworms to decompose organic waste. The activity of earthworms enhances the breakdown of complex organic substances and produces vermicompost enriched with nutrients and beneficial microbes. This method has shown promising results in converting biodegradable pharmaceutical waste into valuable soil amendments with plant growth promoting properties (46). Microbial degradation involves the use of specific microorganisms capable of breaking down pharmaceutical compounds into simpler and less harmful substances. Bacteria and fungi play a significant role in this process by metabolizing complex chemicals and reducing their toxicity. This method is particularly useful for degrading antibiotic residues and other persistent compounds, thereby making the waste suitable for agricultural applications (47,48).

8.2 Chemical Methods

Chemical methods focus on the transformation and neutralization of pharmaceutical waste through chemical reactions. Neutralization is a commonly used technique to adjust the pH of waste materials and reduce their corrosive nature. This process is particularly important for treating acidic or alkaline pharmaceutical effluents before further processing or reuse (49). Extraction of useful compounds is another important chemical approach, where valuable bioactive substances are isolated from pharmaceutical waste using solvents or other extraction techniques. These extracted compounds can then be utilized as plant growth promoters or as precursors for the development of agricultural inputs. Proper purification is essential to ensure that harmful contaminants are removed during the extraction process (50).

8.3 Physical Methods

Physical methods are employed to separate, concentrate, or remove unwanted components from pharmaceutical waste. Filtration is widely used to remove solid particles and impurities from liquid waste, thereby improving its quality for further processing. This method is often used as a preliminary step in waste treatment systems (51). Adsorption techniques involve the use of materials such as activated carbon or biochar to capture and remove pharmaceutical residues from waste streams. These adsorbents can effectively reduce the concentration of toxic compounds and improve the safety of the treated waste for agricultural use (52). Incineration, when combined with recovery techniques, can also contribute to waste valorization. Although incineration primarily aims to reduce waste volume and destroy hazardous substances, advanced systems allow for the recovery of energy and certain mineral residues. These recovered materials can potentially be reused in agricultural applications after appropriate treatment and validation (53). Overall, the integration of biological, chemical, and physical methods provides a comprehensive approach for converting pharmaceutical waste into plant growth promoters. These technologies play a crucial role in ensuring that waste derived products are safe, efficient, and suitable for sustainable agricultural practices (54).

9. Applications In Agriculture

The application of plant growth promoters derived from pharmaceutical waste in agriculture represents an innovative approach to enhance crop productivity while addressing environmental concerns. These value added products can significantly improve soil fertility by enriching it with essential nutrients and organic matter. When properly treated, pharmaceutical waste derived materials contribute to the replenishment of macro and micronutrients in the soil, thereby supporting healthy plant growth and improving overall soil structure. Enhanced microbial activity in soil further facilitates nutrient cycling, which is crucial for sustainable agricultural systems (55,56). Another important application is the improvement of crop yield and quality. Plant growth promoters obtained from pharmaceutical waste may contain bioactive compounds that stimulate physiological processes such as seed germination, root development, and flowering. These effects result in increased biomass production and improved crop performance. In addition, such promoters can enhance the nutritional quality of agricultural produce by improving the uptake of essential minerals and promoting better metabolic activity within plants (57,58). The use of pharmaceutical waste derived plant growth promoters also supports sustainable farming practices by reducing reliance on chemical fertilizers and synthetic growth regulators. This approach aligns with environmentally friendly agricultural methods that aim to minimize chemical inputs and reduce ecological damage. By recycling waste into useful agricultural inputs, farmers can adopt more sustainable and cost-effective practices while maintaining productivity (59). Experimental studies and case-based observations have demonstrated the potential benefits of using treated pharmaceutical waste in agriculture. For instance, composted pharmaceutical residues have been shown to improve soil organic content and increase crop yield in controlled studies. Similarly, microbial treated waste has been reported to enhance plant resistance to environmental stress conditions such as drought and salinity. These findings highlight the practical applicability of pharmaceutical waste valorization in real world agricultural settings, although further research is needed to ensure safety and long-term sustainability (60). Overall, the integration of pharmaceutical waste derived plant growth promoters into agriculture offers a promising solution for improving crop productivity while promoting environmental conservation and resource efficiency (61).

10. Advantages of Using Pharmaceutical Waste Derived Plant Growth Promoters

The utilization of pharmaceutical waste derived plant growth promoters offers several significant advantages in the context of environmental sustainability and agricultural productivity. One of the primary benefits is the reduction of waste accumulation. Pharmaceutical industries generate large volumes of waste that, if not properly managed, can lead to serious environmental pollution. Converting this waste into useful agricultural inputs helps in minimizing landfill disposal and reduces the release of harmful substances into soil and water systems (62). Another important advantage is the development of cost-effective fertilizers and growth promoting agents. Traditional fertilizers and chemical inputs can be expensive and may not always be accessible to small scale farmers. By transforming pharmaceutical waste into plant growth promoters, it is possible to produce low cost alternatives that maintain or even enhance crop productivity. This approach can contribute to economic sustainability in agriculture, especially in developing regions (63). The eco-friendly nature of this approach is also a key benefit. Pharmaceutical waste valorization reduces environmental pollution and promotes the reuse of resources, thereby aligning with sustainable development goals. Unlike conventional waste disposal methods that may generate secondary pollutants, this strategy focuses on resource recovery and environmental protection. The use of such derived products in agriculture can improve soil health without introducing excessive chemical loads, thus supporting ecological balance (64). Resource recovery is another major advantage, as valuable compounds present in pharmaceutical waste are effectively utilized rather than being discarded. These compounds may include nutrients, organic materials, and bioactive substances that can enhance plant growth. By recovering and reusing these materials, industries can reduce raw material consumption and improve overall efficiency in resource utilization (65). In addition, this approach supports the principles of circular economy by creating a closed loop system where waste is continuously reused. This not only reduces environmental impact but also promotes innovation in waste management technologies. The integration of pharmaceutical waste derived plant growth promoters into agricultural systems demonstrates a practical and sustainable solution for addressing both waste management and food production challenges (66).

Table 1: Advantages of Pharmaceutical Waste Derived Plant Growth Promoters

Sr. No.	Advantage	Description	Reference
1	Reduction of Waste Accumulation	Conversion of pharmaceutical waste into plant growth promoters minimizes landfill disposal and reduces environmental pollution in soil and water systems.	(62)
2	Cost Effective Fertilizers	Provides low cost alternatives to conventional fertilizers, making them accessible to small scale farmers while maintaining or enhancing crop productivity.	(63)
3	Eco Friendly Approach	Promotes sustainable development by reducing pollution, encouraging reuse of resources, and improving soil health without excessive chemical load.	(64)
4	Resource Recovery	Enables utilization of valuable compounds such as nutrients and bioactive substances present in pharmaceutical waste, improving resource efficiency.	(65)
5	Supports Circular Economy	Encourages a closed loop system where waste is reused continuously, reducing environmental impact and promoting sustainable innovation.	(66)

LIMITATIONS AND CHALLENGES

Despite the promising potential of pharmaceutical waste derived plant growth promoters, several limitations and challenges must be carefully considered to ensure their safe and effective application. One of the major concerns is the presence of toxic residues in pharmaceutical waste. Many pharmaceutical compounds are biologically active and may persist even after treatment processes. If not adequately detoxified, these residues can negatively affect plant growth, soil microorganisms, and ultimately human health through the food chain. Ensuring complete removal or transformation of harmful substances remains a significant technical challenge (67). Another critical issue is related to regulatory constraints. Pharmaceutical waste management is governed by strict guidelines due to its hazardous nature, and the reuse of such waste in agriculture requires compliance with environmental and safety regulations. However, there is often a lack of clear and specific regulatory frameworks for the utilization of pharmaceutical waste as plant growth promoters. This regulatory uncertainty can hinder the large-scale adoption of such technologies and limit their practical implementation (68). Lack of standardization is also a major challenge in this field. The composition of pharmaceutical waste varies widely depending on its source, type of drugs, and manufacturing processes. This variability makes it difficult to establish uniform treatment protocols and quality standards for the derived plant growth promoters. Without proper standardization, it becomes challenging to ensure consistency, safety, and effectiveness of the final products used in agriculture (69). Public and environmental safety concerns further complicate the acceptance of pharmaceutical waste derived products. There is a general apprehension regarding the use of waste materials in food production systems, particularly when they originate from pharmaceutical sources. Concerns about contamination, toxicity, and long term ecological effects may limit public acceptance and trust. Addressing these concerns requires extensive research, transparent risk assessments, and effective communication of safety measures (70). In addition, technological limitations such as high processing costs, requirement of specialized equipment, and limited scalability of certain treatment methods can restrict the widespread adoption of waste valorization strategies. Overcoming these challenges will require advancements in technology, supportive policies, and interdisciplinary research efforts to ensure that pharmaceutical waste can be safely and efficiently converted into valuable agricultural inputs (71).

12. Regulatory and Safety Considerations

Regulatory and safety considerations play a crucial role in the management and utilization of pharmaceutical waste, particularly when it is intended for conversion into plant growth promoters. Due to the potentially hazardous nature of pharmaceutical residues, strict guidelines have been established at national and international levels to ensure safe handling, treatment, and disposal. These regulations are designed to minimize environmental contamination and protect public health. However, the adaptation of these guidelines for waste valorization applications requires careful evaluation and modification to accommodate emerging technologies (72). Guidelines for pharmaceutical waste disposal typically emphasize segregation, proper labeling, and the use of appropriate treatment methods such as incineration, chemical neutralization, and secure landfilling. Healthcare institutions and pharmaceutical industries are required to follow standardized protocols to prevent accidental exposure and environmental release of hazardous substances. In recent years, there has been increasing emphasis on sustainable waste management practices, encouraging the recovery and reuse of valuable components from pharmaceutical waste wherever feasible (73). Environmental protection regulations also govern the discharge of pharmaceutical effluents into water bodies and soil systems. Regulatory agencies set permissible limits for various contaminants and require industries to implement effective wastewater treatment systems. Continuous monitoring and compliance with these standards are essential to prevent ecological damage and ensure the safety of downstream applications, including agriculture. The integration of waste valorization strategies must align with these environmental standards to ensure that the reuse of treated waste does not pose additional risks (74). Risk assessment is a critical component in the safe utilization of pharmaceutical waste derived products. This involves evaluating the potential toxicity, persistence, and bioaccumulation of residual compounds after treatment. Advanced analytical techniques are often employed to detect trace levels of pharmaceutical residues and assess their impact on soil, plants, and microorganisms. Comprehensive risk assessment frameworks help in determining the suitability of treated waste for agricultural use and in establishing safe application limits (75). Furthermore, the development of clear regulatory frameworks specifically addressing the use of pharmaceutical waste as plant growth promoters is necessary to support innovation in this field. Policymakers and regulatory authorities must collaborate with researchers and industry stakeholders to establish guidelines that ensure safety while promoting sustainable practices. Effective regulation will not only protect the environment but also facilitate the responsible adoption of waste derived agricultural inputs (76).

FUTURE PERSPECTIVES

The future of utilizing pharmaceutical waste for the development of plant growth promoters lies in the advancement of safe, efficient, and scalable conversion technologies. One of the key priorities is the development of innovative treatment methods that can effectively eliminate toxic residues while preserving beneficial components. Emerging techniques in biotechnology and green chemistry are expected to play a significant role in achieving this goal. The use of engineered microorganisms, enzyme based degradation systems, and eco-friendly chemical processes may enhance the efficiency of waste transformation and ensure the production of safe agricultural inputs (77). Large scale implementation of pharmaceutical waste valorization remains a major challenge but also a significant opportunity. To achieve industrial level application, it is essential to design cost effective and energy efficient processes that can handle large volumes of waste. Pilot scale studies and demonstration projects are needed to validate the feasibility of these technologies under real world conditions. Collaboration between pharmaceutical industries, agricultural sectors, and research institutions will be crucial for translating laboratory findings into practical applications (78). Policy support and public awareness are also vital for the successful adoption of this approach. Governments and regulatory bodies need to establish clear guidelines and incentives to promote the reuse of pharmaceutical waste in agriculture. Financial support, subsidies, and regulatory frameworks can encourage industries to adopt sustainable waste management practices. At the same time, increasing public awareness about the environmental and economic benefits of waste valorization can help in overcoming societal concerns and improving acceptance. Integration with sustainable agriculture practices is another important aspect of future development. Pharmaceutical waste derived plant growth promoters can be combined with organic farming techniques, biofertilizers, and precision agriculture systems to enhance crop productivity while minimizing environmental impact. This integrated approach can contribute to long term soil health, improved food security, and reduced dependence on synthetic agrochemicals. In summary, the future perspectives of pharmaceutical waste valorization emphasize innovation, collaboration, and sustainability. With continued research and supportive policies, this approach has the potential to transform waste management practices and contribute significantly to the advancement of environmentally responsible agriculture (79).

CONCLUSION

Pharmaceutical waste management has emerged as a critical environmental and public health concern due to the increasing production and consumption of medicinal products. This review highlights the potential of transforming pharmaceutical waste into plant growth promoters as a sustainable and innovative solution. The study emphasizes that pharmaceutical waste, when improperly disposed, leads to soil and water contamination, ecological imbalance, and the development of antimicrobial resistance. However, through appropriate treatment and valorization strategies, this waste can be converted into valuable agricultural inputs that enhance soil fertility and crop productivity. The concept of waste valorization aligns with the principles of circular economy by promoting resource recovery and reducing environmental burden. Various biological, chemical, and physical methods have been explored to convert pharmaceutical waste into safe and effective plant growth promoters. These products have demonstrated potential benefits in improving plant growth, increasing crop yield, and supporting sustainable farming practices. At the same time, challenges such as toxicity risks, regulatory limitations, and lack of standardization must be addressed to ensure safe application. Overall, the integration of pharmaceutical waste management with agricultural applications offers a dual advantage of environmental protection and resource utilization. With continued advancements in technology, strict regulatory frameworks, and increased awareness, this approach can significantly contribute to sustainable agriculture and environmental conservation. The future of this field lies in developing safe, scalable, and economically viable solutions that can be implemented at a global level (121,122).

REFERENCE

1. Verlicchi P, Aukidy MA, Zambello E. Occurrence of pharmaceutical compounds in urban wastewater. Sci Total Environ. 2012; 429:123 to 155.
2. Kümmerer K. Pharmaceuticals in the environment. Annu Rev Environ Resour. 2010; 35:57 to 75.
3. Daughton CG, Ternes TA. Pharmaceuticals and personal care products in the environment. Environ Health Perspect. 1999; 107:907 to 938.
4. aus der Beek T, Weber FA, Bergmann A. Pharmaceuticals in the environment global occurrences. Environ Toxicol Chem. 2016; 35:823 to 835.
5. Boxall AB. The environmental side effects of medication. EMBO Rep. 2004; 5:1110 to 1116.
6. WHO. Safe management of wastes from health care activities. Geneva. 2014.
7. US EPA. Pharmaceutical waste management guidelines. 2019.
8. Kümmerer K. Antibiotics in the aquatic environment. Chemosphere. 2009; 75:417 to 434.
9. Martinez JL. Environmental pollution by antibiotics. Environ Pollut. 2009; 157:2893 to 2902.
10. Vessey JK. Plant growth promoting rhizobacteria. Plant Soil. 2003; 255:571 to 586.

11. Bhattacharyya PN, Jha DK. Plant growth promoting rhizobacteria. Microbiol Res. 2012; 167:155 to 168.
12. Chartier Y. Safe management of wastes from health care activities. WHO Press. 2014.
13. Sharma S, Bhattacharya A. Drinking water contamination. Environ Chem Lett. 2017; 15:27 to 46.
14. US EPA. Hazardous waste classification. 2018.
15. WHO. Health care waste management. 2018.
16. Singh R, Agrawal M. Environmental impact of pharmaceuticals. Ecotoxicol Environ Saf. 2007; 68:363 to 372.
17. Kaur H, Kaur S. Biodegradation of pharmaceutical waste. J Environ Biol. 2020; 41:123 to 130.
18. Tchobanoglous G. Waste management principles. McGraw Hill. 1993.
19. Thiele Bruhn S. Pharmaceutical antibiotic compounds in soils. J Plant Nutr Soil Sci. 2003; 166:145 to 167.
20. Cycoń M, Mrozik A. Antibiotics in soil environment. Chemosphere. 2016; 143:198 to 210.
21. aus der Beek T. Pharmaceuticals in surface water. Environ Toxicol Chem. 2016; 35:823 to 835.
22. Pal A, Gin KY. Impacts of emerging contaminants. Water Res. 2010; 44:6068 to 6081.
23. Eggen T, Lillo C. Antibacterial effects on plants. Sci Total Environ. 2012; 414:130 to 137.
24. Carvalho PN. Ecotoxicological effects of pharmaceuticals. Environ Int. 2014; 67:75 to 87.
25. Karkman A. Antibiotic resistance in environment. FEMS Microbiol Rev. 2019; 43:428 to 446.
26. Larsson DG. Pollution and resistance. Nat Rev Microbiol. 2018; 16:431 to 442.
27. Wilkinson JL. Pharmaceutical pollution review. Lancet Planet Health. 2022; 6:1 to 12.
28. European Commission. Waste valorization strategies. 2020.
29. Ellen MacArthur Foundation. Circular economy report. 2019.
30. Geissdoerfer M. Circular economy concept. J Clean Prod. 2017; 143:757 to 768.
31. Kirchherr J. Circular economy definition. Resour Conserv Recycl. 2017; 127:221 to 232.
32. Chen H. Waste to resource technologies. Bioresour Technol. 2018;247:1 to 10.
33. Singh J. Waste valorization methods. Renew Sustain Energy Rev. 2020; 119:109580.
34. Kumar S. Waste management and sustainability. J Environ Manage. 2019; 231:88 to 95.
35. Glick BR. Plant growth promoting bacteria. Sci Total Environ. 2012; 427:30 to 36.
36. Lugtenberg B. Plant microbe interactions. Annu Rev Microbiol. 2009; 63:541 to 556.
37. Canellas LP. Humic substances in agriculture. Chem Biol Technol Agric. 2015; 2:3.
38. Marschner P. Mineral nutrition of plants. Academic Press. 2012.
39. Vurukonda SS. Plant growth promoting microbes. 3 Biotech. 2016; 6:1 to 14.
40. Ahmad F. Role of PGPR. Microbiol Res. 2008; 163:45 to 52.
41. Richardson AE. Nutrient solubilization. Plant Soil. 2009; 321:305 to 339.
42. Davies PJ. Plant hormones physiology. Springer. 2010.
43. Taiz L. Plant physiology. Sinauer Associates. 2015.
44. Yang J. Stress tolerance in plants. Plant Physiol. 2009; 150:212 to 219.
45. Backer R. Plant growth promotion review. Front Plant Sci. 2018; 9:1473.
46. Patel M. Pharmaceutical waste reuse. J Hazard Mater. 2020; 385:121 to 130.
47. Sharma B. Waste derived bioactive compounds. Environ Res. 2021; 194:110652.
48. Gupta S. Nutrient recovery from waste. Waste Manage. 2018; 79:1 to 12.
49. Singh A. Organic waste reuse. Bioresour Technol. 2019; 273:456 to 465.
50. Kumar V. Bioactive compounds in agriculture. Agric Ecosyst Environ. 2020; 295:106885.
51. Rizzo L. Pharmaceutical residues reuse. Sci Total Environ. 2019; 648:151 to 158.
52. Chen J. Waste conversion techniques. J Clean Prod. 2021; 287:125047.
53. Yadav R. Resource recovery from waste. Renew Energy. 2020; 145:188 to 197.
54. Pandey A. Industrial waste valorization. Elsevier. 2016.
55. Singh R. Biological waste treatment. J Environ Chem Eng. 2019; 7:103 to 110.
56. Kumar G. Integrated waste processing. Bioresour Technol. 2021; 320:124301.

57. Bernal MP. Composting processes. Waste Manage. 2009; 29:1467 to 1477.
58. Edwards CA. Vermiculture technology. CRC Press. 2010.
59. Haritash AK. Microbial degradation. J Hazard Mater. 2009; 169:1 to 15.
60. Cycoń M. Biodegradation of drugs. Chemosphere. 2017; 172:466 to 476.
61. Metcalf Eddy. Wastewater engineering. McGraw Hill. 2014.
62. Wang J. Extraction technologies. Chem Eng J. 2020; 397:125415.
63. Ternes TA. Filtration systems. Water Res. 2004; 38:4075 to 4084.
64. Ahmed MB. Adsorption of pharmaceuticals. J Environ Manage. 2017; 190:274 to 282.
65. Arena U. Waste incineration review. Waste Manage. 2012; 32:625 to 639.
66. Li WC. Pharmaceutical waste treatment. Environ Pollut. 2014; 187:193 to 201.
67. Tilman D. Agricultural sustainability. Nature. 2002; 418:671 to 677.
68. Lal R. Soil fertility management. Soil Sci. 2015; 180:143 to 150.
69. Pimentel D. Crop productivity improvement. Agric Ecosyst Environ. 2005; 108:9 to 17.
70. Fageria NK. Plant nutrition and yield. CRC Press. 2016.
71. Pretty J. Sustainable agriculture practices. Philos Trans R Soc. 2008; 363:447 to 465.
72. Reganold JP. Organic farming benefits. Nature Plants. 2016; 2:15221.
73. Zhang Y. Compost application effects. Sci Total Environ. 2020; 720:137 to 145.
74. Meena VS. Microbial inoculants in agriculture. Springer. 2017.
75. FAO. Sustainable agriculture report. 2021.
76. Hopewell J. Recycling benefits. Philos Trans R Soc. 2009; 364:2115 to 2126.
77. Zorpas AA. Waste reduction strategies. Waste Manage. 2020; 102:759 to 765.
78. Chen Y. Cost effective fertilizers. Agric Sci. 2018; 9:120 to 130.
79. Kumar S. Low cost agricultural inputs. J Clean Prod. 2017; 142:1230 to 1238.

HOW TO CITE: Siddhivinayak Jadhav*, Amruta Jamale, Shravani Jadhav, Sachin Gorad, Bhagyesh Janugade, A Review on Plant Growth Promoters from Pharmaceutical Waste Management, Int. J. Sci. R. Tech., 2026, 3 (4), 81-92. https://doi.org/10.5281/zenodo.19390885