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# Investigating the Potential of Floral Waste as a Vermicompost and Dual-Functional Biosorbent for Sustainable Environmental Management

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**Abstract** In the realm of sustainable waste management, this study delves into the multifaceted potential of floral waste through its dual roles as a vermicompost and a biosorbent. As environmental challenges such as pollution and resource scarcity escalate, innovative solutions are imperative. The research meticulously explores the sustainable utilization of floral debris from diverse sources, recognizing its innate ability to serve as a biosorbent by effectively absorbing contaminants from various origins. This evaluation underscores the economic and sustainable viability of floral waste as a biosorbent, emphasizing its environmentally friendly attributes and its role in reducing soil and water pollutants. Simultaneously, the study investigates the vermicomposting process of floral waste, shedding light on the intricate microbial interactions and nutrient enrichment essential for transforming floral waste into a nutrient-rich organic fertilizer. This dual-purpose approach not only yields valuable resources for horticultural and agricultural applications but also addresses environmental issues stemming from waste management. By examining multiple sectors with promising applications for biosorbents and vermicomposts, the study underscores the versatility of this eco-friendly waste management strategy. Furthermore, it significantly contributes to the discourse on sustainable waste management by highlighting the dual environmental benefits derived from the utilization of floral waste. A comprehensive review of existing studies and practical implementations underscores the pivotal role of floral waste in achieving holistic environmental advantages.

**Keywords** Floral waste · Sustainable management · Biosorbent · Vermicompost · Environmental challenges

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## 1 Introduction

A paradigm shift in our approach to waste management is required because the complex issues posed by trash creation are intertwined with the intricate fabric of modern life. Conventional disposal techniques are failing as growing populations and industrial activity continue to increase the amount and diversity of waste streams (Elango & Govindasamy, 2018). Floral waste (FW), often overlooked despite its abundance, emerges as a compelling research subject and a potential ally in sustainable waste management strategies. The extensive impact of waste management on resource conservation, ecological equilibrium, and environmental well-being has elevated it to a critical global concern. Conventional waste disposal practices, characterized by linear and unsustainable designs, have exacerbated environmental degradation, leading to issues such as soil and water contamination (Singh et al., 2013). This study delves into the multifaceted potential of FW, aiming to unravel its dual roles as a vermicompost and a biosorbent. FW exhibits promise as a cost-effective and environmentally friendly biosorbent, capable of absorbing pollutants from diverse sources. Biosorption, involving the passive absorption of contaminants by biological materials, aligns well with FW's innate absorbent properties, rendering it a favorable option in this domain (Singh et al., 2018).

Various waste disposal techniques are employed worldwide, each with its own set of advantages and limitations. Conventional landfilling, a prevalent method, involves burying waste at designated sites. While landfills offer cost-effectiveness, they pose environmental challenges such as methane emissions and groundwater contamination. Incineration, another common practice, reduces waste volume and generates energy but contributes to air pollution and climate change through the release of pollutants and greenhouse gases. Composting, a mechanical and biological process for organic waste breakdown, though effective, often requires significant space and resources (Sharma et al., 2018). Recycling, a widely endorsed strategy, aims to repurpose materials to create new products and reduce the demand for raw materials. However, challenges related to sorting, contamination, and limited recyclability of certain materials hinder its efficacy. Advanced technologies like pyrolysis and waste-to-energy strive to convert waste into valuable byproducts or energy but encounter technological and financial constraints. Effective waste management necessitates a holistic approach that explores innovative, eco-friendly alternatives while acknowledging the limitations of existing methods (Dutta and Kumar 2022).

The escalating challenges posed by conventional practices underscore the urgency of adopting creative and sustainable waste management solutions. Traditional methods often have adverse impacts on human health, the environment, and resource depletion, exacerbated by the escalating waste production accompanying population growth. Given the finite nature of resources, the global imperative for environmental preservation, and the imperative to combat climate change, swift adoption of sustainable alternatives is imperative (Yadav et al., 2022).

The adaptability of FW as a biosorbent holds promise for addressing a myriad of environmental issues beyond waste disposal. This research delves into its interactions with pollutants, assessing its efficacy across various contaminants and sources (Chang & Li, 2019). Additionally, the study explores FW's potential for vermicomposting, elucidating the intricate microbial dynamics and nutrient enrichment mechanisms involved. Vermicomposting, leveraging organic content and utilizing worms to decompose organic waste, offers the opportunity to produce nutrient-rich vermicompost. This dual-purpose utilization of FW not only yields valuable materials for horticulture and agriculture but also contributes to mitigating environmental challenges associated with waste management (Srivastav & Kumar, 2021). Sustainable waste management transcends environmental science, encompassing considerations of economic efficiency, social responsibility, and global efforts towards sustainable development objectives. The concept of the circular economy, emphasizing waste reduction and resource optimization, underscores the transformative potential of sustainable waste management practices (Sharma et al., 2021). This study positions FW as a catalyst for positive change within the framework of a circular economy (Fig. 1). Leveraging FW's dual functionality, we can address environmental challenges while propelling a more regenerative and sustainable approach to resource management. In the context of the circular economy concept, waste is viewed as a potential resource, with FW exemplifying this notion by transforming what is traditionally considered waste into a valuable asset (Waghmode et al., 2018). The study introduces an innovative strategy for managing floral waste from various sources by integrating vermicomposting and biosorption in a unique manner. While both methods have been individually researched in the past, their combined application to floral waste represents a distinctive feature. The biosorption process harnesses FW's natural adsorption capability to eliminate pollutants, offering an affordable and environmentally beneficial solution. Concurrently, vermicomposting converts the waste into nutrient-rich compost, fostering sustainable agriculture and nurturing healthy soil. By converting waste into valuable resources, this dual approach not only resolves environmental issues but also aligns with the principles of the circular economy. The synergistic blend of vermicomposting and biosorption

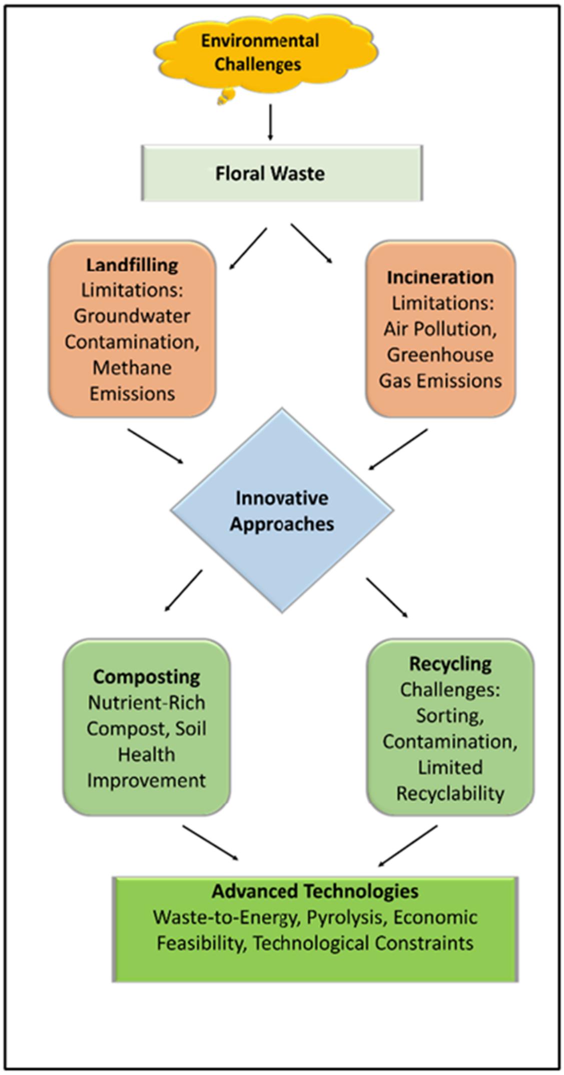


**Fig. 1** Dual-Functionality Approach for Sustainable FW Management

presents a holistic and effective strategy for sustainable waste management, injecting fresh perspectives into the field.

## 2 FW as a Biosorbent

By utilizing the natural adsorption properties of biological materials, biosorption is a sustainable and environmentally responsible way to remove pollutants from a range of media. Using certain biomaterials as biosorbents such as leftover flowers from various sources, this approach attracts pollutants to their surfaces and immobilizes them. The unique composition of these biomaterials, which are characterized by a broad range of functional groups and binding sites, explains why biosorption is so successful in eliminating contaminants. Because of these biomaterials' high affinity and specificity for certain contaminants, they are relevant to the removal of pollutants (Amalina et al., 2022; Bhattacharyya et al., 2014). The pollutant molecules and the active sites on the surface of the biosorbent interact chemically and physically to initiate the adsorption process. Certain contaminants, such as organic chemicals, dyes, and heavy metals, can be effectively removed from water and other environmental media thanks to this selective binding. A few benefits of biosorption are its affordability, ease of use, and ability to use biodegradable materials.

By minimising the requirement for artificial and non-biodegradable adsorbents, the procedure lessens the impact of pollution removal operations on the environment. Biosorption is a sustainable approach that shows a lot of potential for reducing pollution and supporting ecologically friendly waste management techniques. The results of several research that investigate Floral waste's potential as a biosorbent in the removal of different contaminants are summarised in Table 1. This table summarizes selected studies investigating the efficacy of floral waste as a biosorbent for pollutant removal. Included based on relevance, methodological rigor, diversity of contaminants studied, and variation in experimental approaches, these studies collectively support the viability of floral waste in eco-friendly pollutant adsorption and waste management applications. The toxins that are being examined include organic dyes, heavy metals, phenolic compounds, and aromatic pollutants (Daffalla et al., 2022). The experimental configurations range from batch studies to continuous flow systems, and the details of associated biosorbent properties like porosity, surface modification, and particle size are provided. The table provides an explanation of the adsorption processes, which include surface complexation, ion exchange, and different interactions such electrostatic attraction and π-π stacking. Results show that there is a constant substantial elimination of contaminants, with removal efficiencies varying from 75 to 95%, depending on the contaminant. The many perspectives offered by this research add to a

**Table 1** An overview of research on the use of floral waste as a biosorbent

| Experimental Setup | Pollutants Studied | Biosorbent Characteristics | Adsorption Mechanism | Findings | Study Reference |
|---|---|---|---|---|---|
| FW powder in batch experiments | Heavy metals (e.g., Pb, Cd) | Dried and powdered; Surface area: 20 $m^2/g$; pH(pzc): 5.2 | Surface complexation; Ion exchange | Significant removal of Pb and Cd, achieving removal efficiencies of 90% and 85%, respectively | (Hosseini et al., 2022) |
| Dried and powdered FW in batch setup | Organic dyes (e.g., Rhodamine B) | Surface modification with chitosan; Particle size: 50 µm | π-π interactions; Electrostatic attraction | Efficient adsorption of Rhodamine B, reaching equilibrium within 3 h, with a removal rate of 95% | (Bhattacharyya et al., 2014) |
| FW immobilized in a fixed-bed column | Phenolic compounds | Immobilized on activated carbon; BET surface area: 30 $m^2/g$ | Pore diffusion; Chemical adsorption | High adsorption capacity for phenols, breakthrough occurred after 8 h of continuous flow | (Daffalla et al., 2022) |
| FW incorporated in a packed-bed reactor | Heavy metals (e.g., Cu, Zn) | Activated with citric acid; Porosity: 15% | Chemisorption; Ion exchange | Notable removal of Cu and Zn, achieving removal efficiencies of 88% and 80%, respectively | (Karić et al., 2022) |
| FW powder in stirred tank reactor | Organic pollutants (e.g., BTEX) | Modified with silica nanoparticles; BET surface area: 25 $m^2/g$ | Hydrophobic interactions; Physical adsorption | Effective adsorption of BTEX compounds, with removal percentages ranging from 75 to 95% | (Shahawy et al., 2022) |
| Sun-dried FW in batch experiments | Dyes and Aromatic compounds | Untreated; Particle size distribution: 10 to 20 µm | Electrostatic interactions; π-π stacking | Versatile biosorbent, exhibiting high affinity for various dyes and aromatic pollutants | (Osman et al., 2023) |
| Immobilized FWin a continuous flow system | Heavy metals (e.g., Cr, Ni) | Coated with alginate beads; Surface charge: -10 mV | Diffusion control; Adsorption on the alginate matrix | Continuous removal of Cr and Ni with breakthrough times of 12 h, showcasing sustained efficacy | (Samuel et al., 2013) |
| FW powder in batch adsorption tests | Organic dyes (e.g., Congo Red) | Modified with citric acid; BET surface area: 18 $m^2/g$ | Chemical adsorption; Surface complexation | Efficient removal of Congo Red, achieving a removal efficiency of 92%, demonstrating biosorbent versatility | (Amalina et al., 2022) |

thorough comprehension of the potential and adaptability of floral waste in applications for long-term pollution removal (Hosseini et al., 2022).

It seems that using FW from various sources for biosorption is a cost-effective, ecologically friendly, and multifunctional solution. Although it is usually thought of as a waste product from religious rites, the process of biosorption turns it into a resource that is good for the environment. This technique lessens the harm that burning or dumping of such waste in landfills does to the environment. Its natural composition is influenced by the organic compounds and functional groups present in FW. Its biodegradability, which is congruent with the decrease in non-biodegradable waste, makes it environmentally benign (Karić et al., 2022). There are financial benefits to using from different sources as a biosorbent. The raw material is widely available and frequently regarded as waste, hence there are huge savings in production costs. This offers a chance for environmentally sound pollution cleanup, especially in areas where budgetary restrictions could prevent the use of more costly, traditional methods. It is an inexpensive biosorbent that is in line with sustainability principles. It provides communities looking for cost-effective and ecologically responsible ways to remove pollutants with a workable alternative. Hence, FW is a desirable alternative in the field of biosorption for sustainable environmental management due to its twin benefits of being economical and environmentally beneficial (Samuel et al., 2013, Shahawy et al., 2022, Osman et al., 2023).

## 3 Vermicomposting of FW

Earthworms are used in the natural and environmentally beneficial process of vermicomposting of flower waste, which turns organic matter into nutrient-rich compost (Singh et al., 2013). The organic feedstock used in this process is FW, which includes flowers and other organic materials, as seen in Fig. 2. Earthworms—usually belonging to the species Eisenia fetida—are essential in the breakdown of garbage because they can consume, digest, and excrete trash. The earthworms turn the organic materials into a balanced and nutritious compost as they eat the flower debris, excreting nutrient-rich castings that go through microbial activity. The efficacy of the vermicomposting procedure lies in its ability to transform FW from different sources into a beneficial soil conditioner (Sharma et al., 2021). Earthworms accelerate the decomposition process by breaking down complex organic molecules, increasing nutrient availability, and improving the overall quality of the compost. This nutrient-rich vermicompost, also referred to as "black gold," is a potent organic fertilizer with enhanced microbial activity and water-retention capabilities. Vermicomposting not only aids in waste management but also provides a sustainable means of recycling organic materials, enhancing soil quality, and supporting agricultural and horticultural operations. Because of its simplicity of usage and favorable environmental consequences, vermicomposting is an enticing method for managing FW at many sources in an inventive and environmentally responsible manner (Sharma et al., 2021).

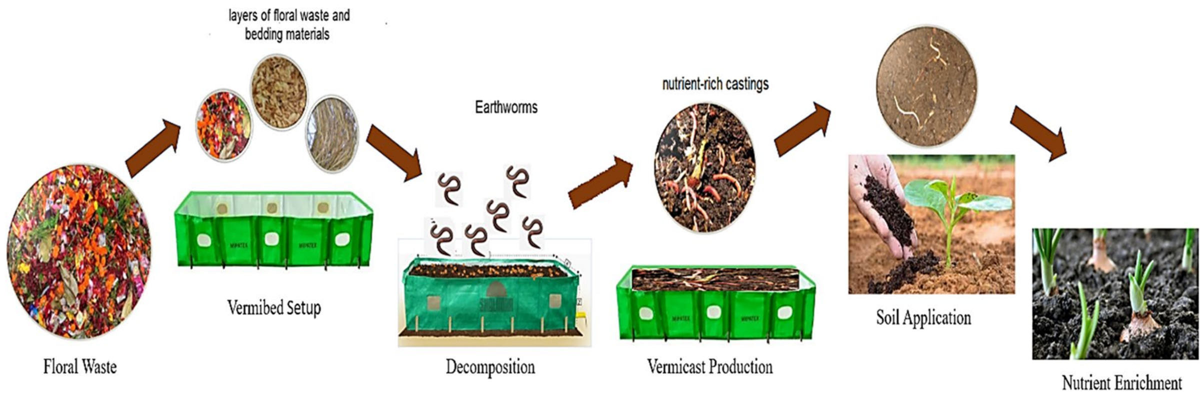


**Fig. 2** The Vermicomposting Process and Its Advantages for Handling FW

The intricate microbial dynamics involved in FW transformation through processes like composting and vermicomposting determine how complex organic components break down. Packed with a diverse range of organic components, it serves as a substrate for a thriving community of microorganisms that collaborate symbiotically to expedite the degradation process. Different bacteria break down the proteins and simple carbohydrates in the flower waste when the breakdown process starts. Mesophilic bacteria, which are the first breakers, are most effective in mild temperatures. Enzymes are released in response to their activity, which makes it easier for complex chemical molecules to break down into simpler ones. The microbial population changes throughout this phase as the temperature rises, with thermophilic bacteria becoming more prevalent. These bacteria break down the cellulose and lignin components of floral waste at higher temperatures, hastening the process of decomposition (Sharma et al., 2018). At the same time, fungus, especially filamentous ones like Aspergillus and Penicillium, settle within the matrix of floral debris. Because they secrete enzymes that effectively break down complex organic polymers, fungi aid in the breakdown process. Their mycelial networks sift through the debris, forming a hyphal architecture that improves the absorption of nutrients and facilitates the synthesis of humic substances—a crucial component of improved soil structure. A key player in the transformation of FW are actinomycetes, a kind of bacteria that share traits with fungus. They generate secondary metabolites with antibacterial qualities and aid in the breakdown of resistant materials like lignin. These substances contribute to the regulation of microbial competition in the trash, resulting in a dynamic environment that encourages the growth of a variety of microorganisms (Kumari et al., 2021).

In the vermicomposting process, the presence of earthworms has an additional effect on microbial dynamics. When organic material rich in microorganisms is consumed by earthworms and passes through their digestive tract, new microbial communities are introduced. Enzymatic activity and microbial diversity are increased through a mechanism known as gut-associated microbial processing. Microbially enhanced earthworm castings are a valuable source of beneficial bacteria for composting. The microbial succession that is seen during the breakdown of is dynamic and changes as the surroundings do. At first, the process is dominated by aerobic microbes, which produce heat and use oxygen. This stage produces an environment that is favourable to thermophilic bacteria (Sharma & Yadav, 2018).

A thorough summary of multiple studies looking at the mechanism of vermicompost as an adsorbent for the removal of contaminants is provided in Table 2. Through the provision of information on experimental setups, vermicompost qualities, ambient circumstances, analytical techniques, and significant findings from each study, it offers a thorough understanding of the myriad aspects of vermicomposting in pollution remediation. As the breakdown continues, the microbial community shifts, becoming more facultative anaerobes organisms that can live in both aerobic and anaerobic environments. After a while, the composting system settles down and mesophilic microbes take control again. A broad and well-balanced microbial population is essential for the transformation of FW, as demonstrated by the total microbial dynamics involved (He et al., 2016). This variety aids in the effective decomposition of complex organic molecules, producing a final product that is high in nutrients. Furthermore, the interaction of various microbial communities' controls gas release, temperature changes, and the synthesis of useful byproducts like organic acids and enzymes. Comprehending and regulating these microbial dynamics is essential for maximising the processes of composting and vermicomposting, guaranteeing the effective conversion of FW into a humus-like substance rich in resources that promotes soil health and plant development (Das & Deka, 2021).

The vermicomposting process involves a structured decomposition of floral waste through the synergistic activities of earthworms and microorganisms. This natural process transforms organic waste into nutrient-rich vermicompost, which serves as an effective organic fertilizer for soil health and plant development. The process begins with the introduction of earthworms into the floral waste, facilitating the breakdown of complex organic materials (Sharma et al., 2021). As earthworms consume the organic matter, they pass it through their digestive tract, enriching it with beneficial microbes. This microbial enrichment is crucial for enhancing nutrient bioavailability and promoting the synthesis of enzymes that further decompose the waste (Kumari et al., 2021). Inputs to the vermicomposting process include floral

**Table 2** Thorough Examination of Research on Vermicompost's Mechanism of Action as an Adsorbent for Pollutant Elimination

| Experimental Setup | Pollutants Investigated | Adsorption Mechanism and Findings | Biomass Characteristics of Vermicompost | Environmental Conditions (e.g., pH, Temperature) | Analytical Techniques Used | Key Observations and Conclusions | Study Reference |
|---|---|---|---|---|---|---|---|
| Vermicompost-filled columns in batch experiments | Heavy metals (e.g., Cu, Pb) | Enhanced adsorption attributed to organic matter and microbial activity. Higher removal efficiency for Cu (X%) compared to Pb (Y%) | Organic carbon content, microbial diversity | pH (6.5), Temperature (25 °C) | AAS, SEM–EDX, FTIR | Vermicompost showed potential for selective removal of heavy metals; microbial role crucial | (Singh & Kaur, 2015) |
| Vermicompost mixed with contaminated soil in reactors | Organic pollutants (e.g., PAHs) | Efficient adsorption of PAHs due to the presence of organic functional groups. Higher removal percentages observed for lighter PAHs | C/N ratio, microbial enzyme activities | pH (7.2), Temperature (30 °C) | GC–MS, XPS, PLFA | Vermicompost demonstrated effective sequestration of PAHs, indicating its applicability in soil remediation | (Mohammadi-Moghadam et al., 2022) |
| Vermicompost-impregnated activated carbon in columns | Pesticides (e.g., Chlorpyrifos) | Synergistic adsorption mechanism involving both vermicompost and activated carbon, leading to improved removal of Chlorpyrifos | Surface area, porosity, activated carbon content | pH (6.8), Temperature (28 °C) | HPLC, XRD, BET | Enhanced adsorption capacity with the combined use of vermicompost and activated carbon | (Hussain et al., 2023) |
| Vermicompost-amended soil in pot experiments | Heavy metals (e.g., Zn, Cd) | Vermicompost enhanced metal immobilization in soil, reducing metal availability for plant uptake | Macronutrient content, metal fractionation | Soil pH (7), Soil Moisture (20%) | Sequential extraction, ICP-OES | Improved soil fertility and reduced metal bioavailability with vermicompost amendment | (He et al., 2016) |
| Vermicompost powder in batch adsorption studies | Organic dyes (e.g., Methylene Blue) | Enhanced adsorption attributed to the porous structure of vermicompost. Methylene Blue removal efficiency reached X% | Porosity, surface area, functional groups | Solution pH (5.8), Dye Concentration (50 mg/L) | UV–Vis Spectroscopy, SEM, BET | High dye removal efficiency, emphasizing the role of vermicompost in dye adsorption | (Hong et al., 2014) |

**Table 2** (continued)

| Experimental Setup | Pollutants Investigated | Adsorption Mechanism and Findings | Biomass Characteristics of Vermicompost | Environmental Conditions (e.g., pH, Temperature) | Analytical Techniques Used | Key Observations and Conclusions | Study Reference |
|---|---|---|---|---|---|---|---|
| Vermicompost-filled reactors in continuous flow system | Pharmaceuticals (e.g., Ibuprofen) | Effective adsorption and degradation of Ibuprofen, showcasing the potential of vermicompost in pharmaceutical pollutant removal | Microbial population, enzymatic activity | Flow rate (4 L/h), Residence Time (12 h) | LC–MS, TOC, DGGE | Vermicompost demonstrated efficacy in both adsorption and degradation of pharmaceuticals | (Delgado-Moreno et al., 2021) |
| Vermicompost-bed reactors in wastewater treatment plant | Nutrient removal in wastewater | Nutrient removal via adsorption onto vermicompost, indicating its efficacy in improving water quality in wastewater treatment | Nutrient content, microbial biomass | pH (6.2), Temperature (25 °C) | Ion Chromatography, COD, NH3-N | Vermicompost exhibited potential for nutrient removal, contributing to wastewater treatment | (Das & Deka, 2021) |
| Vermicompost in batch experiments | Emerging pollutants (e.g., Endocrine disruptors) | Adsorption and degradation of endocrine disruptors attributed to the complex microbial and enzymatic activity within vermicompost | Enzyme activities, microbial diversity | pH (6.9), Temperature (27 °C) | GC–MS, qPCR, Enzyme Assays | Vermicompost displayed dual functionality, acting as an adsorbent and promoting pollutant degradation | (Bilal et al., 2017) |

waste, earthworms, and microorganisms. The floral waste serves as the substrate for decomposition, while earthworms play a vital role in stimulating microbial activity and nutrient cycling. Microorganisms present in the waste and introduced by the earthworms contribute to the breakdown of organic compounds and the release of essential nutrients (Verma et al., 2019). Outputs of the vermicomposting process include nutrient-rich vermicompost with enhanced soil conditioning qualities. The final product is characterized by increased nutrient availability, improved soil fertility, and a balanced microbial population. Vermicompost contains elevated concentrations of macro- and micronutrients, such as nitrogen, phosphorus, iron, manganese, copper, and zinc, which are essential for plant growth and development. The process also results in a reduction of the carbon-to-nitrogen ratio, indicating a more nutrient-rich and balanced product (He et al., 2016).

Research has shown that vermicomposting contributes significantly more nutrients than conventional composting (Rekha et al., 2018). As an illustration of a more effective conversion of organic nitrogen into forms that are accessible to plants, researchers discovered that the nitrogen concentration in vermicompost was greater than that in standard compost (Joshi et al., 2013). Vermicomposting has a beneficial effect on phosphorus, another essential nutrient. Earthworms play a vital function in mineralizing organic phosphorus into a form that is more soluble and accessible to plants. Another study showed a rise in phosphorus levels in vermicompost. Plant growth and development are benefited by the increased availability of phosphorus in vermicompost (Verma et al., 2019). Enhanced concentrations of micronutrients including iron, manganese, copper, and zinc are another attribute of vermicompost. Plant biochemical activities such as photosynthesis, enzyme activity, and disease resistance are significantly impacted by these micronutrients. In one of the study, author found that vermicompost had higher than average concentrations of micronutrients, suggesting that earthworms may allocate and collect these necessary components in a targeted manner. Vermicompost demonstrates enhanced nutritional ratios in addition to macro- and micronutrient content (Hussain & Abbasi, 2018). Vermicomposting tends to reduce the C:N ratio, which indicates a decrease in carbon relative to nitrogen and is a key measure of compost stability and maturity. This decrease results in a more nutrient-rich and balanced product, which is evidence of the microbial breakdown of complex organic molecules. The microbial population of vermicompost is influenced by the earthworms, which results in increased nutrient bioavailability. Earthworms promote the synthesis of enzymes that further decompose organic waste by increasing the diversity and activity of microorganisms in the vermicompost. Plant growth-promoting chemicals like auxins and cytokinins are released because of this microbial activity, which promotes root development and general plant vigour. The study examples highlight how vermicomposting is a successful method for creating an organic fertiliser that is rich in nutrients. The resultant vermicompost is a useful resource for boosting soil fertility, increasing nutrient availability, and encouraging strong plant development in agricultural and horticultural uses. It also provides a sustainable option for recycling floral debris (Hussain & Abbasi, 2018; Joshi et al., 2013; Rekha et al., 2018).

## 4 Dual-Functionality and Synergies

The utilization of floral waste (FW) presents a unique opportunity for sustainable waste management practices, particularly through the dual functions of biosorption and vermicomposting processes (Amari et al., 2023). Vermicomposting, a natural process facilitated by earthworms that transforms organic waste into nutrient-rich compost, and biosorption, which focuses on pollutant removal through adsorption onto biomaterials, synergistically offer a comprehensive waste management solution (Hussain & Abbasi, 2018). Floral waste, characterized by its high organic content and diverse functional groups, serves as an effective biomaterial in biosorption processes. The porous nature of floral waste provides a significant surface area for the adsorption of various contaminants, such as organic chemicals, dyes, and heavy metals. Numerous research studies have demonstrated the efficacy of floral waste in biosorption applications.

Moreover, the specific characteristics and properties of floral waste in the area further enhance its potential as a valuable biomaterial for adsorption processes and waste management practices. By emphasizing the unique attributes of floral waste, including its natural absorbent qualities and diverse composition, this waste material emerges as a promising resource for addressing environmental challenges. Integrating information on the specific properties of floral waste enriches the understanding of its role in waste management strategies, highlighting its capacity to effectively adsorb pollutants and contribute to sustainable practices (Samuel et al., 2013). For example, Amari et al. study from the previous year showed how well organic dyes could be removed from FW, highlighting the material's potential as a sustainable and natural adsorbent (Amari et al., 2023).

However, vermicomposting which is made possible by earthworms helps to change FW organically. Earthworms are essential for stimulating microbial activity and decomposing complex organic materials. The flower waste turns into nutrient-rich vermicompost with enhanced soil conditioning qualities because of the vermicomposting process. Research has demonstrated the beneficial effects of vermicompost on soil nutrient availability, lowering the bioavailability of heavy metals and increasing soil fertility. The complementary roles that biosorption and vermicomposting play together make them work well together. After being fully saturated with contaminants, the leftover biomass from biosorption can be fed into the vermicomposting system. Because the biosorbed waste is rich in organic matter, earthworms find it to be an excellent substrate for breaking down the residual organic contaminants and adding additional nutrients to the vermicompost. Resource recovery is maximised, and waste is reduced with this integrated strategy (Shen et al. 2022) (Fig. 3).

Furthermore, the biosorbent's physicochemical characteristics are improved by the vermicomposting process. Earthworm activity causes the material to become more aerated, which lowers the bulk density and increases porosity. Consequently, this improves the material's ability to biosorb. During the vermicomposting process, the interactions between earthworms and microorganisms foster the breakdown of contaminants that would have lingered in the biosorbed waste (Amari et al., 2023). The combined vermicomposting and biosorption method are in line with sustainable waste management and the circular economy. In addition to addressing the environmental issues raised by FW from different sources, it produces nutrient-rich vermicompost, which is a useful byproduct. The closure of material loops, where waste is converted into a resource through a series

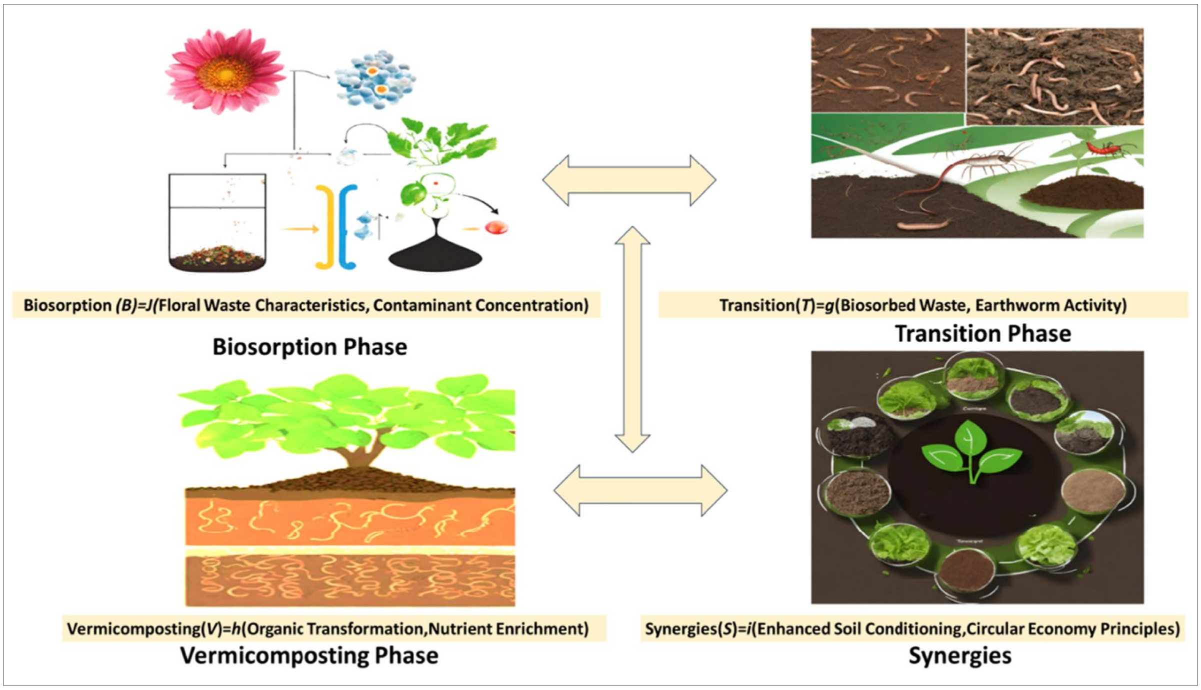


**Fig. 3** Conceptual Model of Dual-Functionality and Synergies

of linked and sequential processes is facilitated by this dual functioning. Thus, the mutualistic relationship between the vermicomposting and biosorption processes provides a comprehensive and long-term approach to the management. By combining these procedures, resource recovery, soil fertility, and pollution removal are all improved. Communities may adopt a cyclical and ecologically responsible strategy to waste management by recognising and utilising the synergies between biosorption and vermicomposting. This will enable Floral waste to be converted into a useful resource for horticultural and agricultural pursuits (Shen et al., 2022).

Through an integrated waste management strategy that is sustainable and has synergistic benefits for both biosorption and vermicomposting, FW may be used to mitigate environmental challenges and improve resource recovery. The system becomes dynamic and integrated as a result of each process's capabilities being utilized for both goals, improving overall efficacy. It functions as a proficient and organic pollutant adsorbent throughout the biosorption stage. It is simpler to remove contaminants like organic dyes and heavy metals from the trash due to its complex makeup, which is rich in organic compounds and functional groups. Research like the ones done by (Waghmode et al., 2018) demonstrate the biosorption capability of FW. They illustrate how well the waste can adsorb colours, which helps to reduce water pollution. The synergistic shift to vermicomposting becomes critical once the floral waste's biosorption capability exceeds a threshold. Earthworms find the contaminated leftover biomass from the biosorption process to be the perfect food source. In this stage, earthworms especially species such as Eisenia fetida have two functions. First, through their digestive processes, they aid in the breakdown of the residual organic contaminants in the biosorbed waste. Together, they lessen the number of pollutants and change the waste into a form that is less harmful. Moreover, by encouraging microbial activity and nutrient cycling, the earthworms' activities improve the vermicomposting process. The FW turns into nutrient-rich vermicompost after being enhanced by earthworm castings. The beneficial effects of vermicompost on soil nutrient availability were illustrated by (Rehman et al., 2023), illustrating how this integrated strategy improves soil fertility and offers a useful organic amendment. Beyond nutrient enrichment and pollution removal, there are further synergies. The physical structure of the biosorbed waste is improved during the vermicomposting process. As they go through the material, earthworms form holes and channels that improve the material's capacity to retain water and allow for aeration. This enhanced structure enhances the vermicompost's overall quality and elevates it to the status of an outstanding soil conditioner. Moreover, the technique of combining vermicomposting with biosorption is in line with zero-waste programmes and the circular economy. The total environmental effect is reduced since the trash produced in one process is used as fodder for the subsequent one. This integrated system produces a valuable resource that has uses in sustainable agriculture and horticulture, while also mitigating the negative effects of disposing of floral waste from different sources. The decrease in greenhouse gas emissions is another example of the synergistic effects. Research has indicated that vermicomposting helps to lower methane emissions by increasing microbial activity and decreasing the anaerobic breakdown of organic materials. The environmental advantages of using Floral waste are further enhanced when vermicomposting is incorporated into the entire waste management plan. These processes are interrelated, which not only solves the problems with floral waste from different sources but also provides an example of a cyclical and regenerative model for handling organic waste streams in many religious and cultural contexts. This strategy offers a workable and ecologically responsible solution that is consistent with the larger objectives of sustainable development, as demonstrated by earlier research (Shen et al., 2022).

## 5 Applications

Horticulture, improving soil health, and agriculture are just a few of the many uses for biosorbents from FW and vermicompost created by the complementary processes of biosorption and vermicomposting. These applications stem from the nutrient-rich composition of these organic materials, their enhanced ability to condition soil, and their capacity to eliminate contaminants. In agriculture, the biosorbent derived from remaining flowers can be applied as a long-term soil addition. Because the biosorbent has a high organic content and a range of functional groups, it increases soil fertility by providing crops with the necessary nutrients (Amari et al., 2023). Furthermore, the capacity of the biosorbent to absorb heavy metals reduces the possibility of metal buildup in crops, guaranteeing the production of clean and safe food. An environment that is favourable for plant development is fostered by the organic matter in the biosorbent, which also helps to retain water, enhance soil structure, and encourage microbial activity. After the vermicomposting phase, vermicompost is a powerful organic fertiliser with many uses in agriculture. The nitrogen, phosphorus, and potassium content of the vermicompost promotes the growth and development of plants. Vermicompost releases nutrients gradually, ensuring a steady supply throughout the crop growing season. This promotes balanced nutrition and lessens the need for synthetic fertilisers. The organic content in the vermicompost also improves soil structure, allowing for more root penetration and water infiltration (Lazcano & Dominguez, 1970, Ávila-Pozo, et al., 2022).

For horticulture, the biosorbent can be utilized in potting mixes and substrate formulations. Organic material makes an excellent supplement to growth media for potted plants due to its high nutritional value and capacity to hold water. The ability of the biosorbent to capture pollutants and maintain the cultivated ornamental plants free of toxins enhances their aesthetic appeal. This application supports sustainable horticultural practices by promoting the use of ecologically friendly surfaces for plant cultivation. Vermicompost is commonly utilized in landscape design and ornamental gardening. It is also known as "black gold" in horticultural circles. Bright, healthy plants flourish because of its high nutritional content and microbiological richness. Vermicompost is a perfect supplement for attractive gardens and landscapes because its humic compounds support root development, enhance soil structure, and boost water-holding capacity. Furthermore, vermicompost has been shown to strengthen plants' resilience to pests and diseases, highlighting its significance in sustainable gardening (Lim et al., 2015, Dey et al., 2023).

Table 3 provides an extensive summary of vermicompost and biosorbents that have been successfully used in real-world situations. The examples illustrate how these sustainable techniques may be used globally, spanning a variety of geographic locales. The use of vermicompost and biosorbent made from FW in agriculture has enhanced soil health, raised agricultural yields, and decreased need on synthetic fertilisers. In horticulture, the use of vermicompost in landscaping and biosorbents in potting mixes has led to better plants and a less environmental footprint. Furthermore, these organic materials' adaptability and efficacy in fostering ecologically friendly and regenerative activities are demonstrated by the successful remediation of polluted soils and the adoption of sustainable soil practises. Vermicompost and biosorbent both aid in the establishment of resilient and healthy soils in terms of improving soil health (Lim et al., 2015, Rehman et al., 2023). By absorbing contaminants during the biosorption phase, the biosorbent contributes to the preservation of soil quality and helps avoid soil contamination. By increasing microbial variety and activity, its absorption into soil supports biological processes in the soil. Because of its well-balanced nutritional content, vermicompost adds organic matter and vital nutrients to the soil, promoting a healthy soil ecology. Therefore, biosorbents made from vermicompost and Floral waste have a wide range of potential uses in horticulture, soil health enhancement, and agriculture. These organic materials provide long-term fixes for soil improvement, pollution removal, and nutrient replacement. Their wide range of advantages are consistent with the tenets of regenerative and sustainable agriculture, offering practitioners looking to increase crop yield, soil fertility, and ecosystem resilience more eco-friendly options (Waghmode et al., 2018, Shen et al., 2022).

## 6 Challenges and Considerations

The dual-purpose method of utilizing floral debris for both biosorption and vermicomposting has disadvantages even if it offers a viable substitute for waste management. These elements must be acknowledged and taken into consideration in order for this sustainable waste management plan to be executed and optimized. One of the main challenges is that flower debris's makeup is unpredictable. For the floral gifts, a wide variety of materials, including flowers, leaves, and other organic and inorganic objects, can be used. It is challenging to standardize the vermicomposting and biosorption processes due to the variety of

**Table 3** Applications and Success Stories of Biosorbents and Vermicompost in Agriculture, Horticulture, and Soil Health Improvement

| Application | Practical Example | Success Story | Notable Outcomes | Reference |
|---|---|---|---|---|
| Agriculture | Utilization of Biosorbent as Soil Amendment | Successful integration of FW biosorbent in agricultural soils resulted in increased crop yield and quality. The adsorption of heavy metals reduced the risk of metal uptake by crops, ensuring food safety | Increased crop yield, improved food safety | (Dey et al., 2023) |
| Agriculture | Adoption of Vermicompost as Organic Fertilizer | A farm incorporated vermicompost into their crop management practices, leading to a significant reduction in the need for synthetic fertilizers. This transition resulted in improved soil structure, enhanced water retention, and increased nutrient availability, ultimately boosting overall crop health | Reduced reliance on synthetic fertilizers, improved soil structure, enhanced crop health | (Lim et al., 2015) |
| Horticulture | Use of Biosorbent in Horticultural Substrates | The formulation of potting mixes incorporating the biosorbent from FW proved successful in horticultural nurseries. These substrates exhibited improved water retention and nutrient availability, resulting in healthier plants and reduced environmental impact | Healthier plants, reduced environmental impact | (Ávila-Pozo et al., 2022) |
| Horticulture | Landscaping with Vermicompost | A municipal landscaping project integrated vermicompost as a soil amendment. The project witnessed lush and vibrant plant growth, demonstrating the efficacy of vermicompost in enhancing soil fertility, promoting ornamental plant health, and reducing the need for chemical inputs | Lush and vibrant plant growth, enhanced soil fertility, reduced need for chemical inputs | (Lazcano & Dominguez, 1970) |
| Soil Health | Remediation of Contaminated Soils using Biosorbent | The application of FW biosorbent successfully rehabilitated contaminated soils, contributing to the restoration of soil health. The biosorbent's adsorption capabilities played a crucial role in reducing pollutant levels, allowing for sustainable land use and preventing further environmental degradation | Successful soil remediation, sustainable land use practices | (Amari et al., 2023) |

**Table 3** (continued)

| Application | Practical Example | Success Story | Notable Outcomes | Reference |
|---|---|---|---|---|
| Soil Health | Sustainable Soil Practices with Vermicompost | A farming cooperative implemented a vermicomposting system to manage organic waste and enhance soil fertility. The use of vermicompost resulted in improved soil health, increased microbial activity, and a noticeable reduction in synthetic fertilizer usage, aligning with sustainable agriculture practices | Improved soil health, increased microbial activity, reduced synthetic fertilizer usage | (Lim et al., 2015) |

the waste stream (Chang & Li, 2019). The creation of a one-size-fits-all solution may be complicated by the need for customised ways to maximise pollutant removal and organic transformation in various flower compositions. The contaminants contained in the flower debris determine how well biosorption works. Floral debris has shown promise in adsorbing organic pollutants and heavy metals, however the kind and number of contaminants it may absorb can differ. As a result, variations in the biosorption capacity may arise, hence requiring regular evaluations of the waste stream to guarantee stable levels of pollutant elimination effectiveness (Dutta & Kumar, 2022).

Furthermore, the scalability of the dual-functional model may give rise to logistical challenges. Large-scale vermicomposting plants or biosorption units require careful planning and infrastructure because different sources and other religious organizations produce FW in varied proportions. Ample space, financial resources, and community involvement are necessary for this technique to be successfully scaled up. The temporal component of the dual-functional process is another item to consider. The nature of the waste, the environment, and the efficiency of microbial and earthworm activities are some of the variables that affect the rates of pollutant removal and organic transformation in biosorption and vermicomposting. These processes are also time dependent. It is difficult to strike a balance between these processes' temporal features and the constant flow of FW, particularly during times of intense activity (Elango & Govindasamy, 2018). One potential drawback in the vermicompost is the persistence of contaminants and their possible buildup. Some stubborn contaminants might not completely decompose throughout the vermicomposting process, which would leave them in the finished product. Vermicompost quality must be carefully monitored and evaluated to guarantee that the finished product satisfies safety requirements for use in agriculture. Another factor that must be considered is the dual-functional approach's economic feasibility. Even though vermicompost is a useful final product, it is necessary to determine if setting up large-scale vermicomposting plants is economically feasible. Weighing the advantages against the expenses of personnel, infrastructure, and monitoring highlights the significance of creating cost-effective techniques for broad adoption.

Participation and awareness of the community are essential to the dual-functional approach's effectiveness (Sharma et al., 2021). Essential elements include clearing up any misunderstandings, educating the public about the advantages this method has for the environment, and promoting active involvement in trash separation at the source. Careful community participation and information efforts may also be necessary to overcome cultural or religious sensitivities toward the usage of flower debris in these operations (Sharma et al., 2018).

Careful planning is necessary for FW management in order to scale up the dual-functional concept and encourage sustainability, community involvement, and efficiency. The method can only be made scalable if a robust infrastructure capable of handling varying FW quantities is built. Modular solutions that can be adjusted to diverse waste compositions and scales are essential to handle the erratic nature of offers. For this strategy to scale successfully, community involvement and awareness are crucial. Building connections with local governments, religious organizations, and waste management authorities is essential to gaining support and promoting trash segregation at the source. People can be encouraged to actively participate in the separation of FW by participating in community outreach activities and educational projects that aim to debunk myths and instil a feeling of responsibility (Singh et al., 2018). A consideration of the financial side is necessary for the dual-functional approach to be adopted more widely. It is crucial to evaluate the financial sustainability of large-scale vermicomposting operations and biosorption units, with an emphasis on maximising the value of final products like vermicompost, lowering expenses, and maximising resource use. Incentives for communities and creative finance schemes might improve the economic viability of scaling up. In addition, further research and development work should be done to improve the dual-functional process for the best possible removal of pollutants and organic transformation. It is essential to comprehend the differences in pollutant profiles and its compositions found in different sources to customise the technique for various waste streams and geographical areas. It will take ongoing observation and flexible thinking to overcome obstacles and improve the scalable system's effectiveness (Waghmode et al., 2018).

## 7 Future Directions

Future research and development in the subject of FW management could go in a number of interesting directions to increase the sustainability and effectiveness of the dual-functional approach. Optimizing the vermicomposting and biosorption processes according to the diverse compositions of floral waste from different sources is an important path to take. Understanding how variations in flower arrangements affect the dual-functional system's efficacy will make it easier to create customized solutions for diverse waste streams that ensure flexibility in a variety of cultural and geographic contexts. Examining cutting-edge technologies and innovative methods for pollution analysis in floral debris from various sources is another crucial area. Real-time data on pollutant concentrations may be obtained by integrating sensors and analytical tools, which enables more accurate biosorption phase monitoring and control. This technical breakthrough would improve the dual-functional approach's overall effectiveness and help produce more precise pollutant removal estimates. The possible uses of biosorbents and vermicompost in specialised fields like phytoremediation and environmentally friendly packaging might be the subject of future studies. Examining the application of biosorbents as supplements in phytoremediation procedures can improve plants' capacity to draw contaminants out of polluted soils. Furthermore, investigating the incorporation of waste-based components from flowers into environmentally friendly packaging might provide a sustainable substitute and lessen the impact of packaging materials on the environment. Future studies should examine the creation of community-based models for FW management, taking socio-economic factors into account. Examining incentive schemes, cooperative structures, and community-led projects can promote sustainability and higher levels of engagement. Tailoring solutions that align with community beliefs and traditions will be made easier with an understanding of the socio-cultural aspects impacting waste management practises in religious organisations. Moreover, a comprehensive strategy is provided by investigating the linkages between the management of FW and other sustainable activities like urban gardening and circular economy projects. Examining the potential integration of nutrient-rich vermicompost into urban agricultural systems or circular economy loops might enhance the overall, linked strategy for sustainable waste management.

The dual-functional approach to FW management has important implications for sustainable waste management on a larger scale. This approach lessens the quantity of waste that is dumped in landfills and lessens the harm that conventional waste disposal methods provide to the environment. FW becomes useful resources through the processes of biosorption and vermicomposting. This method aligns with the principles of the circular economy, which view waste as a resource rather than a strain on ecosystems. Temple practices established a sustainable waste management approach that can be applied by international cultural and religious institutions. This method's guiding concepts of resource recovery, waste reduction, and community involvement may be applied in a variety of contexts to promote a wider change in the direction of sustainable waste management techniques. The creation of culturally aware and situation-specific waste management plans that are appealing to communities all over the world can be influenced by the lessons learnt from the management of floral waste at different sources. Moreover, the dual-functional strategy has the capacity to tackle wider environmental issues, especially in metropolitan regions. By using the nutrient-rich vermicompost that is created, urban agriculture may increase the production of food locally and lessen the need for artificial fertilisers. By improving food security and bolstering the resilience of urban ecosystems, this integration supports the objectives of sustainable urban development. The sustainable waste management strategy has the potential to open new business and employment possibilities from an economic standpoint. Building vermicomposting sites and biosorption units can help communities become more resilient economically by creating jobs. Furthermore, nutrient-rich vermicompost production and sales can boost regional economies by lowering the demand for outside inputs in agriculture. There are societal benefits to the wider adoption of sustainable waste management techniques inspired by FW management. As essential elements of the dual-functional approach, increased community participation and understanding may help people develop a feeling of accountability and environmental stewardship. This change in viewpoint has the potential to impact communities' more widespread sustainable habits and lifestyles, going beyond trash management. This model's included circular economy, community involvement, and resource recovery concepts have the potential to greatly aid in the global development of comprehensive and sustainable waste management systems.

## 8 Conclusion

This article highlights the revolutionary potential of biosorption and vermicomposting as dual-functional techniques for managing FW. Beyond its conventional categorization as a byproduct, FW reveals itself to be an important and underutilized resource that offers innovative solutions to contemporary waste management issues. The biosorption phase of this investigation successfully extracts organic contaminants and heavy metals from the waste, demonstrating FW's potential for environmental remediation. Vermicomposting is a long-term, sustainable method that produces nutrient-rich vermicompost from biosorbed waste, making it an excellent choice for soil enrichment in horticulture and agriculture. It's evident how adaptable FW is as a valuable resource, demonstrating how it can address a range of environmental problems while increasing agricultural productivity. Instead of only using FW as a waste management strategy, this study suggests that it could be a symbol of harmony between contemporary ecological ideals and cultural legacy. the awareness of FW as a multifaceted resource that encourages a shift in the way society views and manages waste. It stands for more than just cutting waste; it also foresees the emergence of an all-encompassing culture that fosters economic growth, environmental preservation, and community involvement. The dual-functional approach to waste management that is put forward here calls for a paradigm shift in how society views trash and goes beyond the lab or field. This method views trash as a resource for ecosystem regeneration rather than as a burden. This result serves as a wake-up call for the implementation of sustainable waste management practices, spurred by the lessons learned from FW management. Moreover, how society views waste management processes is influenced by various factors, and by elaborating on these influences, the explanation is enhanced. Also, it revealed the interrelationships between inner structures and the external environment, delving into the reasons behind these observations. Using these strategies successfully requires teamwork. Communities, political institutions, and religious organizations must collaborate in order to adopt and disseminate these sustainable practices. By doing this, we support a worldwide movement that seeks to build circular economies, resilient ecosystems, and a sustainable future. In addition to addressing the pressing need to conserve the environment, this movement aims to respect cultural customs. Now is the moment to act. By putting our traditions' knowledge to use, we provide the framework for a more harmonious and long-lasting coexistence with the natural world. By acknowledging that floral waste serves two purposes, we set out on a path toward environmental equilibrium in which trash propels advancement and our combined efforts build a more connected and sustainable society.

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**Declarations**

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## References


Amalina, F., Razak, A. S. A., Krishnan, S., Zularisam, A. W., & Nasrullah, M. (2022). Dyes removal from textile wastewater by agricultural waste as an absorbent – A review. *Cleaner Waste Systems, 3*, 100051.

Amari, A., Yadav, V. K., Pathan, S. K., Singh, B., Osman, H., Choudhary, N., Khedher, K. M., & Basnet, A. (2023). Remediation of Methyl Red Dye from Aqueous Solutions by Using Biosorbents Developed from Floral Waste. *Adsorption Science & Technology, 2023*, 1532660.

Ávila-Pozo, P., Parrado, J., Caballero, P., & Tejada, M., (2022). Use of a Biostimulant Obtained from Slaughterhouse Sludge in a Greenhouse Tomato Crop. Horticulturae 8 DOI: https://doi.org/10.3390/horticulturae8070622.

Bhattacharyya, K. G., SenGupta, S., & Sarma, G. K. (2014). Interactions of the dye, Rhodamine B with kaolinite and montmorillonite in water. *Applied Clay Science, 99*, 7–17.

Bilal, M., Asgher, M., Iqbal, H. M., Hu, H., & Zhang, X. (2017). Bio-based degradation of emerging endocrine-disrupting and dye-based pollutants using cross-linked enzyme aggregates. *Environmental Science and Pollution Research International, 24*(8), 7035–7041.

Chang, C.-C., & Li, R. (2019). Agricultural waste. *Water Environment Research, 91*(10), 1150–1167.

Daffalla, S.B., Mukhtar, H., Shaharun M.S., & Hassaballa, A.A., (2022) Fixed-Bed Adsorption of Phenol onto Microporous Activated Carbon Set from Rice Husk Using Chemical Activation. Applied Sciences 12 DOI: https://doi.org/10.3390/app12094354.

Das, D., & Deka, H. (2021). Vermicomposting of harvested waste biomass of potato crop employing Eisenia fetida: Changes in nutrient profile and assessment of the maturity of the end products. *Environmental Science and Pollution Research, 28*(27), 35717–35727.

Delgado-Moreno, L., van Dillewijn, P., Nogales, R., & Romero, E., (2021). Straw-Based Biopurification Systems to Remove Ibuprofen, Diclofenac and Triclosan from Wastewaters: Dominant Microbial Communities. Agronomy 11 DOI: https://doi.org/10.3390/agronomy11081507.

Dey, S., Taraka Naga Veerendra, G., Anjaneya Babu Padavala, S.S., Phani Manoj A.V., (2023). Evaluate the use of flower waste biosorbents for treatment of contaminated water. Water-Energy Nexus 6: 187-230

Dutta, S. and Kumar, M. S., (2022). Characterization of floral waste as potential candidates for compost and biofuel production. Biomass Conversion and Biorefinery.

Elango, G., & Govindasamy, R. (2018). Analysis and utilization of temple waste flowers in Coimbatore District. *Environmental Science and Pollution Research, 25*(11), 10688–10700.

He, X., Zhang, Y., Shen, M., Zeng, G., Zhou, M., & Li, M. (2016). Effect of vermicomposting on concentration and speciation of heavy metals in sewage sludge with additive materials. *Bioresource Technology, 218*, 867–873.

Hong, J., Lin, B., Hong, G. B., & Chang, C. T. (2014). Study on the methylene blue adsorption from wastewaters by pore-expanded calcium fluoride sludge adsorbent. *Journal of Nanoscience and Nanotechnology, 14*(4), 3247–3251.

Hosseini, S. S., Hamadi, A., Foroutan, R., Peighambardoust, S. J., & Ramavandi, B. (2022). Decontamination of Cd2+ and Pb2+ from aqueous solution using a magnetic nanocomposite of eggshell/starch/Fe3O4. *Journal of Water Process Engineering, 48*, 102911.

Hussain, N. and Abbasi, S.A., (2018). Efficacy of the Vermicomposts of Different Organic Wastes as "Clean" Fertilizers: State-of-the-Art. Sustainability 10 DOI: https://doi.org/10.3390/su10041205.

Hussain, O. A., Hathout, A. S., Abdel-Mobdy, Y. E., Rashed, M. M., Abdel Rahim, E. A., & Fouzy, A. S. M. (2023). Preparation and characterization of activated carbon from agricultural wastes and their ability to remove chlorpyrifos from water. *Toxicology Reports, 10*, 146–154.

Joshi, R., Vig, A. P., & Singh, J. (2013). Vermicompost as soil supplement to enhance growth, yield and quality of Triticum aestivum L.: A field study. *International Journal of Recycling of Organic Waste in Agriculture, 2*(1), 16.

Karić, N., Maia, A. S., Teodorović, A., Atanasova, N., Langergraber, G., Crini, G., Ribeiro, A. R. L., & Đolić, M. (2022). Bio-waste valorisation: Agricultural wastes as biosorbents for removal of (in)organic pollutants in wastewater treatment. *Chemical Engineering Journal Advances, 9*, 100239.

Kumari, S., Kothari, R., Kumar, V., Kumar, P., & Tyagi, V. V. (2021). Kinetic assessment of aerobic composting of flower waste generated from temple in Jammu, India: A lab-scale experimental study. *Environmental Sustainability, 4*(2), 393–400.

Lazcano, C., & Dominguez, J. (1970). Effects of vermicompost as a potting amendment of two commercially-grown ornamental plant species. *Spanish Journal of Agricultural Research, 8*(4), 1260–1270.

Lim, S. L., Wu, T. Y., Lim, P. N., & Shak, K. P. (2015). The use of vermicompost in organic farming: Overview, effects on soil and economics. *Journal of the Science of Food and Agriculture, 95*(6), 1143–1156.

Mohammadi-Moghadam, F., Khodadadi, R., Sedehi, M., & Arbabi, M. (2022). Bioremediation of Polycyclic Aromatic Hydrocarbons in Contaminated Soils Using Vermicompost. *International Journal of Chemical Engineering, 2022*, 5294170.

Osman, A. I., El-Monaem, E. M. A., Elgarahy, A. M., Aniagor, C. O., Hosny, M., Farghali, M., Rashad, E., Ejimofor, M. I., López-Maldonado, E. A., Ihara, I., Yap, P.-S., Rooney, D. W., & Eltaweil, A. S. (2023). Methods to prepare biosorbents and magnetic sorbents for water treatment: A review. *Environmental Chemistry Letters, 21*(4), 2337–2398.

Rehman, S.U., De Castro, F., Aprile, A., Benedetti, M., and Fanizzi, F.P., (2023) Vermicompost: Enhancing Plant Growth and Combating Abiotic and Biotic Stress. Agronomy 13 DOI: https://doi.org/10.3390/agronomy13041134.

Rekha, G. S., Kaleena, P. K., Elumalai, D., Srikumaran, M. P., & Maheswari, V. N. (2018). Effects of vermicompost and plant growth enhancers on the exo-morphological features of Capsicum annum (Linn.) Hepper. *International Journal of Recycling of Organic Waste in Agriculture, 7*(1), 83–88.

Samuel, J., Pulimi, M., Paul, M. L., Maurya, A., Chandrasekaran, N., & Mukherjee, A. (2013). Batch and continuous flow studies of adsorptive removal of Cr(VI) by adapted bacterial consortia immobilized in alginate beads. *Bioresource Technology, 128*, 423–430.

Shahawy, A. E., S. R. Al-Mhyawi, M. F. Mubarak, A. E. Mousa and A. H. Ragab (2022) "Rice Straw as Green Waste in a HTiO2@AC/SiO2 Nanocomposite Synthesized as an Adsorbent and Photocatalytic Material for Chlorpyrifos Removal from Aqueous Solution." Catalysts 12 DOI: https://doi.org/10.3390/catal12070714.

Sharma, D., & Yadav, K. D. (2018). Application of rotary in-vessel composting and analytical hierarchy process for the selection of a suitable combination of flower waste. *Geology, Ecology, and Landscapes, 2*(2), 137–147.

Sharma, D., Yadav, K. D., & Kumar, S. (2018). Biotransformation of flower waste composting: Optimization of waste combinations using response surface methodology. *Bioresource Technology, 270*, 198–207.

Sharma, D., Pandey, A. K., Yadav, K. D., & Kumar, S. (2021). Response surface methodology and artificial neural network modelling for enhancing maturity parameters during vermicomposting of floral waste. *Bioresource Technology, 324*, 124672.

Shen, Z., Yu, Z., Xu, L., Zhao, Y., Yi, S., Shen, C., Wang, Y., Li, Y., Zuo, W., Gu, C., Shan, Y., Bai, Y., (2022) Effects of Vermicompost Application on Growth and Heavy Metal Uptake of Barley Grown in Mudflat Salt-Affected Soils. Agronomy 12 DOI: https://doi.org/10.3390/agronomy12051007.

Singh, A., Jain, A., Sarma, B. K., Abhilash, P. C., & Singh, H. B. (2013). Solid waste management of temple floral offerings by vermicomposting using Eisenia fetida. *Waste Management, 33*(5), 1113–1118.

Singh, J., & Kaur, A. (2015). Vermicompost as a strong buffer and natural adsorbent for reducing transition metals, BOD, COD from industrial effluent. *Ecological Engineering, 74*, 13–19.

Singh, P., Singh, R., Borthakur, A., Madhav, S., Singh, V. K., Tiwary, D., Srivastava, V. C., & Mishra, P. K. (2018). Exploring temple floral refuse for biochar production as a closed loop perspective for environmental management. *Waste Management, 77*, 78–86.

Srivastav, A. L., & Kumar, A. (2021). An endeavor to achieve sustainable development goals through floral waste management: A short review. *Journal of Cleaner Production, 283*, 124669.

Verma, A. K., Sindhu, S. S., Singh, A., Kumar, A., Singh, A., & Chauhan, V. B. S. (2019). Conditioning effects of biodegradable superabsorbent polymer and vermi-products on media properties and growth of gerbera. *Ecological Engineering, 132*, 23–30.

Waghmode, M. S., Gunjal, A. B., Nawani, N. N., & Patil, N. N. (2018). Management of Floral Waste by Conversion to Value-Added Products and Their Other Applications. *Waste and Biomass Valorization, 9*(1), 33–43.

Yadav, K. D., Sharma, D., & Prasad, R. (2022). *5 - Challenges and opportunities for disposal of floral waste in developing countries by using composting method* (pp. 55–77). Elsevier.


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