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Bioconversion of Temple Floral Waste Through Vermicomposting and Composting: A Review of the Available Evidence

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Abstract— *Temple floral waste (TFW) is a significant and poorly managed waste stream in India, where flowers and other organic waste products are typically dumped into rivers and other water bodies. Primary research on vermicomposting and aerobic composting as alternatives to this practice is limited. Temple floral wastes have been used in vermicomposting trials with Eisenia fetida, which have demonstrated that the waste can be transformed into a stable product with a nutrient content that is comparable to or better than that of kitchen or farmyard wastes, and for which the nitrogen, phosphorus, and potassium content has been measured in some studies. Similarly, aerobic non-vermicomposting trials have shown that the C:N ratio is reduced and compost matures in approximately 60 days using bin-composting methods. Some scientists reviewed the behaviour of heavy metals in vermicomposting in general (not specifically for floral waste) and found that the availability of metals in vermicomposting is not always the same and depends on the feedstock and co-substrate used. In addition to composting, other valorisation possibilities for floral waste have been explored, such as using it as a precursor for activated carbon and biochar through pyrolysis, indicating that there are more potential applications than just composting. This review summarizes these individual findings, makes no bones about the lack of directly relevant published studies, and refrains from making general statements about the field based on specific numeric results from one small study.*

Keywords— ***Temple Floral Waste, Vermicomposting, Biochar, Activated Carbon, Circular Economy***

I. INTRODUCTION

Flower offerings are a regular and massive source of organic waste in India, especially in religious contexts. The flowers offered to a deity are considered sacred and are not normally disposed of in the regular municipal waste disposal system, but are often thrown into rivers, lakes, or other water bodies (Gupta, et al. 2023). This practice is widely reported to be a major source of organic pollution loading in urban water bodies, but it is difficult to find precise, verified national tonnage figures, and there are significant differences between the figures reported in the literature and in reporting on the subject, depending on what is counted and how. This review does not repeat an unverified precise figure as if it were an agreed scientific estimate, but simply points out that the scale is large and that source-segregated floral waste is a recognisable and recurring waste category in Indian cities, especially in the vicinity of major temple complexes. The major flowers mentioned in the literature as the temple floral waste are marigold (*Tagetes erecta*), rose (Rosa spp.), jasmine (Jasminum spp.), hibiscus, and lotus, which varies according to region and season (Gupta et al., 2023; Elango & Govindasamy. 2018). This waste is mostly biodegradable, organic, and produced at known and concentrated locations (individual temples) and hence has been a subject of research as a potential feedstock for composting and vermicomposting instead of river disposal. This review consolidates the key studies that specifically focus on the use of temple or religious floral waste as a feedstock for vermicomposting or composting and a few related studies on valorisation of floral waste (activated carbon, biochar). It does not explicitly state that it has a large evidence base from systematic reviews, as based on the literature search carried out for this revision, this evidence base is not yet available at scale for this waste stream. If there is evidence from general vermicomposting or composting literature (e.g. heavy metal behaviour), this is clearly indicated as general and not floral-waste-specific evidence.

The amount of floral waste produced daily from religious institutions, known as "Nirmalya," is a major environmental problem, and researchers are investigating different sustainable management options. After considering these options, Devi et al. (2022) pointed out general flower waste management frameworks, and Bennurmath et al. (2021) emphasized novel green approaches that aim to maximize the use of these organic resources instead of letting them rot in landfills. In addition to general waste frameworks, the specific nature of the generation of flower waste from temples requires targeted interventions, and in this context, Kumar et al. (2020) assessed the methods for management and sustainable energy generation from flower waste directly collected from temples. Traditional and biological processing methods have been compared in detail for the conversion of this particular biomass to value-added agricultural inputs. For example, Chakole and Jasutkar (2014) did a comparative study on the effectiveness of vermicomposting and artificial aeration composting of Nirmalya solid waste. In addition to earthworms, other biological accelerators have been tested, such as the use of a specialized microbial consortium from cow dung, which was successfully used for bioconversion of floral waste into high-quality biocompost by Gorasiya and Faldu (2023). In conclusion, these ecological solutions are not just about waste management; they are about a colorful solution that can contribute to sustainable environmental practices and viable small business models, as Saini et al. (2025) highlighted.

II. METHODOLOGY OF THIS REVIEW

The sources were identified by using targeted search terms such as "temple floral waste," "flower waste," "vermicomposting," and "composting" in the search field of the publisher's website (ScienceDirect, SpringerLink, ACS Publications) and/or a reputable indexing service (Semantic Scholar) to verify authorship, journal, volume, and, if available, DOI. Only sources that were able to be verified as real, existing, findable publications were kept. Sources that were not independently found and verified were not included on trust. This is more limited and less ambitious than a formal systematic review with a pre-registered protocol, and is presented as such, not as a full-blown meta-analysis.

III. VERMICOMPOSTING OF TEMPLE FLORAL WASTE

Singh et al. (2013) in Waste Management vermicompost temple flower waste with *Eisenia fetida* and directly compared the vermicompost with kitchen waste and farmyard waste vermicompost. The study revealed that earthworm biomass was maximum in the vermicompost produced from temple-waste at 40-day and 120-day sampling points, and the physicochemical parameters (electrical conductivity, C/N, C/P, total potassium) were more favourable in the vermicompost produced from temple-waste. The 10% water extract of the temple-waste vermicompost was stimulatory for seed germination of chickpea, and pot trials revealed that the 12.5% vermicompost-to-soil ratio resulted in higher shoot length, root length, secondary root number, and total biomass as compared to other waste streams tested. Sannigarahi and Sannigrahi, 2018 small-scale study, Bombax ceiba flower waste was vermicompost with cow dung in 1:1 ratio for 57 days using *Eisenia fetida,* and the final vermicompost was found to contain 1.13% N, 0.48% P, 2.68% K, 0.55% Ca, 0.69% S, and 2.29% Na. The same study also revealed that the nutrient content of the final product could be further enhanced by adding small amounts of urea, rock phosphate, and Mahua seed cake as amendments during the bed preparation, and that vermicomposting was possible even with reduced or no cow dung; however, the ratio of flower to dung influenced the efficiency of the process. The study on temple floral waste from Jaipur revealed that the ratio of flower waste to bulking material (50:50 to 90:10), which produced the highest bioconversion efficiency into vermicompost, was 60:40, with marigold as the predominant type of flower, which is the common trend in temple floral waste in India (Tiwari et al. 2016).

IV. AEROBIC (NON-VERMI) COMPOSTING OF TEMPLE FLORAL WASTE

Kumari, et al. (2021) studied aerobic bin composting of temple flower waste collected from Mahan Shiv Parvati temple, Jammu, in a 20 kg capacity aerated bin along with cow dung in a 1:3 ratio for 60 days. The study found a significant decrease in the C:N ratio during the composting period, and the kinetic modelling of the degradation rate of the organic matter showed that the aerobic valorisation approach resulted in a compost of acceptable quality within the two months. As far as the verification work that has been done for this review, this is one of the few published studies that specifically modelled the kinetics of temple floral waste composting (not vermicomposting).

Table 1. Summary of directly relevant published vermicomposting and composting trials on temple/religious floral waste identified and verified for this review. Figures are as reported in the original studies; readers using this table for a formal submission should consult the primary sources directly to confirm exact wording and any units before citing.

Study	Feedstock	Species/Method	Duration	Key reported outcome
Singh et al. (2013)	Temple floral offerings vs. kitchen waste and farmyard waste	*Eisenia fetida*	40 and 120 days	Highest earthworm biomass in temple-waste vermicompost; improved EC, C/N and C/P; 10% vermicompost extract stimulated chickpea germination
Sannigarahi and Sannigrahi, (2018)	Study on Bombax ceiba flower waste (vermicomposting with cow dung) Bombax ceiba flowers + cow dung (1:1)	*Eisenia fetida*	57 days	Final vermicompost: 1.13% N, 0.48% P, 2.68% K, 0.55% Ca, 0.69% S, 2.29% Na; urea/rock phosphate/Mahua cake amendments improved nutrient status
Tiwari et al. (2016)	Jaipur temple floral waste study: Marigold-dominated mixed temple flowers	Vermicomposting, multiple flower: bedding ratios (50:50–90:10)	Not fully reported in abstract	Best bioconversion ratio at 60:40 flower-waste-to-bulking-material proportion
Kumari, Kothari, Kumar et al. (2021)	Temple flower waste + cow dung (1:3)	Aerobic composting (bin composting)	60 days	Significant reduction in C:N ratio; kinetic modelling of the aerobic valorization process; final germination index consistent with matured compost

V. VERMICOMPOSTING VERSUS CONVENTIONAL COMPOSTING: GENERAL EVIDENCE

Since there is no literature comparing vermicomposting and conventional thermophilic composting of temple flowers on the same batch of flowers, this section is based on the literature available on the general comparison of organic waste composting. Lim, et al. (2016) discussed the mechanisms, benefits, and drawbacks of both technologies and concluded that both technologies could be considered to achieve the general objective of cleaner production, but that they have different operating temperature ranges, feedstock toxicity, and typical scales of application. Table 2 lists the general (not floral-waste-specific) points of comparison most relevant to a prospective temple-waste operator who is considering the two approaches.

VI. EARTHWORM SPECIES USED IN VERMICOMPOSTING OF ORGANIC AND FLORAL WASTE

The vermicomposting studies mentioned above have mostly used *Eisenia fetida* (the red wiggler or brandling worm), the most common epigeic species used in vermicomposting research in general, because of its tolerance of a variety of temperatures and moisture levels and its availability as a commercial culture. Two studies directly relevant to vermicomposting of temple-floral-waste were found in this review, both of which used *Eisenia fetida*. Other epigeic species, such as *Eudrilus eugeniae* and *Perionyx excavatus*, have been successfully used in other types of organic waste streams. Gómez-Brandón, Lores, et al, (2012) in particular showed that different epigeic species leave measurably different microbial fingerprints on the same starting substrate during the earliest stages of decomposition. No comparative trial was found in the literature that compared multiple species of earthworms on temple floral waste specifically during this review, which is another evidence gap that is easily addressable, as the infrastructure to conduct such a trial (vermi-beds, standard physicochemical assays) is already well established in the broader literature and would simply need to be applied to this feedstock.

Table 2. General comparison of conventional composting and vermicomposting, drawn from broader organic-waste literature not specific to temple floral waste. Percentages for nitrogen loss and greenhouse gas emissions are from Nigussie et al. (2016); operational trade-off characterisations are drawn from Lim, Lee, and Wu (2016).

Attribute	Conventional (thermophilic) composting	Vermicomposting
Primary decomposition agents	Thermophilic and mesophilic microorganisms; process passes through a high-temperature phase	Earthworms and their gut microbiota acting together with mesophilic microorganisms; process stays mesophilic
Typical duration	Weeks to a few months, depending on turning frequency and aeration	Similar or somewhat longer active-phase duration, plus a separate maturation phase
Nitrogen loss / GHG profile (general findings, Nigussie et al. 2016)	Higher nitrogen loss and higher nitrous oxide and methane emissions reported relative to vermicomposting	10–20% lower nitrogen loss; 25–36% lower N2O; 22–26% lower CH4; CO2 emissions can be 3–14% higher at high earthworm density
Reported operational trade-offs (Lim, Lee, & Wu, 2016)	Generally lower sensitivity to toxic/high-salinity feedstocks; simpler to operate at large scale	More sensitive to feedstock toxicity, temperature extremes, and moisture; requires earthworm husbandry and monitoring, but can yield a more market-favoured product

VII. REAL-WORLD OPERATIONAL EXAMPLES

Beyond the peer-reviewed literature cited above, there are several operating social enterprises and municipal programmes in India that report significant scale of flower waste processing, most prominently in Uttar Pradesh, where flower waste collected from temples and mosques along the Ganga has been used to produce incense products and other value-added goods as part of river-clean-up linked social enterprise initiatives. These operations are well documented in mainstream and trade press and by international organizations on environmental social enterprise, but as far as this review's search was able to determine, have not published peer-reviewed process data (nutrient content, C:N kinetics, throughput economics) in the scientific literature in the way the academic studies in Sections 3–5 have. For this reason, this review simply notes their existence as evidence that in practice, temple floral waste processing is operationally viable at some scale, but does not cite any operational metric from these sources as if it were peer-reviewed scientific data.

VIII. REGULATORY AND POLICY CONTEXT IN INDIA

The Solid Waste Management Rules, 2016, under the Ministry of Environment, Forest and Climate Change, mandate source segregation of solid waste and promote in-situ or decentralized processing of organic solid waste, including temple floral waste, but do not specifically identify it as a legal category and specify a particular method for its processing. In many places, flowers presented in worship are not considered as ordinary waste and have not been traditionally segregated and collected in the regular municipal waste management system, but are still thrown into the river or water body, as a cultural practice in addition to the formal waste rules. This leaves a certain policy gap: While there is a generic solid-waste-management regulation, which offers a framework for the processing of organic waste in general, it does not address the cultural-practice aspect that is specific to floral offerings. This is not to say that a dedicated national regulatory instrument has not been used to bridge that gap in practice, but, as noted in Section 8, the operational examples cited here indicate that it has come more from targeted local social-enterprise and temple-management partnerships than from a dedicated national regulatory instrument, and this is an area better suited to future targeted research than to a citation-backed claim here.

IX. MICROBIAL ECOLOGY AND ENZYME DYNAMICS DURING VERMICOMPOSTING

Hujuri, et al. 2023 found in this search specifically sequenced the microbial community of temple-floral-waste vermicompost, so this section is based on the general vermicomposting literature and is so indicated. It is known that earthworms modify the microbial community of any substrate they ingest and digest, mainly through gut-associated processes, and then through a cast-associated maturation phase after the material has passed through the earthworm (Domínguez, et al., 2021). Domínguez et al. (2021) conducted a high-throughput sequencing study of sewage-sludge vermicomposting and found that the vast majority of bacterial and fungal taxa present in the raw sludge (96% and 91%, respectively) were not detected after passing through the earthworm gut, but were replaced by a different, more diverse community during the cast-maturation stage. This finding is for sewage sludge, not for flowers as a substrate, but it does show a general mechanism (significant microbial turnover in the gut) that is likely to occur during vermicomposting of flowers as well. Gómez-Brandón, et al., (2012) demonstrated that the effect of earthworms on the structure of the microbial community in the very early stages of the decomposition of organic matter is species-specific: different species of epigeic earthworms leave different microbial fingerprints on the same starting material, which is one reason why the choice of species (*Eisenia fetida* versus *Eudrilus eugenae* versus other epigeic species) is considered a meaningful experimental variable in the vermicomposting literature rather than an interchangeable detail. Along with microbial counts, enzyme activity is often used as a functional for the progress of decomposition. Ganguly and Chakraborty (2021) used toxic paper-mill waste instead of floral waste and monitored a definite sequence of enzyme activities and microbial biomarkers during the vermicomposting process with the earthworm Perionyx excavatus and suggested that the sequence of enzyme activities and microbial biomarkers can be used to assess the extent of vermicomposting of a particular batch. This would be a specific study for temple floral waste and is identified here as an open research question, not a finding for this substrate, as no such study was found during this review.

X. NUTRIENT DYNAMICS AND MATURITY INDICATORS

Commonly measured parameters in the temple-floral-waste studies in Sections 3 and 4 include nitrogen, phosphorus and potassium content, electrical conductivity and the carbon-to-nitrogen (C:N) ratio, and germination index is sometimes used as an indirect measure of phytotoxicity and maturity. The 57-day vermicompost in Bombax ceiba flower-waste trial contained 1.13% N, 0.48% P and 2.68% K, along with measurable calcium, sulphur and sodium, and supplementing the vermi-bed with small amounts of urea, rock phosphate and Mahua seed cake further shifted the nutrient outcome, suggesting that co-amendments can be used to meaningfully alter the nutrient outcome independent of the flower waste itself. The results of Singh et al. (2013) showed that the temple-waste vermicompost had a higher electrical conductivity, C/N and C/P ratios than the kitchen-waste and farmyard-waste vermicompost at both the sampling points, indicating that floral waste is, if not a better feedstock, at least a comparable one to the more widely studied kitchen and farmyard wastes. A general rule of thumb that is often cited in the composting literature is that a germination index of greater than about 50% is indicative of a compost that is free of phytotoxicity, and greater than about 80% is indicative of a well-matured compost; this rule of thumb comes from older general composting maturity research and not from any floral-waste-specific study; readers citing a specific germination-index threshold for temple floral waste compost should trace it back to its original general-composting source, not to a floral-waste study that does not exist. The Jammu aerobic composting trial (Kumari et al., 2021) explicitly modelled the C:N reduction process over 60 days for the temple flower waste mixed with cow dung, and provided one of the only data points on the rate of change of this indicator for a flower waste under aerobic (non-vermi) conditions, moving towards a mature-compost range.

XI. HEAVY METALS IN VERMICOMPOSTING: GENERAL EVIDENCE

No study was found for this review that reported heavy-metal analysis specific to temple floral waste vermicompost. The most relevant available evidence is the more general survey by Swati and Hait (2017) in Process Safety and Environmental Protection of heavy-metal fate and bioavailability in various organic wastes during vermicomposting in general. Their main conclusion is that the bioavailability of a particular metal does not always increase or decrease as a result of vermicomposting, but varies depending on the feedstock, co-substrate, and metal. This review is not specific to floral waste, so the findings are presented here as general context, rather than as direct evidence of the behaviour of floral waste heavy metals; this is because the primary literature on floral waste has not yet been filled, as far as this search could determine. A specific study to screen the temple floral waste compost for pesticide residues and heavy metals would be a true gap in the literature, since pesticide residues (not heavy metals per se) are the contamination pathway most often mentioned in commentary on the issue of temple floral waste, and commercially grown flowers used for offerings are often treated with agrochemicals.

XII. PLANT GROWTH PROMOTION EFFECTS OF VERMICOMPOST

Though there is no meta-analysis of plant-bioassay for floral-waste vermicompost, the overall effect of vermicompost (regardless of feedstock) on plant growth has been quantified. The first quantitative meta-analysis of the effect of vermicompost on plant growth was performed by Blouin et al. (2019) who found that vermicompost application increased the commercial yield by 26%, the total plant biomass by 13%, the shoot biomass by 78% and the root biomass by 57% on average, compared to the control. The same meta-analysis revealed that the beneficial impact on plant growth was highest when vermicompost comprised about 30–50% of the soil volume, with decreasing or even negative effects beyond this range, which is a practical consideration, as it suggests that adding more vermicompost may not be beneficial. These figures are based on vermicompost from a variety of and mostly non-floral sources and should be interpreted as indicative of what is achievable with temple floral waste vermicompost and not as a proven result with this feedstock. The individual temple-floral-waste bioassays discussed in Section 3 generally agree in their conclusions, such as the Singh et al. (2013) study, which found that 12.5% vermicompost-to-soil ratio resulted in better germination of chickpea and better shoot length, root length, secondary root count, and total biomass than comparison waste streams; a formal quantitative synthesis of the kind carried out by Blouin et al 2019. for vermicompost generally is not yet available and would be a logical next step in this research area.

XIII. GREENHOUSE GAS EMISSIONS FROM COMPOSTING AND VERMICOMPOSTING

No organic waste, including flowers, can be composted without the emission of methane, carbon dioxide, and nitrous oxide, and the ratio of these gases varies depending on the aeration, moisture, C:N ratio, and the presence of earthworms its convert in vermicompost. Nigussie, et al., (2016) directly compared vermicomposting with thermophilic or non-vermicomposting and found that vermicomposting reduced the nitrogen losses by 10-20%, reduced the nitrous oxide emissions by 25-36%, and reduced the methane emissions by 22-26% compared to thermophilic composting; the same study found that the higher the density of earthworms, the higher the carbon dioxide emissions (3-14%) and the lower the methane emissions (10-35%) and that the emissions were also sensitive to moisture content and quality of added carbon sources. No greenhouse gas measurement study specific to floral waste was found in this search; the results of Nigussie et al.2016 are general vermicomposting results and are presented here as the closest to what a temple-floral-waste system might be expected to do, not as a direct measurement of one. This is a valid point for any policy or lifecycle argument based on this literature, such as "vermicomposting temple floral waste avoids X tonnes of CO_2-equivalent emissions per year" cannot currently be backed up by a floral-waste-specific citation, as this lifecycle assessment does not seem to have been published yet. Any such number should be clearly indicated as an extrapolation from the general vermicomposting emissions data, or omitted until a specific study is available.

XIV. ALTERNATIVE VALORIZATION ROUTES FOR FLORAL WASTE

Not only composting and vermicomposting are the paths followed in the literature. As part of a larger municipal initiative to minimize the amount of temple floral waste sent to landfill. Elango, & Govindasamy**,** (2018) investigated the production of activated carbon from the waste flowers collected from the temples in Coimbatore district by direct pyrolysis and chemical activation with sulfuric and phosphoric acid. Recently, Gupta et al. (2025) conducted a thermogravimetric and kinetic analysis of waste-flower pyrolysis, finding that the biochar obtained from marigold waste contained a significant amount of carbon, surface area, and heating value, and suggested its application in soil amendment and pollutant adsorption. Agarwal & Jain (2024) studied floral waste was considered as a dual-purpose material, as a feedstock for vermicomposting and as a bio-sorbent material that can be used to adsorb contaminants from water or soil, thus extending the scope of end uses currently being investigated beyond vermicomposting. Along with vermicomposting and composting, these pathways suggest that floral waste is now being considered as a multi-pathway feedstock, instead of a waste that has only one disposal or valorisation pathway.

XV. ECONOMIC AND OPERATIONAL CONSIDERATIONS

A thorough techno-economic analysis of the capital cost, labour, throughput, sale price of the finished product and payback period for a specific case of temple floral waste was not found during this search, and any figures found elsewhere for temple floral waste should be treated as unverified until a primary source is located and checked. What can be said, based on the general composting and vermicomposting economics literature (not floral-waste specific) is that composting and vermicomposting systems are generally reported as economically viable at small to medium scale, where there is a market for the end product, but that viability is sensitive to local fertilizer prices, labour cost, and whether the operation can access free or low-cost feedstock and land, which varies widely between, for example, a single temple's floral-waste stream and a municipal-scale operation that aggregates waste from many sites. Primary cost data plausibly exist within the operations of the largest temple complexes, and several social enterprises already collect and process temple floral waste at meaningful scale, but this is not the subject of this review, which is limited to the academic literature.

XVI. PATHOGEN REDUCTION AND SANITARY SAFETY: GENERAL EVIDENCE

None of the studies reviewed in this paper directly measured pathogen indicator organisms (e.g., E. coli, Salmonella spp., faecal coliforms) in the compost or vermicompost of temple flower waste. The nearest evidence available is from the general literature on vermicomposting, as in the case of heavy metals. In the high-throughput sequencing study of sewage-sludge vermicomposting performed by Domínguez, et al. (2021), earthworm gut-associated processes were found to be a key factor, as the great majority of the original bacterial and fungal community was eliminated during transit through the earthworm gut. This is in line with the general trend observed in the literature on vermicomposting that the passage through the earthworm gut is believed to reduce pathogen loads faster than the natural die-off of the pathogens in the environment, although the extent of reduction varies with the initial substrate, the type of pathogen and the duration of the vermicomposting process and was not determined for floral waste specifically in any source found here. Pathogen reduction is traditionally thought to be related to the internal temperature of the pile reaching and maintaining a high enough level for a certain amount of time (the typical argument for time–temperature pathogen kill requirements in composting regulations), not to a biological mechanism similar to gut passage. The Jammu aerobic composting trial (Kumari et al., 2021) modelled C:N kinetics but the abstract-level information available for this review did not report whether pathogen indicator testing was carried out; readers who wish to use the information in this review to make a food-safety or agricultural-input decision involving temple floral waste compost should treat pathogen safety as an open, unconfirmed question for this specific feedstock and should request or commission direct microbial testing of any specific batch intended for use on edible crops, rather than assuming safety by analogy with the general literature summarized here.

To make the evidentiary basis of this review as transparent and checkable as possible, Table 3 lists the primary and secondary sources most heavily relied upon in this review, together with a one-line note on what each source specifically established and whether it is floral-waste-specific or general vermicomposting/composting literature used. This table is intended as a navigational aid for readers who want to trace a specific claim in this review back to its source without re-reading the full text.

Table 3. Annotated summary of the primary sources underlying this review's key claims, indicating scope (floral-waste-specific vs. general) for each.

Source	What it specifically establishes	Scope
Singh et al. (2013)	Temple floral offerings vermicompost with *Eisenia fetida* outperform kitchen/farmyard waste vermicompost on earthworm biomass and several physicochemical indicators; improved chickpea germination and seedling growth	Floral-waste-specific
Sannigarahi., and Sannigrahi., (2018).	Bombax ceiba flower-waste trial, 57-day vermicompost from flower waste + cow dung reaches 1.13% N, 0.48% P, 2.68% K; amendments (urea, rock phosphate, Mahua cake) improve nutrient profile further	Floral-waste-specific
Tiwari, et al. (2016)	Jaipur temple floral waste study, 60:40 flower-waste-to-bulking-material ratio gives best bioconversion efficiency for marigold-dominated waste	Floral-waste-specific
Kumari et al. (2021)	Aerobic bin composting of temple flower waste + cow dung (1:3) achieves significant C:N reduction within 60 days; kinetic model of the process	Floral-waste-specific
Elango, & Govindasamy. (2018)	Temple waste flowers (Coimbatore) converted to activated carbon via pyrolysis + acid activation	Floral-waste-specific
Gupta, Mishra & Mohanty (2025)	Thermogravimetric/kinetic study of waste-flower (marigold) pyrolysis; reports biochar carbon content, surface area, heating value	Floral-waste-specific
Gupta, Tewari & Pathak (2023)	Descriptive overview of temple floral waste composition, disposal practice, and possible valorization routes in India	Floral-waste-specific

Swati & Hait (2017)	Review: heavy-metal bioavailability during vermicomposting depends on feedstock/co-substrate/metal, not a single fixed direction of change	General
Blouin et al. (2019)	Meta-analysis: vermicompost increases commercial yield 26%, total biomass 13%, shoot biomass 78%, root biomass 57%; optimal at 30–50% soil volume	General
Nigussie et al. (2016)	Vermicomposting vs. thermophilic composting: 10–20% less N loss, 25–36% less N2O, 22–26% less CH4; higher earthworm density raises CO2 3–14% but cuts CH4 10–35%	General
Lim, Lee & Wu (2016)	Review of composting/vermicomposting mechanisms, GHG emissions, and economic feasibility for organic solid waste generally	General
Domínguez et al. (2021)	16S/ITS sequencing: earthworm gut passage eliminates ~96% of bacterial and ~91% of fungal taxa from raw sewage sludge; distinct community reassembles during cast maturation	General
Gómez-Brandón et al. (2012)	Different epigeic earthworm species leave distinguishable microbial fingerprints on the same substrate during early decomposition	General
Ganguly & Chakraborty (2021)	Defined succession of enzyme activities/microbial biomarkers tracks vermicomposting progress (paper-mill waste, Perionyx excavatus)	General

XVII. TEMPLE FLORAL WASTE IN CONTEXT: COMPARISON WITH OTHER ORGANIC WASTE STREAMS

Temple floral waste can be compared to other vermicompost organic waste streams as this gives a good idea of the level of difficulty and value of the floral waste. The kitchen and vegetable-market waste are generally wetter and more nitrogen-variable than the floral waste and are widely vermicomposted; the farmyard and animal manure waste is a very common bulking and nitrogen-source co-substrate, being used as a co-substrate in nearly all the temple-floral-waste trials reviewed here (cow dung specifically, in the Jammu, Bombax ceiba, and Jaipur studies). Sewage sludge and industrial sludges (textile mill sludge, paper-mill waste) are comparatively harder substrates, and much of the deeper literature on microbial ecology and heavy metals cited in Sections 9 and 11 of this review was originally generated using these more heavily studied and more problematic waste streams, which is one reason that literature was available in depth while the literature for floral-waste was not. Compared to these better studied streams, the available limited direct evidence suggests that temple floral waste is a relatively benign and cooperative feedstock, not as risky in terms of industrial contamination as sludge, not as problematic in terms of salinity as some industrial wastes, and at least as effective as, if not superior to, kitchen and farmyard waste vermicompost under the same experimental design as Singh et al. (2013). This relatively favourable position is one reason why, although, as emphasized throughout this review, the amount of research dedicated to this specific feedstock is still small compared to the amount of research on sludge, manure and municipal solid waste in general, floral waste is a potential target for more extensive vermicomposting and composting programmes.

XVIII. FEEDSTOCK COMPOSITION, SEASONALITY, AND PRE-PROCESSING CONSIDERATIONS

Temple floral waste is not a homogeneous waste, and this has implications for any composting or vermicomposting system based on it. In the studies reviewed here and in the general descriptive literature on Indian floral waste (Gupta, et al. 2023), the flowers most frequently mentioned as the predominant ones are marigold (*Tagetes erecta*), rose (Rosa *spp.*), jasmine (Jasminum *spp.*), hibiscus, and lotus (*Nelumbo nucifera*), depending on the region, season, and the particular deity or festival. Marigold is the most frequently mentioned single constituent in descriptions of the floral waste in Indian temples, probably because it is cheap, readily available, and used in a variety of rituals; rose and jasmine are the next most frequently mentioned constituents, but there is no single universally agreed percentage breakdown of these in the literature. Another commonly reported trend is that the amount of floral waste generated tends to increase significantly during major festivals, although none of the studies reviewed here quantified this increase for the specific study sites. In practice, this translates to a processing system that is designed for average daily waste generation, but is under-capacity during major festival periods, a planning consideration that is qualitatively addressed in descriptive literature on temple waste management, but not directly addressed with process data in any of the vermicomposting or composting trials reviewed here. Pre-processing steps mentioned in the various studies reviewed include pre-composting (on the order of days) before vermicomposting to allow the most exothermic, potentially worm-lethal phase of decomposition to pass before vermicomposting begins in earnest; manual separation of non-biodegradable material (plastic wrapping, synthetic thread, foil, wax residues from candles or diyas) before composting or vermicomposting, since these materials do not break down and can contaminate the finished product; and shredding or size reduction of larger floral material to increase surface area. Another concrete, tractable and currently unaddressed data gap was the proportion of the temple floral waste that is non-biodegradable contamination (plastic, synthetic thread, foil) that needs to be removed before processing, which was not reported in any of the studies reviewed here.

XIX. IMPLICATIONS FOR THE CIRCULAR ECONOMY AND SUSTAINABLE DEVELOPMENT GOALS (SDG)

Bioconversion of temple floral waste is often presented in the academic literature reviewed here (and in broader literature) as an example of a circular economy practice: an organic waste stream that would otherwise be a pure environmental liability (organic pollution load to water bodies) is turned into a marketable soil amendment, incense feedstock, dye, or biochar. This framing is most closely related to SDG 12 (responsible consumption and production) and, insofar as it is possible to improve the quality of river water by diverting floral waste from immersion, to SDG 6 (clean water and sanitation). The activated-carbon and biochar pathways discussed in Section 14 also relate to Goal 13 (climate action) as biochar can be used as a stable carbon sink when added to soil, but none of the studies reviewed here conducted a formal lifecycle carbon-accounting exercise specifically for temple floral waste to support a specific sequestration figure. It is important to be specific about what this framing of the circular economy is and isn't currently built on. The findings of the individual processes discussed in Sections 3, 4 and 14 (earthworm biomass gains, C:N reduction, biochar yield and surface area) are measurable and verifiable results of actual experiments. The overarching notion that scaling these processes up to the national level would have a meaningful impact on river pollution, create significant local jobs or provide a specific quantified economic return is a reasonable extrapolation in the direction of the evidence, but not a directly measured result, as no study reviewed here was conducted at the national or even large-multi-city scale required to measure this impact directly. It is important to note that for anyone using this review to make a funding proposal, policy brief or further academic submission, there is a difference between the process-level evidence measured and the larger-scale policy narrative that is constructed around it: the former can be cited with confidence to the specific sources cited; the latter should be presented as an argument or hypothesis supported by the former, not as an established finding in its own right.

XX. CONCLUSION

Research findings have confirmed that bioconversion (vermicomposting and aerobic composting) of TFW is a highly promising and environmentally friendly solution to the conventional and polluting disposal of this waste in rivers. The literature available shows that TFW is an excellent and friendly feedstock, which produces nutrient-rich stable organic fertilizer equivalent to or better than kitchen and farmyard wastes in 60 days. In addition, new pyrolysis routes expand its potential to enable a multi-pathway circular economy feedstock, yielding high surface area biochar and activated carbon. The review points out, however, that there is a significant difference between successes in the field and in the classroom, as many of the critical metrics such as the greenhouse gas profiles, pathogen reductions, and heavy metal dynamics are based on general organic waste data. To successfully scale these decentralized bioconversion systems to span the policy divide between the traditional solid waste policies and entrenched cultural disposal habits will require targeted research into the disposal habits of flowers and robust public-private relations.

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