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Sustainable Management of Floral Waste to Reduce Environmental Pollution by Conversion to Value-Added Products and Their Applications in the Synthesizing of Nanomaterials: a Review

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Abstract In India, floral wastes account for nearly one-third of the total solid wastes, which are usually dumped into the nearest water bodies. Floral wastes (FWs) clog the water channel and release pesticides, harming human beings and resident aquatic biota if left in landfills. Due to a lack of water bodies, flowers are left in landfills, which release methane, increase carbon emissions, and pollute the air and soil. Flowers are widely used for religious rituals, ceremonies, expressions of respect, and industrial use in perfumes, cosmetics, and textiles all over the world. Although the demand for flowers in India has been increasing day by day due to a steady rise in the population and the number of temples and mosques across the nation, the management of FWs is widely overlooked, leading to serious environmental and health hazards. Flowers contain essential phytochemicals such as flavonoids, anthocyanins, carotenoids, phenolic compounds, and other useful substances. The purpose of this review is to examine what has been learned about the management of floral wastes and how values can be added to them while reducing their improper disposal. To achieve the objective of "zero-waste in rivers, lakes, and landfills", floral wastes are to be recycled optimally. This paper provides a critical review highlighting the current state of floral waste in India, followed by existing effective floral waste management strategies from the perspective of the circular economy. We recommend rapid recycling and optimal management of FWs by extracting bioactive substances, prospecting their wide applications, and adding value to them.

Keywords Floral waste · Water pollution · Aquatic organisms · Phytochemicals · Circular economy · Sustainable development

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1 Introduction

A steady rise in the population of India has resulted in a constant increase in places of worship, such as temples, mosques, etc. As these places are increasing in number, religious customs, and rituals are also taking place on an enormous scale, which is currently adding to the already increasing biomass waste. In religious ceremonies, flowers and garlands have ritualistic importance and are used to show devotion. Unfortunately, the flowers used in religious ceremonies become sacred and are not disposed of in landfills. The flower wastes (FWs) are dumped into holy rivers like the Ganga and other rivers considered sacred. The estimated 20.1% growth rate of the floriculture market during 2019–2024 (Sharma, 2021) points to a substantial increase in the number of floral wastes in India.

According to the latest report published by the National Horticulture Board for the year 2018–2019, 291×10^4 metric tonnes of flowers were produced from 3,03,000 ha of land in the country. It is reported that about 40% of the total flowers produced remain unused and are discarded in the trash every day in India and Sri Lanka (Atal, 2022; Bennurmath et al., 2021; Choudhury & Deka, 2024; Masure & Patil, 2014). Among the constituents of municipal solid waste, FWs degrade slowly as compared to vegetable waste (Jadhav et al., 2013). Approximately 8×10^6 tonnes of FWs are dumped in rivers each year, which ultimately leads to the degradation of the water body (Bennurmath et al., 2021; Frost, 2020). This type of floral waste currently accounts for roughly 16% of all river pollution in India (Sharma, 2021).

The solid waste management rules of India accept that landfills should only be used for residual waste and that every effort should be made to recycle or reuse the rejects to achieve the desired objective of “zero-waste to landfill." Wastes produced in temples, farm residues, and pre-and post-consumptive food wastes are major contributors to biomass waste. Out of various disposed wastes, FWs are the most perishable in nature. Improper disposal of FWs is harmful to water bodies in many ways. For instance, (i) FWs are dumped in plastic bags, which creates an issue of plastic pollution. (ii) The flowers are cultivated with pesticides that leach into the river. These may cause changes in the pH of the water, and its consumption increases the risk of cholera, hepatitis, and severe diarrhoea (Wijayapala, 2013). According to Frost (2020), these illnesses are responsible for about 87.6% of child mortality throughout India and Bangladesh. They pose serious hazards to aquatic life by reducing dissolved oxygen (DO) concentration and increasing nutrient concentration in the water, leading to eutrophication.

The improper disposal of FWs in landfills leads to the production of greenhouse gases, leachate, foul odours, etc. Furthermore, the dumping of FWs in an unorganised manner on land degrades its aesthetic and recreational values. Landfills are the third largest source of methane emissions, accounting for 14.1% of the total greenhouse emissions (U.S. Environment Protection Agency; Fang et al., 2019). FWs add to greenhouse emissions as their degradation produces CH_4, CO_2, etc. Therefore, appropriate management of flower waste has become a priority subject for the nongovernmental and governmental waste management institutions in countries like India where large amount of flowers are being used on day to day basis at household as well as large scale rituals and after celebration flowers are dumped in water bodies or on open space.

Thus, a sustainable and effective means of managing FWs is required to prevent the damage they cause to the environment.

Flowers are currently used in the production of natural colours, fragrances, textile industries, and medicines. Studies have indicated the presence of valuable substances such as biogas, organic acids, nutraceuticals, nanoparticles, etc. Therefore, prompt recycling and proper management of FWs by extracting valuable substances and prospecting their applications have been of paramount importance. Many studies have also pointed to the sustainable green synthesis of metallic nanoparticles using flowers and highlighted their various beneficial properties (Kumar et al., 2020; Kumaran et al., 2019; Prabhu et al., 2021). There have been various reports on the extraction of desired chemicals and compounds from vegetable and agri-wastes, such as the extraction of bioactive compounds and nano-emulsion-based delivery systems (Deepa et al., 2022, 2023; Dhanker et al., 2022) and the extraction of polyphenols from vegetable wastes using sustainable methods (Doria et al., 2021).

Extraction of anti-oxidant-rich compounds from fruit and vegetable waste (Montenegro-Landívar et al. 2021), byproducts and peel wastes (Elkatry et al., 2022; El-Beltagi et al., 2023), but the reports on FWs processing are scarce. Since FWs are included in the same category as food and agriwastes, they are equally important sources of valuable bioactive compounds, nanoparticles, etc. (Dutta & Kumar, 2021; Kumar et al., 2020; Waghmode et al., 2016). Previous work by Waghmode et al. (2016) and (Dutta & Kumar, 2021) emphasized management of flower wastes and extraction of value added chemicals from them, however these works Concentrate more on production, disposal and mostly conventional application (e.g. fermentation, composting, biofuels, pigment extraction, incense production, food additives etc.), whereas, in view of recent surge in production and post consumption dumping, new reliable, cost effective and eco-friendly application of FWs requires to be explored and prospected.

Nanomaterials derived from flowers have insecticidal, antibiotic, and antioxidant activities and therefore can be an important means of value addition to floral wastes. This review first highlights the current state of FWs in India, followed by current effective floral waste management strategies. Lastly, we delve into and propose the potential sustainable ways of FW management by extracting bioactive nanomaterials.

2 Floral Wastes: Challenges and Opportunities

FWs pose a significant obstacle to the current solid waste management disposal system (Fig. 1). Due to the growing population, the increase in per capita trash generation in megacities poses a threat to the current waste management system, (Kumar et al., 2017), thereby making an improved waste management system a necessity. In South Asia, almost 40% of flower production is disposed of at landfill sites or nearby water bodies (Masure & Patil, 2014). FWs are the most perishable in nature. Religious flowers used for prayers are not discarded in the garbage but instead immersed in the nearby lakes and rivers, causing further degradation of aquatic ecosystems.

The natural degradation of FWs is a somewhat slower process than the degradation of kitchen waste (Jadhav et al., 2013). Annually, $\sim 80 \times 10^5$ tonnes of FWs are disposed of in the Indian rivers, which results in choking, increased organic pollutants, increased nutrients, increased biochemical oxygen demand (BOD), and finally degradation of the river ecosystem health. The synthetic fertilizers and pesticides used in flower plantations contaminate the river water, rendering them toxic. Therefore, appropriate and environment-friendly FWs management system is required. Thus, prompt treatment of floral wastes at the source and the extraction of products with added value are crucial and need maximum effort.

3 Value-Added Products from Different Flowers and Floral Wastes

FWs have many qualities, including high sugar content, rich in carbohydrates (Table 1), and lovely color, and are recyclable into a variety of value-added items like incense sticks, essential oils, compost, dyes, biofertilizers, biofuels, etc. as shown in Table 2 and Fig. 2. Flower waste in general has an acidic pH ranging between 4.92 and 5.18.

3.1 Compost

Since FWs are one of the perishable substances that are co-dumped with municipal solid waste and reach landfills or rivers that decompose, they can be transformed into compost, or vermicomposting, and used as biofertilizers. Biofertilizers act as soil conditioners and rejuvenate the already-present nutrients in the soil, reducing the need for synthetic nutrients (Dhanker et al., 2023). Since FWs are rich in moisture content (70–80%), there is the possibility of enormous leachate generation. To reduce the excess moisture content and prevent leachate generation, the mixing of flower waste with various bulking agents is preferred. Bulking agents such as sawdust (SD), dry leaves, coco peat, wheat bran, biochar, etc. are used. These bulking agents also aid in excess moisture absorption. The incorporation of cow dung (CD) to facilitate microbial activity is utilised. Various mixture concentrations of FW, CD, and SD are prepared and analysed for better results as shown in Table 3. The moisture content of FW, CD, and SD were observed to be 86.9%, 41.65%, and 8.12% (Prajapati et al., 2022).

Various techniques of co-composting, along with varying mixture concentrations, are carried out for the best possible outcome. 60 days later, the agitated pile co-composting method combining temple FW with CD and SD yield balanced compost (Sharma

Fig. 1 Dumping of floral wastes at the southern bank of the River Ganges in the vicinity of temples in Patna, Bihar, India

& Yadav, 2017). It was observed that vermicompost generated from FWs was found to be a more effective biofertilizer even at smaller concentrations, in contrast to compost from kitchen and farmyard waste, making it more cost-effective (Dutta & Kumar, 2021). Mixed composting of marigold FWs with cow dung using *Eisenia foetida* in five different proportions (50:50, 60:40, 70:30, 80:20, and 90:10) was carried out. The most effective conversion of FWs into biocompost was observed in the 60:40 composition (64.4%), signifying that FWs have a good potential for being utilized as biocompost (Tiwari & Juneja, 2016).

Mixed composting of flower stalks and vegetable waste with twenty-two strains of lignocellulolytic bacteria and seven strains of fungus has been shown to enhance the compost's physical and nutritional properties in addition to increasing its rate of

Table 1 Different flowers with their moisture, sugar, and carbohydrate contents

Flower	Moisture	Sugar	Carbohydrate	References
Camellia	–	40.5%	66.0%	Trinh et al., 2018
Rose	–	24.3%	58.7%	
Roselle	86.7%	11.5%	40.3%	
Mahula	–	46–48 g/ 100 g	-	Mohanty et al., 2009
Hibiscus	83%	–	13.71%	Bahuguna et al., 2018, Kumari & Bhargava, 2021
Tagetes	83.39	–	14.15%	Navarro-González et al., 2014; Kumari & Bhargava, 2021

Table 2 Value added products extracted from FWs

Value added products	FWs utilized	References
Biosorbent	Marigold and rose	Amari et al., 2023
	Marigold	Dey et al., 2023; Agarwal et al., 2021
	Saffron	Khoshsang & Ghaffarinejad, 2018
Biofertilizers	Marigold	Prajapati et al., 2022
Nanoparticles	Safflower	Rodríguez-Félix et al., 2021
Handmade paper	*Calendula officinalis* (Marigold), and *Polianthes tuberosa* (Tuberoses)	Sheth et al., 2021
	Rose	Bekdaş and Karaboyacı (2019)
Biogas	Aster and Marigold	Kulkarni, & Ghanegaonkar, 2019a
	Sunflower	Monlau et al., 2013
Activated carbon	Temple floral waste (Marigold, China rose, Rose, Jasmine, etc.)	Elango & Govindasamy, 2018
Phytochemicals (Carotenoid, flavonoid)	Marigold	Ćetković et al., 2004
	Mountain ebony and Water lily	Zheng et al., 2019
Biochar	Dry FWs (wood parts)	Bogale, 2017

biodegradation (Dutta & Kumar, 2021; Lu et al., 2004). As a better alternative to commercial compost, biocompost made from FWs after 43 days using nine microbial consortiums isolated from cow dung is said to be superior. These suggest that flower wastes should be used properly and mitigated, as well as promote organic farming and improve soil fertility (Gorasiya & Faldu, 2022).

3.2 Bio-Purifiers

The major contributors to water pollution are industries, tanneries, and pharmaceuticals (Dutta & Kumar, 2021). In recent years, because of the practice of eco-friendly methods, there has been an enormous shift towards the biological process of wastewater treatment (Mathew et al., 2022). Different contaminants can be removed from the wastewater using a physico-chemical and metabolically independent process called biosorption (Dutta & Kumar, 2021). FWs can potentially be used for the bioremediation process as they are rich sources of organic matter. FWs can effectively remove pollutants from the air and water. Composted FWs after mixing in soil can improve the activities of soil microbes and enhance the breakdown of the soil. FWs have the efficiency to remove heavy metals and other pollutants from soil, water, and air. FWs added biofertilizers effectively utilized for reducing contamination from air and water. FWs provide a potential substrate for beneficial

Fig. 2 Schematic presentation of flower wastes: consequences of improper disposal and possible extraction of valuable products from flower waste

Table 3 Co-compost mixture combination and methods of co-composting for optimizing results

Experiment	Mixture composition (%)			Method of co-composting	References
	FW	CD	SD		
01	60	30	10	Agitated pile method	Sharma & Yadav, 2017
02	65	25	10	Agitated pile method	Sharma et al., 2018a
03	85	–	15	Rotary drum method	Sharma et al., 2018b
04	70	20	10	In-vessel composting	Prajapati et al., 2022

FW Flower waste; *CD* Cow dung; *SD* Saw dust in terms of micro and macro nutrients

microorganisms to thrive, which can break down pollutants in the air or water passing through the biofilter.

The utilization of hyperaccumulator plants seems to be promising in the removal of heavy metals from contaminated soil or water (Biswal et al., 2022; Raj et al., 2020). The translocation factor (TF) of hyperaccumulator plant species should be greater than 1 (TF > 1), and they have the capability to accumulate metals 100 times more than typically occurring plants (Biswal et al., 2022; Rezapour et al., 2019). While opting for the phytoremediation method, there are high risks of bioaccumulation and biomagnification of the heavy metal up the food chain; hence, edible crops must be avoided (Biswal et al., 2022; Ramana et al., 2013). The use of floriculture plants, therefore, is considered safer and also enhances the aesthetic value (Biswal et al., 2022). *Tagetes patula* (French marigold) and *Tagetes erecta* (African marigold) were used for the removal of Cd, Pb, Cr, and Ni from the soils. Both species of *Tagetes* were found effective with TF > 1 in the removal of heavy metals (Biswal et al., 2022). *T. patula* was reported to be more effective in the removal of Ni (TF ~ 14.9); however, *T. erecta* was found to be more suitable for the removal of Cd (TF ~ 12.1). Due to its high biomass yield, *T. erecta* was more suitable for the removal of heavy metals, except Cr. *Tagetes erecta* L. was utilized for the removal of Cd, Zn, and Pb in laterite soil. Similarly, it is found to be a hyperaccumulator (TF > 1) for Cd and Zn but not Pb. Zn accumulates to the greatest degree in roots, followed by Cd and Pb, while Cd accumulates to the greatest degree in shoots, followed by Zn and Pb (Madanan et al., 2021).

Synergistic use of FWs with food wastes or agriculture wastes can be a more effective way of reducing pollutants in the environment (Fig. 3). Co-composting of FWs and food wastes can enhance the growth of pollutant-degrading microbes that enhance the health of the soil by effectively removing pollutants from the water, soil, and air. It can also be used to generate bioenergy, a renewable form of energy that mitigates greenhouse gas emissions.

Fig. 3 Applications of Flower Wastes for management of industrial effluents

3.2.1 Charcoal

FWs can be used for the production of biochar, a stable form of carbon that can be applied to the soil (Bogale, 2017). Biochar can remove or degrade contaminants and heavy metals from the soil, enhance fertility, and support the growth of beneficial microbes in the soil (Murtaza et al., 2023). The implementation of the FWs for degrading the pollutants rely on several factors, for instance, heavy metals, soil types, pollutants, and flower wastes (Table 4).

Agarwal et al. (2021) reported the use of marigold FWs collected from the Durgapuri temple in Shahdara, Delhi for charcoal production. The charcoal prepared from marigold FWs is sieved to obtain a particle size of less than 300 µm. Cu (II) solution of 1 mM concentration was prepared and diluted to 0.2 mM, 0.6 mM, and 0.8 mM concentration for determining removal efficiency. With time there is an increase in the removal efficiency of Cu (II) ions that became constant after 60 min. Maximum adsorption (55.6%) was reported for 0.2 mM concentration with 2 g dose of charcoal prepared from marigold FWs.

A study by Bogale (2017) reported the utilisation of FWs for biochar production in Ethiopia- the second-largest flower exporter in Africa. It is reported that around 560 kg of dry FWs are generated every day from one flower farm in Ethiopia. Since in Ethiopia, the traditional earth kiln methods were commonly used for charcoal production that has a low yield of only 10–15% and releases toxic pollutants in the atmosphere, an efficient and cost-effective reactor has been designed and tested. The woody portion of the FWs is utilised for this study. 18 kg of dry FWs is fed into the reactor yielding 10 kg of biochar in 30 min with a conversion rate of 55%, much higher than traditional methods. It is estimated that with this much conversion efficiency around 392.2 kg of firewood can be replaced daily with biochar produced from FWs.

Elango and Govindasamy (2018) utilised temple FWs generated in Coimbatore to produce activated carbon. Initially, the FWs were pretreated (washed, sun-dried, and powdered). Activated carbon produced from FWs was then categorised according to three different adopted processes. 1. $\mathbf{FW_D}$ – the powdered material obtained after direct pyrolysis, 2. $\mathbf{FW_S}$ – the powdered material obtained after treating the powdered FWs with H_2SO_4, 3. $\mathbf{FW_P}$

Table 4 Different FWs used for the removal of various `heavy metals

Biosorbent	Targeted heavy metals and pollutants	Maximum efficiency of elimination (%)	References
Mixed FWs	Cu	91.69	Racha et al., 2022
Tagetes erecta	Pb (II)	98.63	Saranya et al., 2020
P. tuberosa		95.42	
Crossandra infundibuliformis		93.69	
Marigold powder	Methyl red dye	61.16	Amari et al., 2023
Rose powder		56.08	
Carnation, Rose, and Daisy (Stem)	Acid blue 9	90	Echavarria-Alvarez & Hormaza-Anaguano, 2014
Powdered Cut FWs	Antibiotic (Levofloxacin)	60	Sabri et al., 2021
	Pb^{2+}	45	
KOH-activated Cut FWs	Antibiotic (Levofloxacin)	~100	
	Pb^{2+}	>99	
CO_2-activated Cut FWs	Antibiotic (Levofloxacin)	90	
	Pb^{2+}	85	
Chrysanthemum indicum	Co(II)	96.12	Vilvanathan & Shanthakumar, 2015
Sunflower	Cr(VI)	85.4	Jain et al., 2010
Hibiscus rosa sinensis	Cd^{2+}	67.82	Vankar et al., 2010
	Pb^{2+}	85.12	
	As	96	Nigam et al., 2013
	Zn	88.88	Vankar & Shukla, 2011
	Cr (VI)	59.92	Vankar et al., 2013
Canna indica	As	85	Nigam et al., 2013
Tagetes erecta	As	90	Nigam et al., 2013
	Cu (II)	55.6	Agarwal et al., 2021
Canna indica	As	85	Nigam et al., 2013
Canna indica	Cr(VI)	3.61	Vankar et al., 2013
Portulaca		6.42	
Trapa (Fruit)		95.75	
Rosa centifolia	Pb(II)	>90	Javed et al., 2007
	Co(II)		
Rosa rosa	As	98	Nigam et al., 2013
Rosa 'Gruss an Teplitz'	Pb (II)	49.77	Haq et al., 2011
	Co (II)	67.7	
Mespilus germanica	Ni^{2+}	83	Chergui et al., 2014
Borassus aethiopum	Cr(VI)	99.2	Elangovan et al., 2008
	Cr(III)	82.7	
Alstonia scholaris	Cr(VI)	94	Sharma & Kothiyal, 2013

– the powdered material obtained after treating the powdered FWs with H_3PO_4. The final powdered product for all three categories possesses a particle size of 110 µm. Various physiochemical properties, structural morphology, and cost-effectiveness were analysed and it was found that the activated carbon prepared from direct pyrolysis (FW_D) is better than the chemically assisted activated charcoal processes (FW_S and FW_p).

3.3 Biofuels

Bioenergy generation from FWs is another environment-friendly and innovative approach to utilize the organic matter of FWs. It not only reduces waste and landfill disposal but also helps create more sustainable and promising renewable energy generation method (Singh et al., 2023). FWs can be utilized for bioenergy production by different methods, such as anaerobic digestion, biomass combustion, pyrolysis, fermentation, bioconversion, and gasification. However, the efficiency and feasibility of these methods depend on various parameters, for example, the types and quantity of FWs, the composition of the flowers, the technologies used, the availability of local resources, and the demand for energy (Aidonojie et al., 2023).

In India, biogas production accounts for about 2.07 billion m^3/year however, the estimated generation potential accounts for about 29–48 billion m^3/year (Mittal et al., 2018). The primary constituent of biogas is methane (CH_4) alongwith CO_2 and other gases in traces. The FWs are digested with the help of microorganisms in the absence of oxygen for the production of biogas. For biogas production, FWs are collected from different sources and sorted to remove any non-organic matter and contaminants. The sorted FWs are loaded into a sealed container for the anaerobic digester. Microorganisms decompose the organic matter of FWs in the absence of oxygen through different biological reactions. Based on the metabolic activities of microorganisms, methane production takes place in the highest quantity and is most commonly utilized for many applications (Sonawane et al., 2022).

Biogas produced is collected in the digester, which has a gas collection system and a gas cleaning unit for maintaining optimum conditions and removing impurities. Biogas may be used for many applications, such as electricity, heating, cooking, and renewable vehicle fuel. After anaerobic digestion, the leftover content, which has a high nutrient content, can be used as organic fertilizers in agriculture fields. Biogas production per unit biomass was higher from FWs than from vegetable waste (Deepanraj et al., 2015). Because of the acidic nature of FWs, treatment with NaOH, Na_2CO_3, or other neutralizing agents is required before processing for biogas production (Kulkarni & Ghanegaonkar, 2019a, b). Alkaline pre-treatment with Na_2CO_3 and $NaHCO^3$ is reported to provide 106% increased biogas generation in comparison to pre-treatment with NaOH (Chauhan et al., 2022). Organic waste is then fed as feedstock, which is then acted upon by microorganisms in anaerobic conditions. It is reported that solar heating of digesters yields a 122% higher amount of biogas (Kulkarni & Ghanegaonkar, 2020; Chauhan et al., 2022).

Experiments are manipulated for the best possible yield. The biogas yield increases by 32.60% by co-composting FWs with food waste (Chauhan et al., 2022). Valorization of marigold plant parts (stem and leaves) is reported to produce biogas. High concentrations of volatile solids in marigold plants indicate higher biogas productivity (Poveda-Giraldo & Cardona Alzate, 2020). Followed by anaerobic digestion, the productivity was reported to increase until 12 days and diminish by the onset of day 17, possibly due to substrate depletion.

Similar to biomethane, biohydrogen is regarded as another type of sustainable energy source. A study found that FWs can be a great source for using sewage sludge as a co-substrate for the synthesis of biohydrogen since they have a high C/N ratio (20.7) and are rich in carbohydrates (Yang & Wang, 2018). Dark fermentation is the most common process in which the flower wastes are mixed with the consortia of microorganisms under anaerobic conditions, during which hydrogen gas is produced as by-products, including CO_2 and volatile fatty acids (Atal, 2022). Cellulose and hemicellulose are the main products. Photofermentation, enzymatic hydrolysis, and two-step fermentation are common methods for hydrogen gas production (D'Silva et al., 2023).

The most widely used liquid biofuel is bioethanol, which has an octane rating of 108 and makes a great alternative to gasoline by preventing engine knocking and premature ignition. Because bioethanol has higher oxygen content (34.7%), it burns more cleanly and emits fewer greenhouse gases (Aditiya et al., 2016). Mahua flowers make a great substrate for the synthesis of bioethanol since they have 40–47% of their fresh weight in fermentable sugars (Behera et al., 2010). In bioethanol production, the carbohydrates of FWs are fermented to ethanol by the process of in fermentation, FWs, for example, petals, stems, and other flower residues, are pre-treated with cellulose and hemicellulose for enzymatic hydrolysis.

Pre-treatment can be done by mechanical, thermal, or chemical processes that are used to break down complex plant materials (Fig. 4). Thereafter, enzymes are added to pre-treated biomass to break plant materials into simpler saccharides such as xylose and glucose (Nugrahini et al., 2022). Nobel strains of yeast or bacteria are added to a fermented sugar solution, in which the production of ethanol and carbon dioxide takes place. As the solution contains ethanol, water, and some impurities, it is distilled through the process of distillation. Due to the difference in boiling points of water and ethanol, high-quality ethanol is produced with the help of this process (Doda & Sahu, 2022). To ensure the desirable purity of ethanol, the remaining water is removed during the process of dehydration. For converting ethanol as fuel, small amounts of chemicals are added that are further used as biofuel, which has various applications in many areas (Doda & Sahu, 2022).

Bioenergy production from FWs is a viable and emerging area of research in the area of renewable energy, in which the organic matter of FWs is used to generate bioethanol, biohydrogen, and biogas through different biological and biochemical methods (Rekha & Vijayalakshmi, 2018). However, it is worth noting that flowers have many aesthetic, cultural, and ecological values (Nugrahini et al., 2022). So, bioenergy production from FWs should be balanced with responsible waste management and environmental considerations. Further research and advanced technologies are needed for the optimum utilization of FWs for clean and renewable energy production (Fig. 5).

3.4 Food, Nutraceuticals, and Pharmaceuticals

FWs are crucial sources of bioactive compounds and natural ingredients that can be utilized for food and pharmaceutical applications. Phytochemicals, essential oils, antioxidants, and other bioactive compounds extracted from FWs show significant health benefits and increase the flavours, aromas, and taste of food products (Dutta & Kumar, 2021). Extracted bioactive compounds enhance the quality of various food products, such as milk products, fruits and vegetable products, baked products, and beverages. Some pigments can be used as natural food colorants as a replacement for synthetic food dyes that can make food attractive and increase the appeal of visualization (Takahashi et al., 2020). Bioactive compounds can be used as nutraceuticals and dietary supplements that provide extra health benefits and boost the immune system (Elkatry et al., 2023). FWs can be used as traditional herbal medicines for different therapeutic purposes. Flower-derived phenolics have multifaceted ethnobiological applications, generally as disease antidotes in floral therapy (Pushpa Ayurveda).

Humans have utilized flowers as food and medicine since time immemorial. For example, flowers like Mahula have traditionally been used to make foods

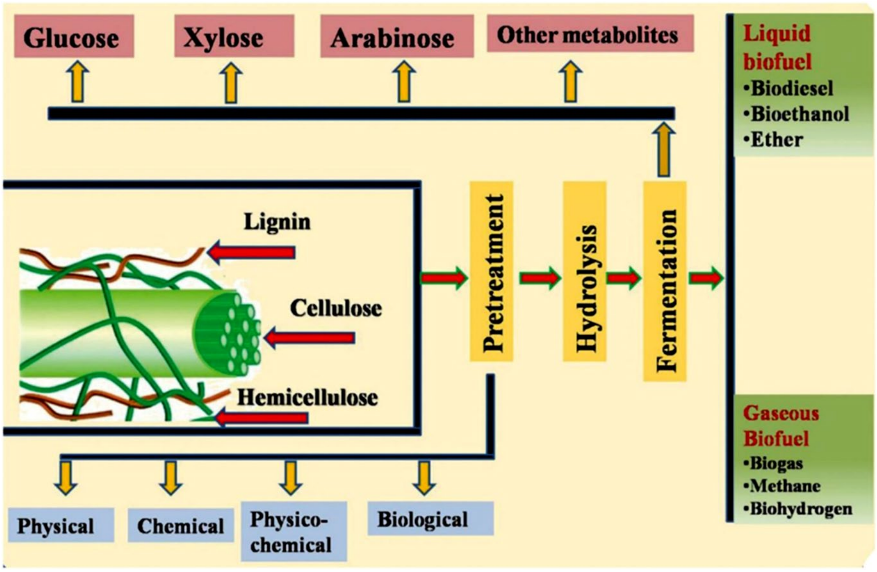


Fig. 4 Schematic illustration of biofuel production

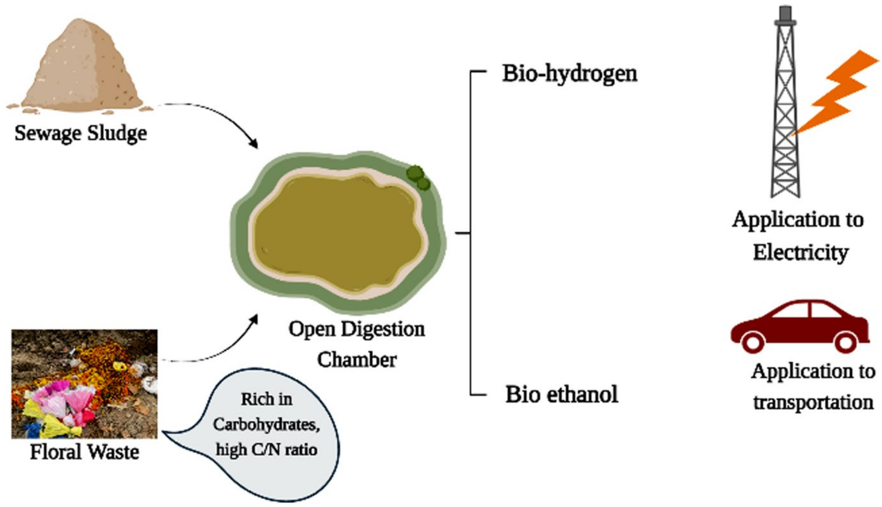


Fig. 5 Schematic diagram showing utilization of FWs in bioenergy production

like jellies, sugar syrup, and fermented beverages (Patel & Naik, 2010). Flavonoids and carotenoids, two naturally occurring plant pigments that can be used as food and dietary supplements, are abundant in flowers. While carotenoids generate red, yellow, and orange pigmentation, flavonoids give the petals their yellow, red, or blue colour. The most common flavonoids found in plants are anthocyanins and anthocyanidins. The most common carotenoid is lutein. Since marigold FWs make up over 80% of the carotenoid content in marigolds, they can be used as a commercial source of lutein because they are abundant in FWs produced from gardens and holy sites (Dutta & Kumar, 2021). Due to their antioxidant characteristics, these pigments are commonly employed as food colouring, dietary supplements, and food additives (Waghmode et al., 2016).

They also have a wide range of possible health advantages. To make egg yolks and feathers a brighter yellow, birds are fed carotenoids manufactured from marigolds. Although the human body is unable to synthesize lutein, it has been linked to several health advantages, including protection against cardiovascular disease, eye difficulties, and muscle degeneration. Using a novel technique called microwave-assisted aqueous two-phase extraction (MEAATPE), Fu et al. (2018) were able to extract lutein from *Tagetes erecta* flowers with a yield of 7.32 mg/g and a 99.85% recovery rate.

Food is the basis of all the metabolic activities in organisms. It serves the purpose of satiety as well as nutrition. Nutritional components present in food help fight several diseases and build immunity against foreign particles. Flowers are long used as a food component for bringing new colour and taste, and they are used in garnishing food. Flowers contain many nutritional benefits (Table 5). It has been reported that various phytochemicals, such as flavonoids, anthocyanins, carotenoids, and phenolics, present in flowers are beneficial for human health (Kumari & Bhargava, 2021). Traditionally, edible flowers have long been used for nutritional benefits.

However, before applying extracts for food and pharmaceutical purposes, identification of the suitable flower strains is essential. Scientific verification and testing of the compounds should be conducted to ensure the quality and safety of the compounds. The presence of flavonoids, anthocyanins, and phenolic acids was investigated among 70 commonly edible flowers in China. Among these flowers, kaempferol was an abundant flavonoid in Azalea flower (138.5 $\mu g\ g^{-1}$) and French rose (138.3 $\mu g\ g^{-1}$). A significant amount of kaempferol was also found in peony (69.0 $\mu g\ g^{-1}$), mountain ebony (91.1 $\mu g\ g^{-1}$), Kunlun chrysanthemum (40.9 $\mu g\ g^{-1}$), sophora flower (38.2 $\mu g\ g^{-1}$), water lily (28.9 $\mu g\ g^{-1}$), etc. (Zheng et al., 2019). The presence of flavonoids (kaempferol, quercetin, rutin, and glycosides) and phenolic acids (chlorogenic, caffeic, p-coumaric, and vanillic acids) was reported in *Calendula arvensis* L. and *Calendula officinalis* L. (Ćetković et al., 2004), performed by using methanolic and water extracts and analysed through thin layer chromatography. Total phenolic compounds range from 14.49–57.47 mg/g

Table 5 Molecular structure of certain flower-derived phytochemicals

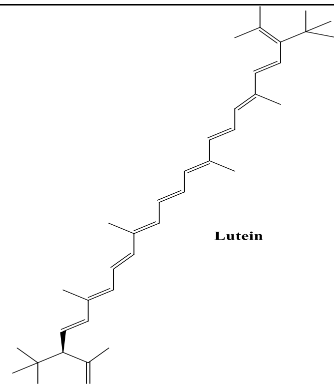
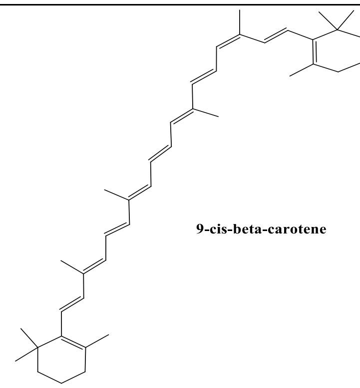
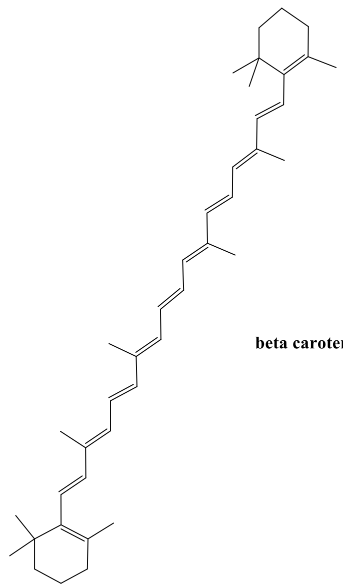
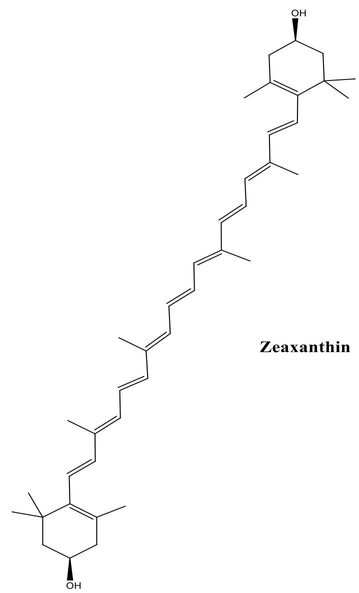
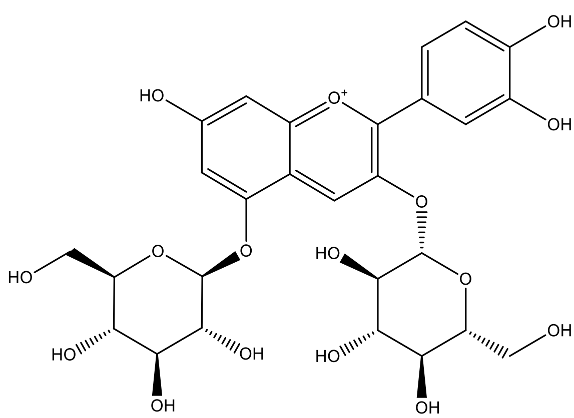
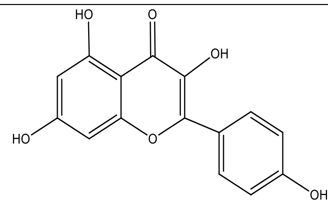
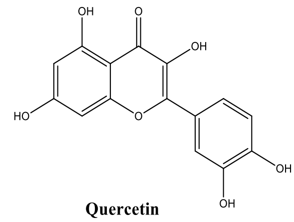
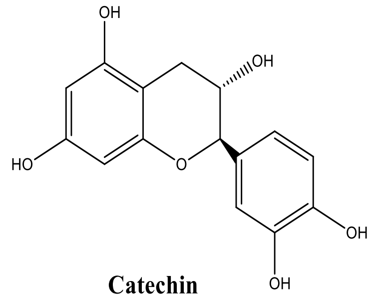
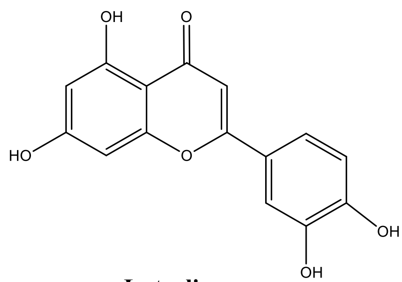
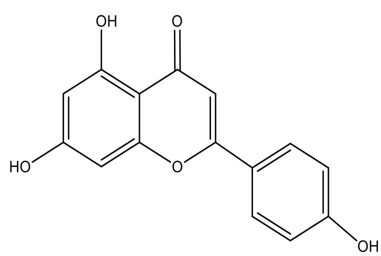
Phytochemicals	Chemical Structure
Carotenoids	 Lutein  9-cis-beta-carotene  beta carotene  Zeaxanthin
	 **Cyanidin- 3,5-O- diclucoside**

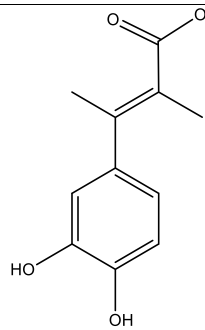
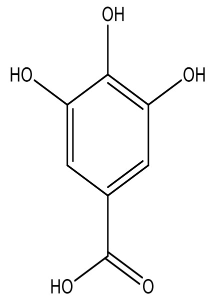
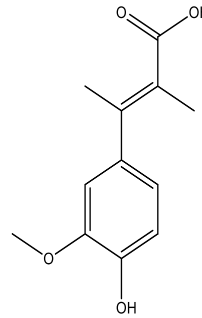
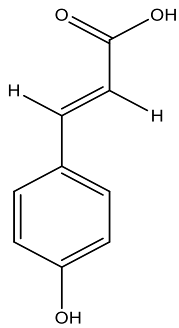
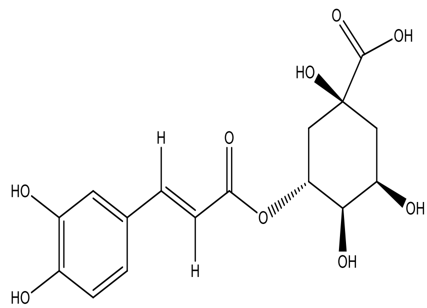
Table 5 (continued)

Phytochemicals	Chemical Structure
Flavonols	 **Kaempferol**  **Quercetin**  **Catechin**
Flavones	 **Luteolin**  **Apigenin**

and flavonoids range from 5.26–18.62 mg/g, depending upon the type of extract and species of plant used.

A study reported the presence of flavonols (kaempferol and quercetin), anthocyanins (cyanidin 3,5-diglucoside, pelargonidin 3,5-diglucoside, cyanidin 3-O-glucoside, and pelargonidin 3-O-glucoside), and carotenoids (β-carotene, zeaxanthin, lutein, violaxanthin, neoxanthin, luteoxanthin, and antheraxanthin) from the petals of rose cultivars (Wan et al., 2019). These were identified using

Table 5 (continued)

Phenolic acids	 **Caffeic acid**  **Gallic acid**  **Ferulic acid**  **4-coumaric acid**  **Chlorogenic acid**

HPLC (High-performance liquid chromatography) and MS (Mass spectrometry).

Chiang et al. (2021) conducted a study on stem, leaf, and flower extracts of *Dendranthema morifolium* for extraction of phytochemicals using HPLC and determined the presence of luteolin (Flower- 261.2 ± 2.74 μg g^{-1}, Stem and leaf- 467.6 ± 9.53 μg g^{-1}), apigenin (Flower- 931.6 ± 8.19 μg g^{-1}, Stem and leaf- 453.2 ± 11.6 μg g^{-1}), luteolin-7-O-glucoside (Flower- 3973 ± 104 μg g^{-1}, Stem and leaf- absent), and apigenin-7-O-glucoside (Flower- 31780 ± 83.9 μg g^{-1}, Stem and leaf- 990.8 ± 168 μg g^{-1}).

Kumari et al. (2018) performed HPLC analysis and determined the presence of five phenolic acids in 13 varieties of rose petal extracts- quercetin (23.83—6038.78 μg/g), catechin (27.50 μg/g and 38.73 μg/g), epicatechin (20.43—1980.66 μg/g), rutin (11.68 μg/g—94.37 μg/g), and 3-hydroxy cinnamic acid (9.76 μg/g).

3.5 Essential Oils

Bioactive compounds extracted from FWs can be utilized for aromatherapy and cosmetic products for their skin benefits. A study conducted by Bahadirli (2020) in Turkey revealed the presence of essential oil in *Tagetus minuta* L. with the main components being trans-β-ocimene (45.92%), verbenone (32.68%), anethole (6.67%), and dihydrocarvone (3.78%). The essential oil composition found in *Tagetus minuta* L. was reported for its antimicrobial properties (Santoyo et al., 2005) and insect defence mechanism (Navia-Giné et al., 2009). According to a study, *Tagetes erecta* essential oil was produced using a Soxhlet extraction method with light petroleum, yielding 0.4% oil. Camphor and methyl eugenol were found to exhibit antioxidant properties (Perez Gutierrez et al., 2006).

The presence of essential oils was reported in the two cultivated varieties of leaves and petals of *T. patula*- 'Mikrus' and 'Petite yellow' (Salachna et al., 2021). Palmitic acid, isopropyl myristate, linoleic acid, 2-heptadecanone, and spathulenol were found in the essential oils isolated from the leaves of Mikrus cultivar, while in Petite yellow cultivar, phytol was isolated in addition to the constituents obtained from the oil extracted from the leaves of Mikrus cultivar except 2-heptadecanone. Palmitic acid, myristic acid, 2,2′:5′2″-terthiophene, isopropyl myristate, dodecanoic acid, and caryophyllene were the constituents of the essential oils obtained from the petals of Mikrus and Petite yellow cultivars. Higher concentrations of spathulenol, isopropyl myristate, and palmitic acid were reported in the leaves while the petals exhibited greater concentrations of caryophyllene, myristic acid, heptadecanoic acid, 2,2′:5′2″-terthiophene (α-terthienyl) and 7-nonacosene.

A study by Gil-Jasso et al. (2022) reported the use of essential oils made from Lily, Nard, Lavender, Jasmine, Violet, Ylang-Ylang, Orange Blossom, and Mexican Gardenia for recycling waste expanded polystyrene (WEP). The advantage of using essential oils for recycling WEP over other methods is that it is cost-effective, environment friendly, without any use of advanced instruments, and most importantly it does not change the chemical constituents of WEP so it is available for further reuse.

Another study reported the presence of essential oils extracted from FWs of *Polianthes tuberosa* (Nugrahini et al., 2017). Hexane and petroleum ether were utilized as solvents in the maceration processes used to extract the essential oils. The hexane-mediated yield of antioxidants is greater (13.13%) in comparison to petroleum ether (9.27%).

3.6 Synthesis of Natural Dye

Since the Industrial Revolution, the amount of synthetic color used has increased dramatically.. Synthetic dye is known to be allergenic and carcinogenic and has various other negative consequences for human health and the environment. Several applications of natural dyes can be implemented as food colorants, in cosmetics, and in clothing (Sivakumar et al., 2011). Globally, the demand for natural dyes is estimated to be 10,000 metric tonnes, which corresponds to 1% worldwide consumption of synthetic dyes (Sivakumar et al., 2011). The cost of manufacturing, such as 1 kg of plant material needed to dye 1 kg of fiber, is the largest disadvantage of using natural dyes (Karaboyaci, 2014). Wool, cotton, silk, and leather can all be dyed using the yellow dye that is derived from the leftovers of marigold flowers. Aloe vera juice and other natural mordants are being investigated for use in dyeing various natural and synthetic textiles with marigold flower dye (Nilani et al., 2008). Additionally, dyes can serve as indicators in a variety of chemical investigations. (Mishra et al., 2012). Additionally, it has been reported that the dye derived from *Hibiscus rosa sinensis* possesses anti-solar properties, shielding the skin from harmful UV radiation and making it suitable for use as a coloring agent during outdoor activities (Hayat & Jacob, 2016).

The process of extracting natural dye by using bio-mordants like pomegranate, turmeric, and acacia from *Rosa indica* enhanced the chromatic distinction ranging from yellow to green and improved fastness properties (Adeel et al., 2022). It is reported that pre-mordanting with the metal salts resulted in good fastness properties in the case of silk yarns dyed with colour extracted from *Delphinium zalil* flowers (Kiumarsi et al., 2017). The presence of quercetin in the *Delphinium zalil* flowers resulted in the yellow shade that showed the best affinity with Fe (II), followed by Al (III), and Sn (II) (Kiumarsi et al., 2017). After being pre-treated with various metal mordants, the dyes derived from *Tagetes erecta* displayed a variety of color patterns, including yellow, green, brown, and black. They also had a greater affinity for silk and wool than cotton (Vankar et al., 2009). The stability and colour intensity of dye synthesized from the FWs depend on the types of flower waste, mordants used, and extraction methods. Dyes synthesized from FWs can reduce landfill burdens and create eco-friendly products (Table 6).

3.7 Incense Sticks

People have used incense for religious and other important occasions since the beginning of time. Several studies have reported indoor air pollution from incense sticks (Dutta & Kumar, 2021). On combustion, synthetically prepared incense sticks emit particulate matter, NO_2, SO_2, benzene, formaldehyde, polycyclic aromatic hydrocarbons (PAHs), and other carcinogens (Dutta & Kumar, 2021). Lee and Wang (2004) reported increased concentrations of CO, CO_2, NO_x, CH_4, NMHC, $PM_{2.5}$, PM_{10}, carbonyl

Table 6 Various color types extracted from different flower species

Flower species	Common name	Colour extracted	References
Tagetes erecta	Marigold	Yellow	Sivakumar et al., 2011
Mirabilis jalapa	4 'o' clock plant	Pink	
Celosia cristata	Cocks comb	Red	
Clitoria ternatea	Blue pea	Blue	Wongcharee et al., 2007, Terahara et al., 1990
Hibiscus sabdariffa	Roselle	Reddish purple, Purple	Wongcharee et al., 2007
Hibiscus rosa—sinensis	China rose	Red (pH—acidic), Blue (pH—basic)	Vankar & Shukla, 2011
Butea monosperma	Flame of the forest	Yellow	Singh & Srivastava, 2015
Alcea Rosea	Pink hollyhock	Green	
Crocus Sativus Linn	Saffron	Dark yellow	
Nyctanthes arbor-tristis	Night flowering jasmine	Brown	
Spathodea campanulata	African tulip	Red	
Callistemon citrinus	Bottle brush	Purple	
Rosa indica	Rose	Yellow—green	Adeel et al., 2022
Delphinium zalil	Larkspur	Yellow	Kiumarsi et al., 2017

compounds, and VOCs associated with indoor burning of incense sticks. In Hong Kong, ten different types of incense sticks, distributed into three different categories, namely, traditional, aromatic, and church incense, were studied, and it was found that the carbonyl compound emission was highest among the traditional incense, followed by aromatic and church incense. Also, the VOC emission is reported to be highest among the aromatic incenses, followed by traditional and church incenses (Lee & Wang, 2004).

In a study conducted by Lui et al. (2016), five different incense sticks were taken for study, of which three were marketed as traditional incense and two as environment-friendly incense. Comparing environment-friendly incenses to traditional incenses, it was discovered that the former produced $PM_{2.5}$ at a lower concentration; on the other hand, non-volatile PAHs and several oxygenated polycyclic aromatic hydrocarbons (OPAHs) were found to be most abundant in the environment-friendly incenses.. Incense sticks prepared by FWs could be a great alternative in comparison to synthetically prepared incense sticks, making them more consumer- and environment-friendly. For making incense sticks, the FWs are collected from different sources and sorted for further processing. The sorted part of the FWs is dried to reduce moisture and preserve its fragrance. The dried FWs are ground into small pieces or as fine powder, depending on the desired texture. Thereafter, it is mixed with a base material such as sawdust or charcoal, binding agents such as gum or resin, and bamboo sticks. Essential oils purified from FWs are added to maintain the fragrance of the dried incense sticks. Finally, the mixture is shaped around the bamboo sticks, creating the incense sticks. Thereafter, they are left to dry thoroughly for the binding agents to set and solidify. After complete dryness, incense sticks are packaged and sold in the market. Research institutes, many municipal corporations, non-governmental organizations (NGOs), and waste management companies in different parts of India are working on FWs management. These organisations may be working on different projects and activities involved in the collection, recycling, and sustainable utilization of the FWs, focusing on environmental considerations.

Wijaya et al. (2021) conducted a study on Bali Island where temple floral waste was taken and mixed with sandalwood essential powder in three different concentrations (1:0), (1:1), and (1:2). Based on the three concerned parameters—structure, smell, and burning time of incense sticks—the 1:2 ratios gave the best result. The study also reported that, following this recycling method, 45 tonnes of temple FWs from 230 temples can be recycled as incense sticks. Flowers of Marigold are widely utilized for the production of herbal incense sticks (Waghmode et al., 2016; Saoji et al., 2021). Various contributors came forward to recycle FWs into incense sticks, incense cones, etc., deviating a notable amount of FWs and promoting a circular economy.

3.8 Biosurfactant Production

A study on the generation process of biosurfactants by *Microbispora* V2 was carried out using *Madhuca latifola* flower extract medium with 20 μg mL^{-1} of anthracene. Strong antibacterial, antifungal, and antiviral properties combined with their ability to act as pathogen-adhesive agents make biosurfactants effective in treating a wide range of diseases in addition to being used as a probiotic and therapeutic agent (Gharaei-Fathabad, 2011). A study has been conducted on the synthesis of surface active chemicals by *Microbispora sp.* V2 using flower extract from *Madhuca latifolia* L. (Waghmode et al., 2015). The resulting surface-active chemical exhibited biosurfactant properties.The surface tension was lowered to 35% by the cell-free supernatants of the *Madhuca latifolia* flower extract medium with 20 μg ml^{-1} of anthracene. The glycoprotein biosurfactant demonstrated potent antibacterial, antifungal, and antiviral action in addition to having good wetting ability. According to the study, using *Madhuca latifolia* L. flowers can be a viable bioresource for the synthesis of exopolysaccharides with surface-active characteristics (Waghmode et al., 2015).

3.9 Handmade Paper

Wood is used to make common household commodities like paper, which are then processed with chemicals that produce some hazardous byproducts. Flowers can be used to make handmade paper that is both affordable and environmentally beneficial compared to other materials. Handmade papers can help create a better and more sustainable environment because they are completely chemical-free and environmentally benign (Dermitrescue et al., 2004). According to Bhati et al. (2021), garbage gathered from temples and rivers can be used to create the raw materials needed to make handmade papers.

A study reported the use of Calendula officinalis (Marigold), and Polianthes tuberosa (Tuberoses) along with corn husks, rice water, and potato peels for biodegradable paper production. (Sheth et al., 2021). Potato peels and rice water are rich sources of starch which acted as a binding agent for the paper. The paper produced was thick and categorized as 'Greyboard quality paper' which can be used as packaging material, bookbinding, stationery folders, photo frames, etc.

Another study by Mohan et al. (2018), reported the production of paper from FWs collected from temples, mosques, ceremony halls, and markets. The basic constituent of paper is cellulose. After the FWs are processed for pulp formation, the presence of cellulose is confirmed by the Schultz Test. The FWs are then poured over a mesh and after drying in an oven at 60°c for 2 min, the paper is obtained.

Bekdaş and Karaboyacı (2019) performed several tests using rose waste for paper production. Three experiments were set up and their physical and chemical properties were determined. **1.** The paper produced when the rose waste is treated with sodium chlorite showed the desired whiteness however, due to bleaching the cellulose content which is essential for structural integrity was degraded and no satisfactory result was obtained. **2.** In the second experiment, the flower pulp was produced using soda-sodium borohydride method. The paper produced lacked smooth texture and hence the desired output was not obtained. **3.** In the third experiment, the waste rose pulp was mixed with different concentrations of waste paper (50–90%) pulp to obtain the ideal result. The burst index, breaking length, and optical qualities of the paper were found to be negatively impacted by an increase in the content of waste rose pulp. Considering the physical, economical, and optical properties, the 30:70 (waste rose pulp: waste paper pulp) is ideal for paper production.

3.10 Nanoparticles

FWs are rich sources of various biochemical compounds, for example, polyphenols, flavonoids, and other organic molecules, which can be proved as potential reducing agents for the synthesis of metal/metal oxide nanoparticles (NPs). In addition to being a precursor molecule for NP synthesis, flower-derived chemicals can also act as stabilizing agents (Fig. 6).

Nanomaterials from FWs have a significant commercial impact and have the potential to expand in the future. Various metabolites like proteins, phenolic acids, polyphenols, alkaloids, terpenoids, and

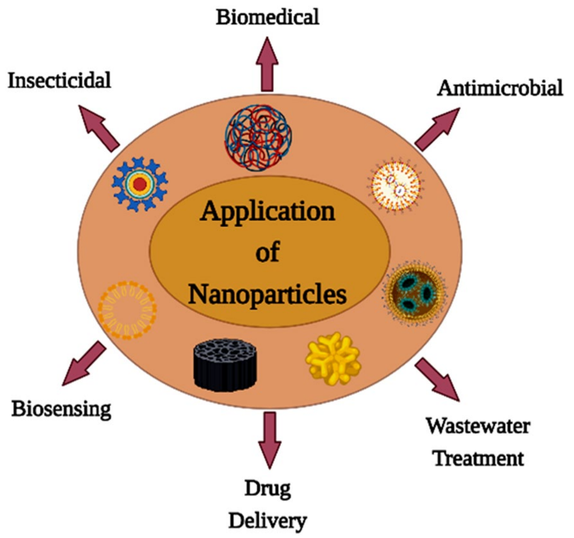


Fig. 6 Different applications of flower-derived nanoparticles

sugars are generally used as reductants that facilitate the metal ions reduction into nanoparticles. The existing physical and chemical processes for creating nanomaterials are neither eco-friendly nor safe for humans. Contamination from the atmosphere and/or milling media may occur, causing the powder product to solidify without causing the nanocrystalline microstructure to become coarse. Furthermore, because they become transparent to the cell dermis and may be poisonous because of their high surface area and increased surface activity, this could be biologically detrimental (Dhanker et al., 2021). Therefore, one of the most emerging research interests nowadays is the green synthesis of metal NPs. Green synthesis of NPs is favoured as it is non-toxic, highly stable, simple, and rapid (Dhanker et al., 2021, 2022). This bottom-up approach is applied to synthesise nanoparticles involving aggressive reduction, a capping agent, and volatile solvents like chloroform and toluene. FWs are gathered and processed to extract bioactive chemicals using suitable solvents, such as ethanol, methanol, or water, to create nanomaterials in an environment-friendly manner.

The extracted solution is mixed with metal compounds such as silver nitrate, gold chloride, and copper sulphate. The reducing agents' bioactive compounds convert metal ions into nanoparticles under optimising conditions. The synthesis is environment-friendly and generally done at ambient temperatures, as no toxic derivatives are formed (Deepa et al., 2023; Dhanker et al., 2022). For ensuring the size, structure, and composition of nanoparticles, nanoparticles are characterized by various techniques, including i) UV – Vis analysis, carried out in the range between 300–800 nm, operated at a resolution of 10 nm, ii) FTIR (Fourier transform infrared spectroscopy): Recorded in the range of 400–4000 cm^{-1}, iii) XRD (X-ray diffraction): It determines the structure and composition of synthesized silver nanoparticles; iv) TEM (Transmission electron microscopy): This method is used to visualize the shape as well as measure the diameter of the bio-synthesized silver nanoparticles.

The green synthesized nanoparticles from flower extracts showed antimicrobial, larvicidal, insecticidal, and antibacterial properties (Table 7). By using the green synthesis technology of metal NPs, a lot of food, agricultural, and floral wastes that are generated on a global scale can be recycled and contribute to the circular economy. As the green synthesis method of metal NPs is non-toxic, highly stable, simple, and rapid, it can be promoted for the management of FWs being dumped in river water to reduce the potential threat to aquatic life. It has been demonstrated that plant floral extracts can be used as significant pesticides and nematocides. *Tagetes sp*. flower extract was found to contain a high quantity of thiophene, which is thought to have biocidal effects, potentially making the flower species a suitable choice for pest management (Dhanker et al., 2021; Marotti et al., 2010).

Additionally, it was shown that *Tagetes erecta* floral extract possessed insecticidal qualities against *Tribolium castaneum*, the red flower beetle that causes significant post-harvest damage to food grains (Nikkon et al., 2009). Numerous phytochemicals that have been isolated from flowers have been shown to have mosquitocidal characteristics. For *Aedes albopictus* larvae, cadmium nanoparticles (CdNPs) derived from the petals of *Tagetes sp.* and *Rosa sp.* exhibit 100% and 98.8% mortality after 72 h of dosage, confirming CdNPs a potential mosquitocidal agent. Silver nanoparticles (AgNPs) synthesized from the buds of *Polianthus tuberosa* showed mosquito larvicidal effects on *Culex vishnui* and *Culex quinquefasciatus*. The highest mortality for *Culex vishnui* is recorded at 20 ppm, with LC50 and LC90 values of 8.25 ppm and 17.9 ppm, 7.46 ppm, and 23.26 ppm against the 3rd and 4th instars, respectively. In *Culex*

Table 7 Green synthesis of Nanoparticles from different parts of flower extract and their bioactive potential

Type of nanoparticle	Plant species	Parts used	Size of Ag NPs	Bioactive potential	References
Ag	*Musa acuminate*	Extract of peels	20–50 nm	Larvicidal activity against *Aedes aegypti*	Verma & Preet, 2021
Ag	*Tagetes erecta L*	Leaf extract	7–35 nm	Antioxidants for the treatment of different diseases caused by oxidative stress	Tyagi et al., 2021
Ag	*Annona squamosa*	Leaf broth	–	Larvicidal activity against *A. aegypti, Anopheles sphetensi, Culex quinquifasciatus.* Decreased adult longevity by 30%. Decreased no. of eggs by 36%	Arjunan et al., 2012
Ag	*Ficus racemose*	Stem, leaves, and fruit extract	–	Antibacterial against *B. subtilis*, and *S. equorum*	Sneha et al., 2020
Ag	*Tagetes erecta*	Flower broth	10–90 nm	Antimicrobial potential against Gram + ve and Gram –ve and antifungal activity against Candida	Padalia et al., 2015
Ag	*Amaranthus virdis*	Leaf extract	10–45 nm	–	Phanjom et al., 2012
Ag	*Saccharum officinarum*	Activated cabon pyrolyzed sugarcane bagasse	50–150 nm	Inhibited bacteria growth of *E. coli.* Advantages in water purification process However, have a toxic effect to aquatic organisms *Hydra attenuata* i.e., LC50 value of 1.94 mg/l	Gonçalves et al., 2016
Ag	*Ficus racemose*	Bark extract	25–150 nm	Larvicidal activity *against Culex quinquefasciatus* and *Cx. gelidus*	Velayutham et al., 2013
Ag	*Polianthus tuberosa*	Bud extract	–	Larvicidal activity *against Culex quinquefasciatus* and *Cx. vishnui*	Rawani, 2017
Ag	*Polianthus tuberosa*	Flower extract	–	Antimicrobial effects on *Staphylococcus aureus, Bacillus subtilis, Escherichia coli, Pseudomonas aeruginosa, and Klebsiella Pneumoniae*	Kumaran et al., 2019

Table 7 (continued)

Type of nanoparticle	Plant species	Parts used	Size of Ag NPs	Bioactive potential	References
Ag	*Caesalpinia pulcherrima*	Stem	3–15 nm	*a)* Antimicrobial activity against *E. coli*, *Salmonella typhimurium*, *Klebsiella pneumoniae*, *S. aureus*, *Bacillus cereus*, *B. subtilis, Corallium rubrum, Pseudomonas aeruginosa* *b)* Antioxidant activity *c)* Cytotoxic activity against HeLa Cell lines	Moteriya & Chanda, 2018
Ag	*Lonicera Japonica*	Flower extract	2–100 nm		Nagajyothi et al., 2012
Cu	*Mimusops elengi*	Flower extract	42–90 nm	a) Antibacterial activity against *Escherichia coli, Streptococcus, Staphylococcus*, *Pseudomonas,* and *Bacillus subtilis* b) Antifungal activity *Aspergillus flavus, Candida albicans, Penicillium* and *Aspergillus fumigates* c) Antioxidant activity d) Thrombolytic activity e) Anti-larval activity f) Cytotoxicity activity Heavy metals removal	Sarah & Iyer, 2019
Mg	*Rosmarinus officinalis L*	Flower extract	20 nm	Antibacterial activity against *Xanthomonas oryzae* pv. *oryzae*	Abdallah et al., 2019
ZnO	*Clitoria ternatea*	Flower extract	41 nm	Antibacterial activity against *Escherichia coli* and *Staphylococcus aureus*	Prabhu et al., 2021
Au	*Polianthes tuberosa*	Flower extract	38.76 nm	-	Alghuthaymi et al., 2021
Ni	*Butea monosperma*	Flower extract	31.77 nm	-	Tayade et al., 2017
MgO	*Rosa floribunda charisma*	Flower extract	35.25–55.14 nm	a) Antioxidant b) Antiaging c) Antibiofilm activities	Younis et al., 2021
ZnO	*Jacaranda mimosifolia*	Flower extract	2–4 nm	a) Antibacterial activity against *Escherichia coli* and *Enterococcus faecium* Adsorption studies	Sharma et al., 2016

quinquefasciatus, the LC50 and LC90 values are 9.65 ppm and 27.18 ppm, 7.94 ppm, and 22.47 ppm, respectively, against the 3rd and 4th instars (Rawani, 2017).

Silver nanoparticles synthesized from the aqueous extract of the flower of *Polianthus tuberosa* showed strong antimicrobial activity against the human pathogens *Staphylococcus aureus, Bacillus subtilis, Escherichia coli, Pseudomonas aeruginosa, and Klebsiella pneumoniae,* even at the lowest concentration (Kumaran et al., 2019). In the study, the antibacterial activity was conducted at different concentrations of AgNPs, ranging from 100 µg to 300 µg. The maximum zone of inhibition (mm) was recorded at 300 µg for all the test pathogens. The results obtained were compared with the effects of the standard antibiotic, tetracycline. Cytotoxicity was determined based on cellular morphologic alterations described by El-Ansary et al. (2023).

Gold nanoparticles (AuNPs) synthesized from the flower extract of *Polianthus tuberosa* exhibited antibacterial activity against gram-positive *Staphylococcus aureus* and gram-negative *Escherichia coli* (Alghuthaymi et al., 2021). The presence of a thick peptidoglycan layer in *S. aureus* and a thin layer in *E. coli* acts as a barrier for synthesized AuNPs (Alghuthaymi et al., 2021). Reactive oxygen species (ROS) are created when the AuNPs attach to the negatively charged cell membrane. This damages the cellular respiration chain, which further modifies the DNA, proteins, and cellular synthetase function and eventually causes cell death. The stem of *Caesalpinia pulcherrima* was used to synthesize silver nanoparticles (AgNPs), which demonstrated antibacterial efficacy against *Salmonella typhimurium*, *E. Coli*, *Klebsiella pneumoniae*, *S. aureus*, *Bacillus cereus*, *B. subtilis*, *Corallium rubrum*, and *Pseudomonas aeruginosa* (Moteriya & Chanda, 2020). However, the flowers of *Caesalpinia pulcherrima, which are* used in large amounts and are claimed to be effective against intestinal worms and in treating sores, have not yet been prospected for nanoparticles.

Other metal-based nanoparticles (e.g., Ti, Cd, Cu, Fe, Zn, and Mg) are being proposed as an alternate class of flower-derived nanoparticles. For instance, MgO nano-flower synthesis has been conducted with rosemary (*Rosmarinus officinalis* L.) extract under a stirring condition at 70 °C for 4 h (Abdallah et al., 2019). Petals of the marigold flower (*Tageta sp.*) have been reported for deriving cadmium nanoparticles (Hajra et al., 2016). Similarly, ferrous NPs have been extracted from the aqueous flower extract of *Piliostigma thonningii (*Igwe & Nwamezie, 2018), and titanium dioxide nanoparticles have been synthesised from *Calotropis gigantean* flower extract. CuNPs have been synthesised from *Mimusops elengi* flower powder (Marimuthu et al., 2013).

Therefore, flowers are not only a source of aesthetic pleasure and delicacy but also a potential source of multiple drugs and nutraceuticals. A distinct ancient Indian discipline, the 'Puspa Ayurveda' originates from the historical 'Paintings' depicting applications of flowers in curing multiple ailments, recording medicinal advancement during the Buddhist period. Classical Indian literature classifies flowers based on their various uses, and important recipes are recorded in medical treatises. This classifies flowers as 1. ornamental flowers. 2. commercial flowers 3. medicinal flowers. 4. kitchen or vegetable flowers. However, the synthesis of such useful compounds from flowers has not been standardised yet. Flowers are being wasted and dumped to contaminate human and ecosystem health. Recently, ZnO NPs extracted from the floral extract of *Nyctanthes arbortristis* have been shown to possess strong antifungal activity (Jamdagni et al., 2016).

Nanotechnology has offered a multitude of benefits to the environment, health, agriculture, and food industry with the properties of antimicrobial agents, nanobiosensors, food packaging material, catalysts, etc. (Dhanker et al., 2022; Deepa & Dhanker, 2022; Deepa et al., 2023). In the case of the agri-industry, mycotoxin contamination is one of the major stresses of the agriculture and sustenance industries. Farmers require eco-friendly compounds that can fight fungi. The antifungal potential of floral nanoparticles has immense potential to mitigate mycotoxin pollution. Utilization of FWs for the green synthesis of nanoparticles is an emerging sustainable and eco-friendly method. It is a cost-effective and biocompatible alternative to conventional methods that can be used potentially for various applications such as medicines, environmental remediation, and catalysis. The green synthesis of nanoparticles from FWs is an exciting area of research in which further progress in research will benefit the environment and society.

4 FWs Recycling Business in India

India generates tonnes of FWs every day. Several social entrepreneurs are aware and focused on upcycling these FWs into valuable products, mitigating the adverse effects on aquatic and human health. These companies are focused on mitigating environmental pollution and providing employment and a better livelihood to the unemployed women from rural backgrounds.

Various Indian companies and organizations involved in the collection, recycling, and utility of FWs are as follow:

a) **Art of Living Foundation**: Collaborating with entities such as Coal India to scale its solid waste management project
b) **Help Us Green**: Upcycle 2.4 TPD FWs from the temples and mosques of Uttar Pradesh (Prakati India, 2022).
c) **Phool:** Upcycle FWs into essential products like incense sticks, organic composition, and eco-friendly alternatives to Styrofoam-Florafoam. Collects about 4 TPD FWs of religious waste every day from temples around Uttar Pradesh (Prakati India, 2022).
d) **Holywaste** is an initiative by Oorvi Sustainable Concepts Pvt. Ltd., based in Hyderabad. The company recycles 200 kg of FWs daily and prevents improper disposal and landfilling of FWs in collaboration with 40 temples, 2 flower vendors, and a market zone.
e) **Indian Institute of Horticultural Research** (IIHR):- IIHR is a research institute under the Indian Council of Agriculture Research (ICAR) that focuses on horticultural research development.
f) **Aaruhi Enterprises:** A startup by Poonam Sherawat and Pinki Yadav in June, 2019 is a Delhi-based company (Mani, 2024). Upcycle 1000 kg of FWs every month from temples in Delhi into incense sticks, incense cones, diyas, and idols.
g) **Sanjeevani Self-Help-Group (SHG):** A group of 10 women working under the guidance of Rekha Rani collect almost 100 kg of FWs every day from Kol Kandoli shrine in Jammu and Kashmir (Mathur, 2022). These FWs are then upcycled into incense sticks and are then marketed in Kol Kandoli shrine, Vaishno Devi shrine, and other major shrines in Jammu.

4.1 Economic Feasibility and Cost Analysis

Scaling the floral waste recycling approach to the commercial level is an extensive task. While finding the possible ways of FWs recycling should not be limited to research work it should be implemented globally so that it can contribute towards a better environment, reducing resource depletion, implementing the habit of using environment-friendly products, and awareness among the citizens about the benefits of recycled and upcycled material. The expense in the FWs recycling business will include collection, segregation, treatment, production, marketing, and awareness. However, much more needs to be done to have an understanding of the expense included in recycling FWs, the information provided here is completely based on our observation and understanding.

a. **Collection and Transport:** The collection cost will be minimal as the material is already regarded as waste. The only cost included here can be the transport of FWs and that too can be reduced if recycling at a small scale can be done at the source itself.
b. **Segregation:** Manual sorting needs to be done to separate different floral wastes according to their properties to obtain the best valuable product out of it.
c. **Pretreatment:** Out of all the valuable products that can be extracted from FWs, mostly water is used as a cleaning agent to wash away the impurities, and if drying is required, the air-drying process is mostly carried out under sunny weather making it cost-effective.
d. **Production:** Value-added products such as biofertilizers, biogas, charcoal, incense, dye, etc. require no advanced technologies. Also, the by-product of one process can be used as a feed for another.
e. **Marketing:** Since people are becoming aware of the use of renewable and biodegradable products, producers and consumers both are concentrating on being environment friendly. Tons of FWs are being dumped daily. Conversion of these FWs

into valuable products will bring revenue generation and also lessen the new resource extraction.

f. **Awareness:** Several campaigns and training programs need to be conducted in collaboration with NGOs for awareness of people to understand the value of depleting resources, reusables, environmental degradation, and how to extract valuables out of waste at a small scale.

5 Appropriate Methods of Recycling FWs at Source (= at Home)

People generally use flowers for worship and aesthetic purposes at home. However, the flowers once utilised are considered stale and are usually dumped away. These flowers possess multiple beneficial properties that can be utilised to increase household income.. For instance, *Hibiscus* has been traditionally known for its hair nurture properties. The ground paste of the *Hibiscus* flower when infused with coconut or almond oil is beneficial for hair growth. Rose petals are also traditionally utilised in making gulkand (a sweet preserve of rose petals), rose petal tea which is proven to be beneficial for hyperacidity, constipation, vata, pitta, and integumentary diseases, and have a cooling effect (Hegde et al., 2022). In addition, FWs at home can be utilised as compost by mixing it with vegetable wastes, or FWs can be dried and crushed to spread over the soil in pots or gardens to be used as a mulching agent.

6 Meeting the Sustainable Development Goals (SDG) and Promoting Circular Economy

Towards global solution of ongoing biodiversity loss, climate change, habitat degradation and in the background of millennium development goals-2015, UN adopted 17 agenda to be achieved by 2030, known as the SDG-2030. The current review is thus focused on addressing – **(i) SDG-6**: Clean Water and Sanitation by mitigating the FWs that end up in water bodies and landfills producing toxins, causing eutrophication, and converting water non-consumable and lands unsuitable for vegetation. (ii) **SDG-12**: Responsible Consumption and Production by extracting the maximum potential of flowers to gain valuable products and limiting resource usage, providing a green and clean alternative to synthetic products with minimum environmental impacts (fertilizers, dyes, incense, fuels, etc.), increasing the longevity of flowers, mitigating the greenhouse gas generation from landfills, extracting valuables from waste, and thus promoting circular economy.

The fundamental principle of circular economy is “to covert waste into useable materials generating more income while reducing “waste”. Thus whole concept of circular economy is based on reapplication, recreation, repair and recycling postconisation residues to generate a “closed loop” system, maximizing output and minimizing (Nandi et al., 2021). Here the wastes of conventional use of flowers act as raw materials for the creation of other valuable products. Thus, we intended to describe all the possible ways of FWs management, recycling, value-added product generation, economy generation, and mitigating the adverse effects caused to the environment. The current review is thus focused on addressing **1. SDG-6**: Clean Water and Sanitation by mitigating the FWs that end up in water bodies and landfills that produce toxins, cause eutrophication, and make water non-consumable, lands unsuitable for vegetation. **2. SDG-12**: Responsible Consumption and Production by extracting the maximum potential of flowers to gain valuable products and limiting resource usage, providing a green and clean alternative to synthetic products with minimum environmental impacts (fertilizers, dyes, incense, fuels, etc.), increasing the longevity of flowers, mitigating the greenhouse gas generation from landfills, extracting valuables from waste, and thus promoting circular economy. Also, the waste product of one process can be used as a feed to another. For instance, the waste generated after dye, essential oils, phytochemicals, and nanoparticle extraction, can be used as a feed for biofertilizer production thus enhancing circular economy. The extraction of valuable product, decentralised reuse of flower wastes after conventional use at to increase household income has potential to achieve the Goal 8 of SDG 2023: that targets to meet higher levels of economic productivity through diversification, technological upgrading and innovation, including through a focus on higher value added and labour intensive sectors.

As per the Sustainable Development Goals Report-2022, 8, 29,000 people die every year due to unhygienic water and improper sanitation. According to the report, only 74% of people globally are accessible to safe drinking water in 2020. Urban livelihoods are generating more waste as compared to rural ones. Also, the unsustainable practices of production and consumption add to it. Besides all the waste management approaches, solid waste dumping and environmental degradation is still a concern for the existing and upcoming generations. With the increasing population, the waste generation is also increasing. Flowers are utilised for religious offerings, ceremonies, industrial uses, aesthetic purposes, etc. However, once utilised these flowers end up in landfills or rivers polluting the soil and water, threatening life, and causing environmental degradation.

7 Conclusion

With a steady rise in population and the number of temples in the country, the quantity of floral waste is increasing enormously. Among the constituents of municipal solid waste, the degradation of floral waste is steady in comparison to vegetable or kitchen waste. Approximately 8 million metric tonnes of floral waste are dumped in rivers in India every year. Flower possesses high nutritional content and essential phytochemicals such as carotenoids, flavonoids, and phenolic acids. Though value addition to ornamental flower crops has been recently proposed in consideration of enhancing employment and economic value, suggested measures ultimately escalate the dumping of flower waste in landfills. The floriculture industry includes ornamental plants, flowers (cut and loose), and value-added products from flowers and flower parts that are earning huge amounts of money in the market, and several industries are adding economic value and creating jobs. Flower value creation is the process of deriving genetic and processing changes and using innovative methods to increase the economic value and attractiveness of all floricultural products. However, more attention needs to be paid to waste flowers after being used as potpourri, flower bouquets, bouquets, floral bangles, floral wreaths, floral crowns, religious offerings, decorations, etc., i.e., after such value additions as suggested earlier.

Proper management of floral waste is required to prevent land and water pollution. Floral waste can be a possible source of synthesizing anti-microbial and anti-pathogenic agents, too, without any ecological imbalance. Mitigating floral waste for essential extractions like biofertilizers, biosorbents, bioenergy, pharmaceuticals, dyes, incense sticks, and nanoparticles can reduce the increasing burden of floral waste management and also yield high economic gains, promoting a circular economy. The natural degradation of wasted flowers is a very slow process compared to the degradation of kitchen waste. These FWs are wrapped in plastic or mixed with other wastes and dumped either into landfills or rivers, slowing their natural degradation time, so useful substances cannot be extracted; therefore, it will be prudent to extract the useful substances at the source itself to save transportation time, enhance the farmer's income, create a circular economy, and promote Sustainable Development Goal 6: Clean Water and Sanitation and Sustainable Development Goal 12: Responsible Consumption and Production.

This way, it will help to minimize the floral waste, decrease the decay process, decrease the methane gas emission, and mitigate river eutrophication from floral waste disposal. UNEA 4. Resolution 1 (UNEP/EA.4/Res.1) describes the circular economy as one of the sustainable economic models in which products and materials are extracted to be reused, recycled, or recovered, the generation of waste is minimized, and greenhouse gas emissions are prevented or reduced. In the light of UNEA.4/RES.1, the present review summarizes the ongoing and possible extraction from floral waste, their applications, and their bioactive potential for harvesting resources from the waste.

8 Future Research and Recommendations

While using FWs for food, nutraceuticals, and pharmaceutical purposes, it is necessary to identify the suitable flower species. It is essential to conduct proper testing and analysis to ensure the safety and quality of the extracts. Besides this, sustainable and responsible waste management practices must be followed to minimize the environmental impacts of where the flowers are sourced. Bioethics and biosafety regulations and guidelines should be followed carefully before evaluating FWs for these purposes commercially.

FWs management is a promising and innovative way of reducing waste in the environment and has various future perspectives and recommendations. The composting of FWs provides opportunities to produce nutrient-rich fertilizers that can be used for gardening in communities, in agriculture, horticulture, and in landscaping. It will enhance soil health and biodiversity. Biogas, a renewable energy produced from the anaerobic digestion of FWs, can be used for domestic as well as other purposes. Proper management of FWs can be utilized for various purposes; for example, it can be used to extract natural dyes, valuable compounds, nanoparticle generation, environmental remediation, medicines, food, and pharmaceuticals that show eco-friendly alternatives to synthetic products. Government, flower companies, communities, and the public may come together to develop a circular economy model for FWs management in which FWs should be collected from the source, processed, and used to generate value-added products, bioenergy, natural dyes, important oils, nutrient-rich fertilizers, and green synthesised nanomaterials for promoting responsible waste management with minimum environmental impacts. Generated biofertilizers can be delivered for urban gardening and green spaces. It will beautify the cities, enhance the air quality and aesthetics of the cities, and provide creative spaces for the communities.

The government and communities should encourage FWs by creating awareness, providing education, incentives, and facilities for FWs composting and recycling. The government can put hands together with florists, retailers, and flower shops for effective, maximum, and timely management of FWs. In-depth research on FWs will promote its maximum fruitful utilization. A significant amount of funds invested in research by the government can encourage research and promote innovative technology development that further enhances economic opportunities and future markets. The government can work with different stakeholders to formulate policies and regulations for FWs management, recycling, and their requirements for a positive impact on the environment and society. By adopting these future prospects and recommendations, we will enhance the optimum utilization of FWs, which will contribute to a greener future and a more circular economy for the country.

Various investigations have been done so far for the green synthesis of metal nanoparticles from certain biological materials. Green synthesis of nanoparticles from flower wastes will be a highly facile, non-toxic, and inexpensive approach with the potential to produce very useful NPs. However, few works have been done on the green synthesis of metal nanoparticles from temple FWs and their bioactive potential. Research and development at a scalable level for the synthesis of metal nanoparticles from dumped floral wastes and characterising their bioactive potential Farmer- or people-friendly methods of green synthesis of metal nanoparticles from waste need to be developed at commercial levels in light of sustainable development goals for 2030. Modifications at different concentrations, temperatures, and pH for synthesis and a comparative study of the bioactive potential of synthesized metal nanoparticles from various flower wastes need to be analysed. Also, the long-term exposure effects of these nanoparticles in the natural system and on non-targeted organisms need to be investigated.

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Declarations

Ethics Approval This article does not contain any studies with human participants or animals performed by any of the authors.

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Consent for Publication The manuscript is original. It has not been published previously by any of the authors and even not under the consideration in any other journal at the time of submission.

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