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Exploring temple floral refuse for biochar production as a closed loop perspective for environmental management

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ABSTRACT

Religious faith and ritual activities lead to significant floral offerings production and its disposal as waste to the nearby open lands and water bodies. These activities result into various social and environmental nuisances because of their high organic content. Alternatively, it can be used as valuable resources for various biochemical and thermo-chemical processes. Floral refuse has been utilized in natural dye extraction, however, the residual solid refuse is of significant environmental concern due to its nutrient rich nature. This study explores the potential utilization of solid residue of temple floral refuse after natural dye extraction by thermo-chemical decomposition of it. The slow pyrolysis of solid residue was performed at 350 °C and 500 °C, and the biochar yield of 42 and 36% was obtained, respectively. TGA-DTG analysis was performed to observe the thermo-chemical behaviour of floral refuse. The biochar products were further characterized by FTIR, SEM, EDX, BET, XRD, and RAMAN spectroscopy to observe the impact of pyrolysis temperature (PT) on the resulting material, *i.e.* biochar and its possible application measures. EDX results revealed the presence of various macro-nutrients such as C, N, P, K Ca and Mg in different proportions which showed its soil amelioration potential. Moreover, based on the SEM and BET results, biochar prepared at 500 °C was further explored for adsorption of methylene blue dye at various dose and pH conditions. Based on Langmuir (R^2 = 0.98) and Freundlich (R^2 = 0.97) isotherms, it is found as a potential adsorbent material for removal of methylene blue dye. The results revealed that biochar conversion of colour extracted floral refuse can be a vital option for quick and efficient management of it in a closed loop approach.

1. Introduction

As the second most populous country in the world, challenges concerning waste management are deep-rooted in India. The country produces a diverse range of wastes possessing distinct characteristics which calls for specific handling and disposal provisions. For instance, due to their dietary, cultural, religious, social and several other day-to-day habits, solid waste in Indian cities is often comprised of 70–80% organic matter (Ramachandra and Bachamanda, 2007; Gupta et al., 2015; Aparcana, 2017). Floral refuse, generated from ritual offerings, is one of the potential waste generated in the Indian cities which need a special attention for its management (Singh et al., 2017). It mainly contains a mixture of several flower types, leaves of different trees, milk and milk products. Moreover, marigold flowers (yellow to orange-red in colour), which are rich source of carotenoid (lutein) and flavonoids (kaempferol or quercetin-like structures, quercetagetin, luteolin, patulitrin and patuletin) pigments, mainly constitute the floral refuse generation from Indian cities (Bhardwaj et al., 1980). Environment-friendly disposal of floral waste/refuse in itself is a major sustainability concern due to the lack of appropriate

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dumping facilities and stringent environmental legislations in cities (Shinde, 2012). Therefore, appropriate management of floral waste has the potential to provide incentives for a wide range of commercially significant industries.

Varanasi, situated in Uttar Pradesh state of India, is considered as one of the holy cities in the country, and thus, attracts a potential tourist attraction and ranks among the top ten tourism cities. However, the city is subjected to a severe challenge of managing its waste, including significant portions of floral refuse, generated from its hundreds of temples on a daily basis. A common practice in the temples of the city is to throw away the flowers offered at the temples into the nearby rivers or other water bodies, once the idol worship is performed. This practice results in severe water pollution events across the city, specifically in rivers. Further, due to the lack of proper waste disposal facilities, floral refuse is often open dumped, causing various environmental consequences such as foul odour, as breeding centre for disease causing microorganisms, decreases recreational importance of water bodies as well as causes soil contamination due to its nutrient-richness and their leaching (Singh et al., 2013). Nevertheless, Varanasi is not the only city subjected to severe floral waste disposal crisis. The situation is equally worrisome in several other pilgrimage sites throughout the Indian subcontinent. This calls for immediate attention towards the implementation of proper floral waste management mechanisms in the city.

Floral waste, for instance, could act as major resource material for a variety of processes in industries such as colour extraction, biogas production, vermicomposting, biochar for agricultural application and so on (Singh et al., 2013; Singh et al., 2017). Recently, Singh et al. (2013) and Singh et al. (2017) explored the floral refuse as a source for Vermicomposting and natural dye extraction, respectively. However, these approaches did not show the holistic management of such waste. For example, vermicomposting appears to be the most suitable biotechnological process where earthworms and soil microorganism causes degradation of waste material into valuable manure (Singh et al., 2013). However, it is highly influenced by environmental variables and nature of composting mixtures (especially cellulose) which directly affects the growth and other activities of earthworms and microorganisms resulting into delayed response (Singh et al., 2013). Moreover, composting/vermicomposting is inversely proportional to the amount of cellulose and lignin (dominated by phenolic compounds) as their structural complexity resulted into time-lag in degradation (Buswell, 1995). These flaws resulted in failure of established composting and vermicomposting plants. Thus, it is necessary to search for other reliable methods of floral refuse management.

Recently, thermo-chemical conversion of lignocellulosic biomas is getting significant attention of scientific communities, as the by-products (bio-oil, *syn* gas and biochar) of the process have multifaceted applications in addition to the environmental management (Singh et al., 2015). For example, the biochar has been explored for soil improvement, increasing nutrient retention, and for global climate change mitigation (Zhang et al., 2016). Biochar is highly carbonaceous material having high surface area and several micro- and macro-nutrients in addition to various functional groups on its surface (Lehmann and Joseph, 2009; Gunarathne et al., 2017; Mohan et al., 2018). Therefore, biochar synthesis by pyrolysis of floral refuse can be explored for multifaceted applications such as soil ameliorant and as an adsorbent for removal of pollutant from wastewater (*i.e.* synthetic dye, heavy metals and other organic pollutant) (Singh et al., 2015; Mohan et al., 2018). In the light of recent literature, thermo-chemical decomposition of natural dye extracted floral refuse can be explored as a sustainable measure of waste management, in addition to its multiple benefits as adsorbent and soil ameliorant. Therefore, in the present study, the floral refuse has been used for biochar preparation which has been further characterised using various advanced techniques to merit its suitability as an adsorbent and soil ameliorant.

2. Material and methods

2.1. Raw material collection, processing and colour extraction

Residual floral waste (mainly marigold flower, *Tagetus erecta* L.) was collected from waste bins of a few temples of Varanasi city, India. The collected materials were segregated and flowers were washed with tap water and dried in a hot air dryer at 50 °C. The dried materials were shredded and grinded to about 200 mess sizes. The detailed process is depicted in Fig. S1. The colour from the flower refuse was extracted by using ultrasonication process. The grinded flower sample (200 mesh size) was mixed with methanol (1:10 *w/v* of sample:methanol) in a beaker and the pH was adjusted to 2.0 by using diluted NaOH and/or HCl to attain maximum colour extraction (Mishra et al., 2012). The beaker was then placed in an ultrasonic bath and sonicated for 40 min. After sonication, the content of beaker was filtered to remove the solid materials. The filtrate colour liquid was vacuum evaporated in a rotary vacuum to half of the original volume. The concentrated liquid was spray dried using LSD-48 mini spray dryer (JISL India). The inlet and outlet temperatures were maintained at 110 and 70 °C, respectively, and the aspiration speed was kept constant at 1200 rpm. The details of colour production and its characterization are reported earlier (Singh et al., 2017).

2.2. Pyrolysis of floral refuse

The residue left after the colour extraction was air-dried initially and oven dried at 72 °C for 48 h to remove moisture. The oven-dried floral refuse was pyrolysed at two pyrolysis temperatures (350 and 500 °C) to observe the variation in the biochar produced because of low- and high-temperature pyrolysis. Temperature hold time was 30 min under continuous N_2-gas flow. The ramp rate of the pyrolyzer was 10 °C min^{-1} (signifying a slow pyrolysis process). The pyrolyzer schematic diagram is presented in Fig. S2. The gas released during the pyrolysis process was passed through a condenser and the liquid representing bio-oil was collected in a separate vessel, whereas the solid remains representing biochar, was collected for further characterization and application. Mass of solid biochar was calculated to define the pyrolysis yield.

2.3. Advanced characterization of floral refuse and biochar

The decomposition behaviour of the floral refuse was observed by using thermo-gravimetric analysis (TGA). The thermal properties of adsorbents were analysed using a DTA-TG apparatus (DTG-60H, Shimadzu, Japan) in the temperature range of 25–550 °C, at a heating rate of 10 °C min^{-1} in nitrogen atmosphere. Further, the biochar obtained from the pyrolysis of floral refuse at 350 and 500 °C were characterized for surface, phase and chemical characteristics using various analytical and spectroscopic techniques such as Brunauer–Emmett–Teller (BET)-surface analyser, Scanning Electron Microscopy (SEM), Energy Dispersive X-ray Spectroscopy (EDX), X-ray diffraction (XRD), RAMAN spectroscopy and Fourier-Transformed Infra-red Spectroscopy (FTIR). The specific surface area of different biochar samples were measured by BET-N_2 adsorption method (Brunauer-Emmett-Teller) using Micrometrics ASAP-2020, where the samples were dried with constant flow of N_2 at 600 °C for 24 h, with relative pressure (P/P_o) ranging from 0.01 to 0.20 (Bai et al., 2009). Surface characteristics were observed using SEM (FEI QUANTUM 600F) operating at 4 kV