



Implementation of *Syzygium cumini* Garden Waste Biochar as a Sustainable Source for the Synthesis of Paints and Pigments

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ABSTRACT

With increasing concerns about environmental degradation and the need for sustainable alternatives, the repurposing of organic waste materials, such as garden waste biochar, is considered a feasible opportunity to mitigate waste accumulation by creating value-added products. The present research study aims to identify the potential and investigate the feasibility of utilizing *Syzygium cumini* garden waste biochar as a sustainable source for pigment and paint formation. Biochar was produced from garden waste via carbonization, highlighting its chemical composition and physical properties that are conducive to the development of pigments and paints. Furthermore, this study examined various extraction techniques to isolate pigments from biochar by assessing their color properties, stability, and compatibility with paint formulations. These findings suggest that *Syzygium cumini* garden waste biochar holds promise as a sustainable source for pigment and paint formation, offering environmental benefits and contributing to the circular economy. In the case of feed-derived pigments, the *Syzygium cumini* biochar-based pigment exhibited a comparatively better color intensity. Spectrophotometric analysis indicated high color retention and stability over time, suggesting its viability for various applications in the paint and dye industries. This establishes the novelty of this work, as commercial pigments are oil-based products that generate carbon footprints. This study contributes to the growing body of knowledge on sustainable material utilization and provides insights for the development of eco-friendly paint products in the construction and coatings industries.

INTRODUCTION

The Industrial Revolution brought about a rapid transformation in the socio-economic lives of people on Earth. Due to rampant energy usage, particularly fossil fuels, the environment is suffering from consequences such as the generation of excessive waste, climate change, soil and water pollution, and food shortages. By emphasizing innovative waste management, waste that mainly contains biomass or biomass-derived products can be reduced. Recent epidemics and pandemics have proven that improper waste management poses a significant threat to human health. In addition to its unattractive appearance, it leads to air pollution, contaminates water bodies through dumping, and contributes to ozone layer depletion when waste is incinerated, accelerating unwanted climate change. According to reports, 1.3 billion tons of bio-waste are generated annually worldwide, and this amount is predicted to increase to 2.2 billion tons per year by 2025 (Nizami et al. 2017). The global market value of biotechnology for bio-waste-to-energy was approximately \$25.32 billion in 2015 and surged to \$40 billion by 2023 (Ubando et al. 2021). Innovative technologies are being researched to convert bio-waste into valuable materials using techniques such as aerobic fermentation, hydrothermal liquefaction, gasification, pyrolysis, carbonization, and anaerobic digestion (Joshi et al. 2023, Reshmy et al. 2022a).

To address these issues, the Sustainable Development Goals have been established to tackle a range of ecological concerns. One such greener method is to prepare biochar, which has multidisciplinary applications in the cement and fertilizer industries, construction industries, composites in polymers, and materials science and engineering (Kinney et al. 2012, Shackley et al. 2012). Biochar is a carbonaceous substance (carbon neutral/carbon negative) produced after carbonizing biomass in the absence of oxygen (Vassilev et al. 2013). Biochar possesses various physicochemical properties depending on the type of biomass used and the carbonization temperature for its preparation (Gaur & Pooniat 2024). Carbonization is a promising approach for thermally converting organic materials into carbon in the absence of oxygen-rich residues and value-added products. The carbonization process can accommodate different feedstocks, ranging from municipal solid waste and industrial effluents to agricultural residues and forestry by-products (Joshi & Kulkarni 2012, Aruna et al. 2018). Under controlled pyrolytic conditions, feedstocks yield a spectrum of carbonaceous materials with tailored properties suited for specific applications. The resultant carbonaceous materials exhibit a myriad of beneficial characteristics, including high surface area, chemical stability, electrical conductivity, and mechanical strength, rendering them suitable for various value-added applications (Alam & Ahmade 2013). For instance, biochar derived from biomass carbonization has demonstrated efficacy in soil amendment, water filtration, and carbon sequestration, thereby addressing pressing environmental concerns such as soil degradation and water pollution (Dehankar & Joshi 2024, Ogwueleka 2009). The bioavailability of heavy metals in soil and water is reduced by biochar, which ultimately reduces heavy metal pollution and improves the quality of contaminated soil and water (Lasaridi et al. 2018, Joshi et al. 2015, Khan et al. 2018).

Biochar, a form of charcoal produced from biomass via pyrolysis or gasification, has garnered attention as a sustainable alternative to conventional pigments derived from non-renewable sources. Incorporating biochar into paints offers a means of utilizing carbonization residues and reduces the environmental impact of paint production. The utilization of biochar as a pigment in paint is a novel and sustainable concept, and significant research is needed to explore its feasibility, efficacy, and environmental impact. This study aims to address this gap by investigating the properties of biochar as a pigment, its compatibility with different paint formulations, and its potential impact on the performance and sustainability of paint products. This study focuses on the implementation of *Syzygium cumini* garden waste biochar for pigment and paint synthesis and explores sustainable alternatives to traditional materials by utilizing organic waste

for value-added applications. This study investigated the biochar properties and pigment formation mechanisms from feed and offered insights into the resource efficiency and environmental benefits in the pigment and paint industries.

MATERIALS AND METHODS

Collection of Garden Waste and Feed Formation

Leafy biomass, mostly consisting of Jamun leaves (*Syzygium cumini*), was collected. The leaves were atmospherically dried for a few days and crushed using a pulverizer to a particle size of 9-45 mm. The dried leaves were sieved through a 1000 μ sieve before feeding into the carbonization process (Toledo et al. 2018, Jain et al. 2022, Awasthi 2022, Awasthi et al. 2021).

Conversion of Biomass to Biochar

The carbonization reactor configuration is a crucial aspect of the pyrolysis process, which involves the conversion of biomass into valuable biochar. The design and setup of the reactor significantly impact the efficiency and quality of biochar production. During carbonization, biomass is heated within a temperature range of 0–500°C, devoid of oxygen but with a continuous flow of nitrogen at a set point of 0.2, over a 4-h reaction period. Constructed from high-grade stainless steel, the cylindrical chamber ensured durability and withstood high temperatures. A tightly sealed lid creates an oxygen-free environment that prevents biomass combustion. The precision-designed lid facilitates easy loading and unloading of the biomass, ensuring seamless operation.

The heating system is an integral component of the reactor setup and usually comprises electric or gas-fired heaters. The temperature control system maintains optimal pyrolysis temperatures, which are crucial for influencing the carbon yield and quality. Temperature control removes volatile components and enhances the stability of carbon. To improve process efficiency, a syngas collection system captures and redirects the evolved gases, including syngas and vapors, for further processing or energy recovery. This maximizes resource utilization and minimizes environmental impact by reducing emissions. The reactor also features an exhaust-gas treatment system to mitigate environmental concerns. This system minimizes the release of harmful by-products, such as tar and particulate matter, ensuring compliance with emission standards and promoting sustainable biochar production. The overall process of biochar formation is illustrated in Fig. 1.

Pigment Preparation from Feed

Pigment formation from dried jamun leaves in a water-

based medium involves several key steps, as shown in Fig. 2. Initially, dried jamun leaves were collected and finely ground into a powder. Subsequently, a water-based extraction method was employed to extract the pigments. This process involved immersing the powdered leaves in distilled water

for a specific duration to facilitate pigment extraction into the solution. After complete soaking, the solution was filtered to eliminate solid debris, resulting in a clear, pigment-enriched extract. The filtered solution was then allowed to settle in a normal environment for 24 h. The solution was then dried at

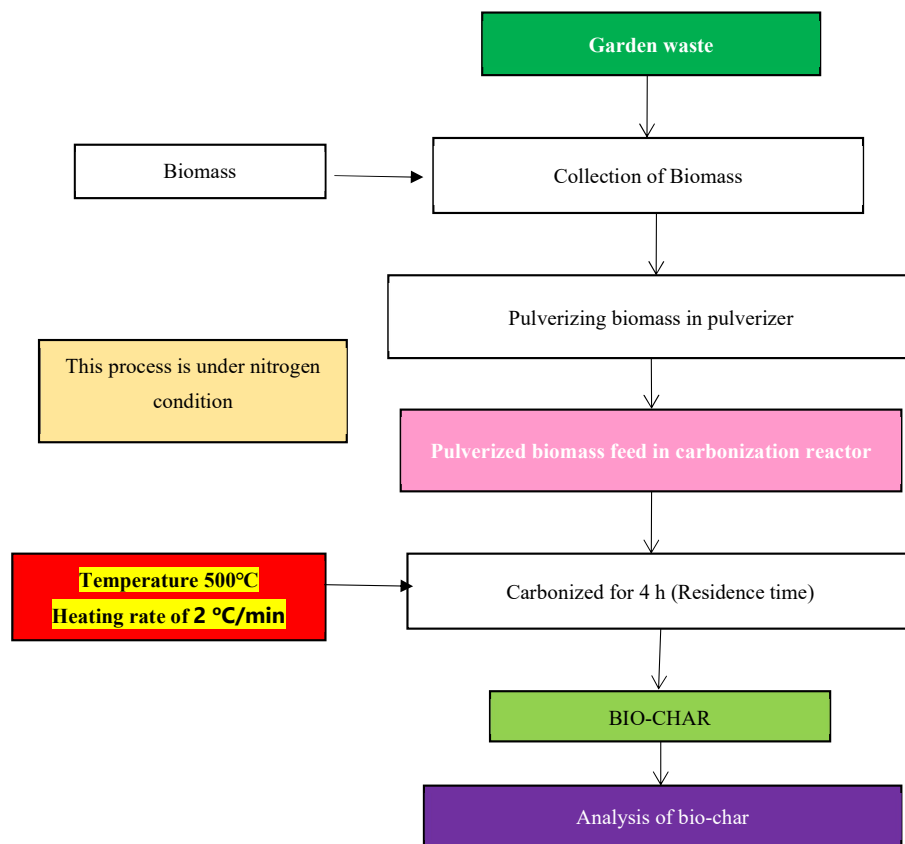


Fig. 1: Block diagram representing the carbonization process.

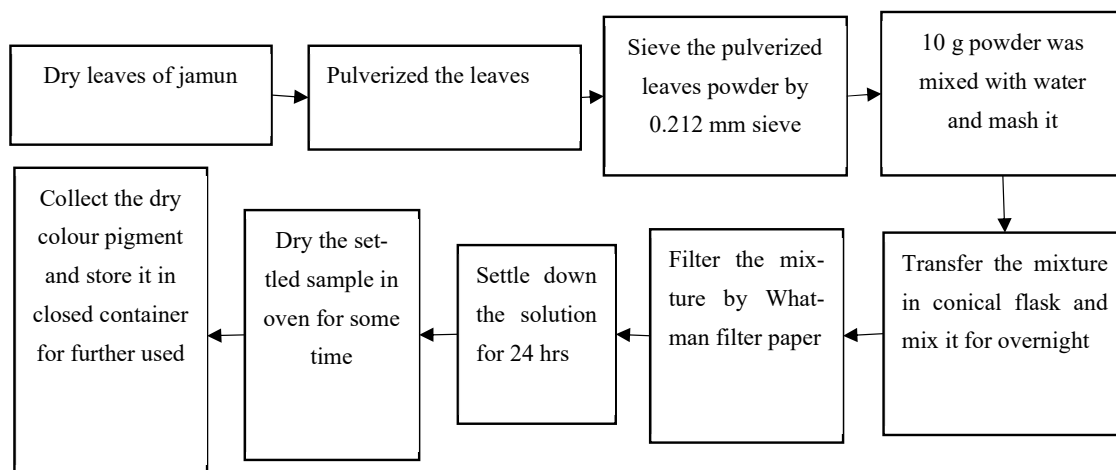


Fig. 2: Block diagram demonstrating the process of pigment formation from dry leaves.

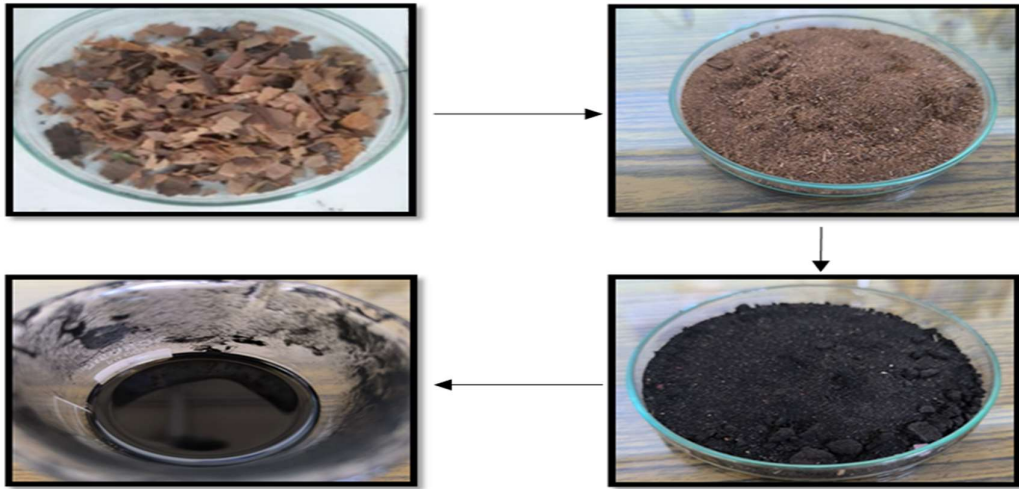


Fig. 3: Process of paint formation using *Syzygium cumini* garden waste biochar.

50°C in a hot air oven. Once dried, the pigment material was crushed, sieved to ensure uniformity, and stored in airtight containers for further analysis (Fig. 3).

Formation of Paint from Extracted Pigment

Biochar is extracted through carbonization, a process that involves subjecting biomass to high temperatures in low-oxygen environments. A 2 g sample of biochar was meticulously ground into a fine powder using a mortar and pestle to ensure uniformity and consistency in the particle size. Subsequently, the powdered biochar was sieved through a mesh with a pore size of 0.21 μ . This finely processed biochar was added to a solution used for the thermocatalytic

conversion of polystyrene. This solution was mentioned in detailed research (Hemnea & Kale 2023, Reshmy et al. 2022b, Angouria-Tsorochidou et al. 2021, Duan et al. 2020) and serves as a crucial component in facilitating the conversion process. The paint process is illustrated in Figs. 4 and 5. By integrating powdered biochar into this solution, the efficiency and effectiveness of the thermocatalytic conversion process have been enhanced, potentially unlocking new avenues for sustainable and eco-friendly material transformation (Steiner & Glaser 2019, Borchard et al. 2018, Jeffery et al. 2011). No chemical modifications were performed for color stability, as the results were quite promising..

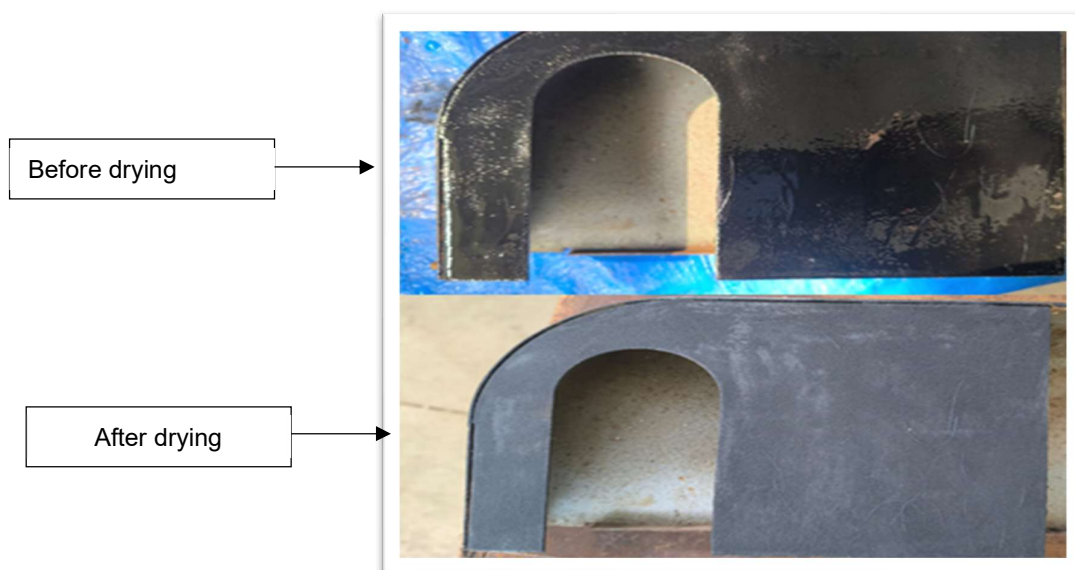


Fig. 4: The pictorial representation of paint before and after drying.



Fig. 5: The pictorial representation of water-based feed paint before and after 7 days.

RESULTS AND DISCUSSION

An approximate analysis of the biochar is presented in Table 1. After subjecting the material to the carbonization process, the results revealed that the moisture content indicated the extent of water present in the sample. Volatile matter suggests the proportion of combustible components that vaporize during heating, reflecting the material's potential for combustion. The ash content indicates the inorganic residue left after complete combustion, which influences the purity and suitability of the material for various applications. The pH value indicates the acidity or alkalinity of a material, which can affect its chemical properties and interactions. Additionally, the electrical conductivity (EC) was recorded at V, providing insight into the material's

ability to conduct electricity, which can be crucial in specific industrial processes. Finally, the calorific value highlights the energy content of the material, which is essential for assessing its potential as a fuel source. These findings underscore the significance of the carbonization process in altering the composition and properties of the material, elucidating its potential applications in various fields.

The experimental results revealed promising outcomes regarding the utilization of *Syzygium cumini* garden waste biochar as a sustainable source for pigment and paint formation. In the case of feed-derived pigments, the biochar-based pigment exhibited a comparatively better color intensity. Spectrophotometric analysis indicated a high color retention and stability over time, suggesting its viability

Table 1: Proximate analysis of samples used for the pigment production.

Sl. No.	Sample name	Moisture (%)	Volatile Matter [%]	Ash [%]	Calorific Value [cal.g ⁻¹]	pH	EC
1	Garden waste (Jamun leaves feed)	7.65	80	4.45	4163		
2	Garden waste bio-char	-	-	-	5631	8.34	3.66

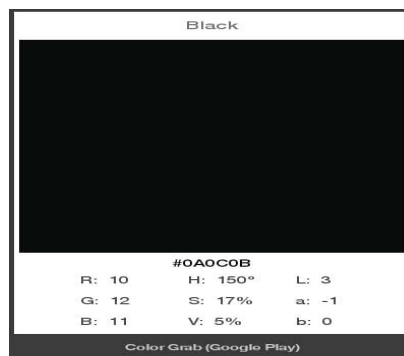
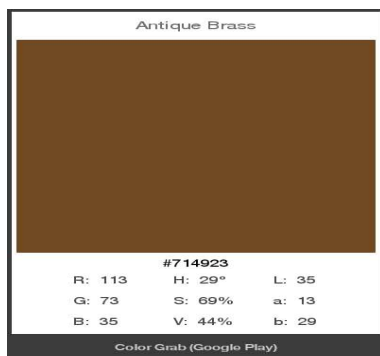


Fig. 6: Colors from the painted work.

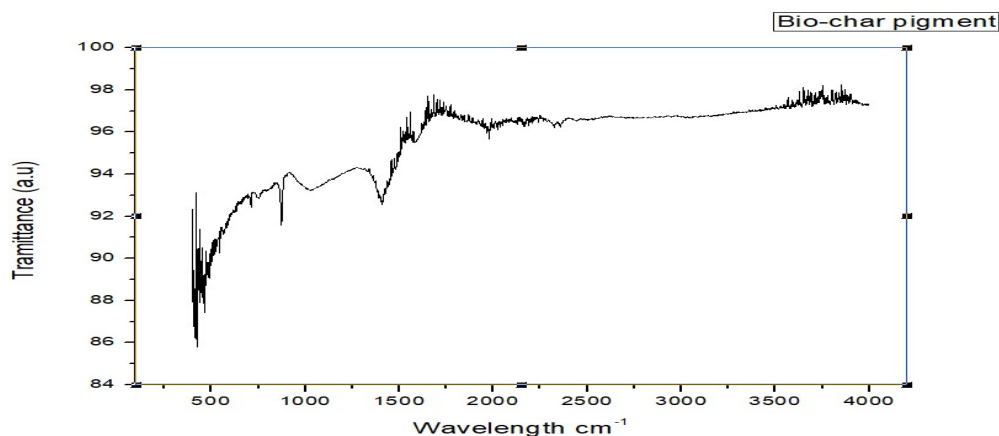


Fig. 7: FTIR analysis confirming the retention and applicability of biochar pigment.

for various applications in the paint and dye industries. Moreover, biochar-derived pigments demonstrate enhanced lightfastness and resistance to environmental degradation compared to conventional alternatives. Furthermore, the incorporation of biochar into paint formulations exhibited favorable rheological properties, contributing to improved paint adhesion and durability (Figs. 6 and 7). FTIR analysis revealed the presence of 500-1500 cm^{-1} , aromatic rings, and at 2000 cm^{-1} , carboxylic acids are observed. This indicates that the functional groups of biochar were well represented by the prepared samples. The outcomes are promising and emphasize the potential use of *Syzygium cumini* garden waste biochar as a sustainable and eco-friendly alternative for pigment and paint production, offering both aesthetic appeal and environmental benefits. The potential of biochar-derived pigments as sustainable alternatives to conventional pigments is emphasized, particularly their eco-friendly nature and contribution to waste management efforts. Furthermore, this study underscores the importance of further research to optimize extraction techniques and refine paint formulations for broader industrial applications.

CONCLUSIONS

This study explored the potential of using *Syzygium cumini* garden waste biochar as a sustainable source for pigment and paint production. Through a series of experiments involving the processing of feed and biochar, this study demonstrated the feasibility of extracting pigments from *Syzygium cumini* garden waste biochar and incorporating them into paint formulations. The biochar-derived pigments exhibited promising color properties suitable for paint production, showcasing their potential as a sustainable alternative to traditional pigments. This novel application aids in waste management and promotes the development of eco-friendly paint formulations, fostering a circular economy and

environmental sustainability. Therefore, the utilization of garden waste biochar holds significant promise for creating sustainable pigments and paints, offering both environmental and economic benefits.

REFERENCES

- Alam, P. and Ahmade, K., 2013. Impact of solid waste on health and the environment. *International Journal of Sustainable Development and Green Economy*, 2(2), pp.165–168.
- Angouria-Tsorochidou, E., Teigiserova, D.A. and Thomsen, M., 2021. Limits to circular bioeconomy in the transition towards decentralized biowaste management systems. *Resources, Conservation and Recycling*, 164, p.105207. DOI
- Aruna, G., Kavitha, B., Subashini, N. and Indira, S., 2018. An observational study on practices of disposal of waste garbages in Kamakshi Nagar at Nellore. *International Journal of Applied Research*, 4(3), pp.392–394.
- Awasthi, M.K., Sarsaiya, S., Wainaina, S., Rajendran, K., Awasthi, S.K. and Liu, T., 2021. Techno-economics and life-cycle assessment of biological and thermochemical treatment of bio-waste. *Renewable and Sustainable Energy Reviews*, 144, p.110837. DOI
- Awasthi, M.K., 2022. Engineered biochar: A multifunctional material for energy and environment. *Environmental Pollution*, 298, p.118831. DOI
- Borchard, N., Prost, K., Kautz, T. and Moeller, A., 2018. Biochar, soil and land-use interactions that reduce nitrate leaching and N₂O emissions: A meta-analysis. *Science of the Total Environment*, 651(2), pp.2354–2364. DOI
- Dehankar, S. and Joshi, R.R., 2024. Advanced processes for pharma wastewater treatment: A mini review. *Journal of Chemical Health Risks*, 14(1), pp.3349–3357. DOI
- Duan, Y., Pandey, A., Zhang, Z., Awasthi, M.K., Bhatia, S.K. and Taherzadeh, M.J., 2020. Organic solid waste biorefinery: Sustainable strategy for emerging circular bioeconomy in China. *Industrial Crops and Products*, 153, p.112568. DOI
- Gaur, L. and Pooniat, P., 2024. Optimization, characterization and evaluation of biochar obtained from biomass of invasive weed *Crotalaria burhia*. *Nature Environment and Pollution Technology*, 23(4), pp.1995–2008. DOI
- Hemnea, A.D. and Kale, G.R., 2023. Thermo-catalytic conversion of waste thermocol and acrylic to paint. *Indian Journal of Engineering and Materials Sciences*, 30(3), pp.780–787.
- Jain, A., Sarsaiya, S., Awasthi, M.K., Singh, R., Rajput, R., Mishra, U.C., Chen, J. and Shi, J., 2022. Bioenergy and bio-products from bio-waste

- and its associated modern circular economy: Current research trends, challenges, and future outlooks. *Fuel*, 307, p.121859. DOI
- Jeffery, S., Verheijen, F.G.A., Van Der Velde, M. and Bastos, A.C., 2011. A quantitative review of the effects of biochar application to soils on crop productivity using meta-analysis. *Agriculture, Ecosystems and Environment*, 144(1), pp.175–187. DOI
- Joshi, R.R., Topare, N.S., Jadhav, P. and Joy, M., 2015. Treatment of petroleum industry wastewater using TiO₂-UV photocatalytic process. *Journal of the Indian Chemical Society*, 92(2), pp.219–222.
- Joshi, R.R. and Kulkarni, B.D., 2012. Simulation of a biomass gasification reactor for fuel in a gas turbine. *International Journal of Chemical Sciences and Applications*, 3(1), pp.232–240.
- Joshi, R.R., Chandorkar, N. and Pandey, P., 2023. Design of a novel BioCNG production plant using mixed agro-waste as an affordable source of green hydrogen. *European Chemical Bulletin*, 12(3), pp.3119–3126. DOI
- Khan, M., Chniti, S. and Owaid, M., 2018. An overview on properties and internal characteristics of anaerobic bioreactors of food waste. *Journal of Nutrition, Health and Food Engineering*, 8(4), pp.319–322.
- Kinney, T.J., Masiello, C.A., Dugan, B., Hockaday, W.C., Dean, M.R. and Zygourakis, K., 2012. Hydrologic properties of biochars produced at different temperatures. *Biomass and Bioenergy*, 41, pp.34–43. DOI
- Lasaridi, K.E., Manios, T., Stamatiadis, S., Chroni, C. and Kyriacou, A., 2018. The evaluation of hazards to man and the environment during the composting of sewage sludge. *Sustainability*, 10(7), p.2618. DOI
- Nizami, A.S., Rehan, M., Waqas, M.U.H.A.M.M.A.D., Naqvi, M., Ouda, O.K., Shahzad, K., Miandad, R., Khan, M.Z., Syamsiro, M., Ismail, I.M. and Pant, D., 2017. Waste biorefineries: Enabling circular economies in developing countries. *Bioresource technology*, 241, pp.1101–1117.
- Ogwueleka, T.C., 2009. Municipal solid waste characteristics and management in Nigeria. *Iranian Journal of Environmental Health Science and Engineering*, 6(3), pp.173–180. DOI
- Reshmy, R., Athiyaman Balakumaran, P., Divakar, K., Philip, E., Madhavan, A. and Pugazhendhi, A., 2022a. Microbial valorization of lignin: Prospects and challenges. *Bioresource Technology*, 344, p.126240.
- Reshmy, R., Philip, E., Madhavan, A., Tarfdar, A., Sindhu, R. and Binod, P., 2022b. Biorefinery aspects for cost-effective production of nanocellulose and high value-added biocomposites. *Fuel*, 311, p.122575.
- Shackley, S., Sohi, S. and Hammond, J., 2012. Pigments, paints and biochar. In: Lehmann, J. and Joseph, S. (eds.) *Biochar for Environmental Management: Science, Technology and Implementation*, 2nd ed. Earthscan, pp.283–307. DOI
- Steiner, C. and Glaser, B., 2019. Biochar in environmental management: A review. *Environmental Science and Technology*, 53(17), pp.9887–9894. DOI
- Toledo, M., Siles, J., Gutiérrez, M. and Martín, M., 2018. Monitoring of the composting process of different agro-industrial waste: Influence of the operational variables on the odorous impact. *Waste Management*, 76, pp.266–274.
- Ubando, A.T., Del Rosario, A.J.R., Chen, W.H. and Culaba, A.B., 2021. A state-of-the-art review of biowaste biorefinery. *Environmental Pollution*, 269, p.116149.
- Vassilev, N., Martos, E., Mendes, G., Martos, V. and Vassileva, M., 2013. Biochar of animal origin: A sustainable solution to the global problem of high-grade rock phosphate scarcity. *Journal of the Science of Food and Agriculture*, 93(8), pp.1799–1804. DOI