iJRASET
International Journal For Research in Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH
IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 13 Issue: VI Month of publication: June 2025

DOI: https://doi.org/10.22214/ijraset.2025.72508

www.ijraset.com

Call: 08813907089 | E-mail ID: ijraset@gmail.com

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 13 Issue VI June 2025- Available at www.ijraset.com

Investigating the Adsorption Efficiency of Banana Pseudo-Stem Derived Biochar for Polyethylene Microplastic Removal from Aqueous Solutions

Prof. Dr. Jagdish Rameshrao Dhanuskar[1], Aditya Appasaheb Gaund[2]
[1]*Department Of Civil Engineering, JSPM's Rajarshi Shahu College of Engineering, Tathawade-411033, Pune, India*
[2]*Department Of Civil Engineering B.Tech, JSPM's RSCOE, Pune, India*

Abstract: Microplastic pollution, particularly from polyethylene terephthalate (PET), has emerged as a significant environmental concern due to its persistence and toxicity in aquatic systems. This study evaluates the use of banana pseudo-stem (BPS) biochar as a low-cost, sustainable adsorbent for removing PET microplastics from water. Biochar was synthesized at 450°C, 550°C, and 650°C using slow pyrolysis. PET microplastics (<150 µm) were prepared from plastic waste and used to create stock solutions. Batch adsorption experiments were conducted under varying pH (4, 7, 9), dosage (2, 4, 6 mg), and contact times (30–90 min). Characterization via TGA, FTIR, and CHNS revealed that higher pyrolysis temperatures enhanced the aromaticity, surface area, and carbon content of the biochar. The highest adsorption efficiency was recorded at 650°C, with 6 mg of biochar at pH 9. These findings support the potential of BPS biochar as an environmentally friendly and effective solution for microplastic removal and valorization of agricultural waste.
Keywords: Microplastics, PET, Biochar, Banana Pseudo-Stem, Adsorption, Pyrolysis, FTIR, TGA, CHNS.

I. INTRODUCTION

Plastic pollution has become one of the most critical environmental issues of the 21st century, with microplastics emerging as a particularly concerning category of contaminants. Defined as plastic particles less than 5 millimeters in size, microplastics are ubiquitous in the environment and have been detected in oceans, rivers, drinking water, soil, and even the atmosphere. Their widespread presence is primarily attributed to the degradation of larger plastic waste and the release of microbeads and fibers from consumer products. These persistent particles pose significant risks to aquatic organisms and humans alike due to their small size, durability, and ability to adsorb toxic substances, such as heavy metals and persistent organic pollutants (POPs).

Among the various types of plastics contributing to microplastic pollution, Polyethylene Terephthalate (PET) is of particular concern. Widely used in packaging, especially for food and beverages, PET is valued for its strength, transparency, and recyclability. However, improper disposal and environmental exposure lead to its fragmentation into microplastics, which are resistant to biodegradation and can persist in the environment for decades. PET microplastics can be ingested by aquatic life, leading to bioaccumulation and potential entry into the food chain, thereby posing ecological and human health risks.

Traditional methods for microplastic removal, such as sedimentation, filtration, and chemical coagulation, are often inefficient, expensive, and not feasible for large-scale or decentralized applications. These methods may also generate secondary pollutants or require advanced infrastructure, limiting their use in resource-constrained settings. As a result, there is a growing interest in low-cost, sustainable, and effective alternatives for microplastic removal from water.

One promising material for environmental remediation is biochar, a carbon-rich byproduct produced via the pyrolysis of organic biomass under low-oxygen conditions. Biochar has garnered significant attention for its potential in soil enhancement, carbon sequestration, and pollutant adsorption due to its high surface area, porous structure, and chemically active surface functional groups. Numerous studies have demonstrated its effectiveness in removing heavy metals, dyes, and pharmaceutical residues from water. More recently, researchers have started exploring its capacity to remove microplastics through mechanisms such as electrostatic attraction, hydrophobic interactions, and π–π stacking.

Despite the growing body of literature on biochar for pollutant removal, a critical research gap exists in the context of using agricultural waste-derived biochar—specifically from banana pseudo-stem (BPS) for the removal of PET microplastics. BPS is an abundant and underutilized agricultural residue in banana-producing regions like India. Converting it into biochar not only addresses the problem of biomass waste but also provides renewable and sustainable material for water purification applications.

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 13 Issue VI June 2025- Available at www.ijraset.com

II. MATERIALS AND METHODS

A. Materials

The materials used in this study were selected based on their relevance to microplastic pollution mitigation and their potential for sustainable and scalable application. The banana pseudo-stem (BPS) was used as the biomass feedstock for biochar production. BPS is a readily available agricultural waste rich in cellulose, hemicellulose, and lignin, making it ideal for producing porous, carbon-rich biochar.

Polyethylene Terephthalate (PET) plastic bottles were selected as the source of microplastics due to their widespread use in the packaging industry and their significant contribution to secondary microplastic pollution. The bottles were cleaned, cut, and ground to simulate environmentally relevant microplastic particles.

Distilled water was used as the solvent for preparing microplastic stock solutions to avoid interference from external ions. pH buffer solutions were employed to control the acidity or alkalinity of the medium during adsorption experiments.

B. Preparation of Biochar

The banana pseudo-stem was initially oven-dried at 110°C for 24 hours to remove moisture. The dried material was then ground using a mechanical grinder and sieved to obtain particles less than 150 µm in size.

The powdered BPS was subjected to slow pyrolysis in a muffle furnace under limited oxygen conditions. Three different temperatures were used for pyrolysis: 450°C, 550°C, and 650°C, with a residence time of 1 hour for each batch. The resulting biochar was allowed to cool under an inert atmosphere and stored in airtight containers for further use.

Fig 1: - The process of making BPS.

C. Microplastic Preparation

PET bottles were cleaned and cut into small fragments, which were then shredded and ground into fine particles using a mechanical grinder. The resulting PET powder was sieved to obtain particles smaller than 150 µm, simulating microplastics commonly found in natural environments.

The pH of the solution was adjusted to 4, 7, and 9 using standard buffer solutions to evaluate the impact of pH on adsorption behavior.

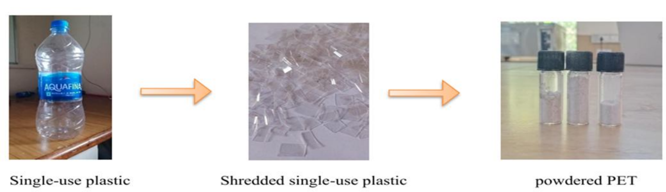

Fig 2: - The process of making PET Microplastic

D. Characterization Techniques

The physicochemical properties of the BPS-derived biochar were characterized using the following techniques:

- Thermogravimetric Analysis (TGA): TGA was used to determine the thermal stability and decomposition behavior of the biochar samples by analyzing their mass loss as a function of temperature.
- Fourier Transform Infrared Spectroscopy (FTIR): FTIR was performed to identify surface functional groups such as hydroxyl (-OH), carbonyl (C=O), carboxyl (-COOH), and aromatic (C=C) groups that contribute to adsorption mechanisms.
- CHNS Elemental Analysis: The CHNS analyzer was employed to quantify the elemental composition—specifically carbon (C), hydrogen (H), nitrogen (N), and sulfur (S) in the biochar, providing insights into its chemical makeup and adsorption potential.

ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 13 Issue VI June 2025- Available at www.ijraset.com

E. Batch Adsorption Experiments

Batch adsorption experiments were conducted to evaluate the effectiveness of BPS biochar in removing PET microplastics under varying conditions. Each experiment involved the following:

- Biochar Dosages: 2 mg, 4 mg, and 6 mg
- Contact Times: 30 minutes, 60 minutes, and 90 minutes
- Solution Volume: 15 mL of PET microplastic solution
- Shaking Speed: 150 rpm using an orbital shaker

After the designated contact time, the solutions were filtered and analyzed to determine the residual PET concentration. The adsorption efficiency was calculated using the following formula:

$$\text{Adsorption Efficiency (\%)} = \left(\frac{C_i - C_e}{C_i}\right) \times 100$$

Where:

- CiC_iCi = Initial concentration of PET microplastics (mg/L)
- CeC_eCe = Equilibrium (final) concentration after adsorption (mg/L)

This setup allowed for the systematic study of the effects of pyrolysis temperature, biochar dosage, and solution pH on the adsorption behavior of biochar toward PET microplastics.

III. RESULTS AND DISCUSSION

This section presents the outcomes of biochar characterization and batch adsorption experiments. The effects of pyrolysis temperature, solution pH, and biochar dosage on the removal of polyethylene terephthalate (PET) microplastics were systematically studied. Analytical techniques such as Thermogravimetric Analysis (TGA), CHNS elemental analysis, and Fourier Transform Infrared Spectroscopy (FTIR) were employed to gain insights into the physicochemical changes in the biochar, and these were correlated with its adsorption performance.

A. Thermogravimetric Analysis (TGA)

TGA was used to examine the thermal decomposition and stability of BPS-derived biochar. The analysis revealed multiple weight-loss stages associated with different components in biomass. An initial weight loss (~8%) occurred below 200°C, attributed to the evaporation of moisture and low-molecular-weight volatiles. A major decomposition phase (~46%) occurred between 200°C and 600°C, corresponding to the degradation of hemicellulose and cellulose. Further weight loss (~20%) between 600°C and 800°C was linked to the breakdown of more stable lignin compounds. A final minor decomposition (~14%) between 800°C and 1000°C indicated the release of residual volatile matter. The residual ash content (~11%) confirmed the presence of stable inorganic minerals. These results suggest that biochar produced at temperatures ≥600°C maintains thermal integrity and structural stability, which are favorable for adsorption applications.

B. CHNS Elemental Analysis

CHNS analysis provided the elemental composition of the biochar samples produced at 450°C, 550°C, and 650°C. A gradual increase in carbon content and decrease in hydrogen content was observed with rising pyrolysis temperature. This translated into an increasing C:H ratio—an indicator of aromaticity and carbonization degree. For example, the C:H ratios were:

- BPS 450: 50.56
- BPS 550: 78.67
- BPS 650: 83.49

A higher C:H ratio indicates greater aromatic ring formation and enhanced surface stability, which improves the biochar's adsorption performance through hydrophobic interactions and π–π stacking with microplastic polymers.

C. Fourier Transform Infrared Spectroscopy (FTIR)

FTIR analysis was conducted to determine the surface functional groups in the biochar. Key functional groups identified included:

- Hydroxyl (-OH): Broad absorption band at 3200–3600 cm^{-1}
- Carbonyl (C=O): Sharp peak around 1700 cm^{-1}

ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 13 Issue VI June 2025- Available at www.ijraset.com

- Aromatic C=C: Peaks at 1500–1600 cm^{-1}
- C–H bending: 870–970 cm^{-1}
- C–O stretching: 1000–1200 cm^{-1}

As the pyrolysis temperature increased, the intensity of oxygen-containing groups (–OH, C=O) decreased, while aromatic C=C and C–H groups became more prominent. This evolution suggests a transformation from aliphatic to aromatic structures, which enhances hydrophobicity and facilitates interactions with plastic surfaces. The presence of these functional groups plays a crucial role in adsorption via hydrogen bonding, electrostatic attraction, and π–π interactions.

D. Adsorption Trends

Batch adsorption experiments were conducted to evaluate how different parameters—pH, dosage, and pyrolysis temperature—affected PET microplastic removal. The results demonstrated a clear trend:

- BPS 450 (2 mg) showed maximum removal at pH 7
- BPS 550 (4 mg) performed best at pH 7
- BPS 650 (6 mg) showed the highest adsorption efficiency at pH 9

The overall trend showed that adsorption efficiency increased with pyrolysis temperature, biochar dosage, and contact time. This is primarily due to the enhanced surface area, porosity, and aromatic content of biochar produced at higher temperatures.
pH played a crucial role in modifying the surface charge of biochar and the ionization state of microplastics:

- At acidic pH (4), the biochar surface tends to be positively charged, promoting electrostatic attraction with negatively charged PET.
- At alkaline pH (9), hydrophobic interactions and **π–π stacking** become dominant due to reduced polarity and enhanced aromaticity of the biochar surface.

The highest adsorption efficiency was achieved using BPS biochar produced at 650°C, at a dosage of 6 mg and pH 9, confirming the importance of temperature-induced structural evolution and optimal environmental conditions.

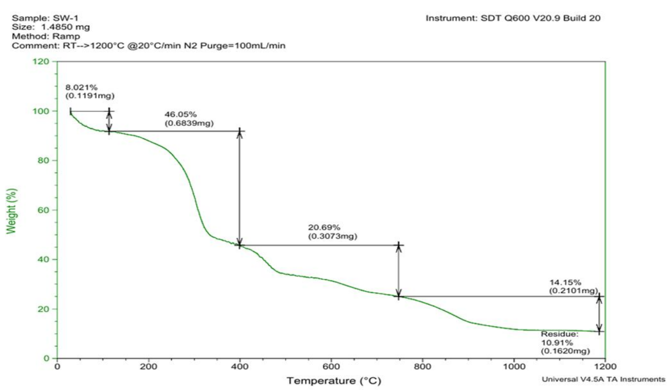

Fig 3: - Thermo Gravimetric Analysis for Powdered BPS

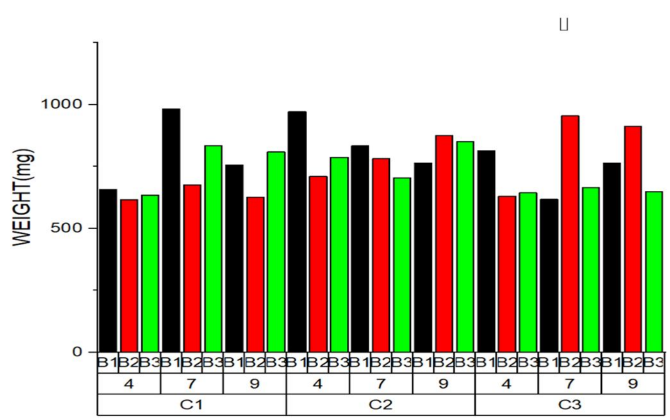

Fig 4: - Adsorption capacity of biochar produced 450C,550C and 650C for varying pH and concentration

IV. CONCLUSION

This study successfully demonstrates the potential of biochar derived from banana pseudo-stem (BPS) as a cost-effective and environmentally sustainable adsorbent for the removal of polyethylene terephthalate (PET) microplastics from aqueous solutions. Through systematic experimentation involving pyrolysis at three different temperatures (450°C, 550°C, and 650°C), varying biochar dosages, and multiple pH conditions, the adsorption efficiency was thoroughly evaluated.

Furthermore, the characterization of biochar using TGA, CHNS elemental analysis, and FTIR confirmed the structural evolution of the material with temperature, highlighting the development of functional groups and surface features critical to adsorption mechanisms such as electrostatic interaction, π–π stacking, and hydrophobic forces.

Overall, the study validates the conversion of agricultural waste into a functional material for microplastic remediation. The approach aligns with principles of circular economy and sustainable development by addressing two key environmental concerns: plastic pollution and biomass waste utilization. This work lays the foundation for scaling up biochar-based technologies for microplastic removal and invites future exploration in real-world wastewater treatment systems.

V. FUTURE WORK

While this study establishes the potential of banana pseudo-stem (BPS) derived biochar as an effective adsorbent for PET microplastic removal, there remains considerable scope for expanding the research into more advanced and real-world applications. The following directions are proposed for future work:

1) Surface Modification for Enhanced Adsorption: To further increase adsorption capacity and selectivity, future studies can explore chemical or physical modifications of BPS biochar. Approaches such as impregnation with metal oxides, acid/base activation, or the incorporation of magnetic nanoparticles may significantly enhance the surface reactivity and facilitate easier separation from treated water.
2) Pilot-Scale Testing: Current experiments have been conducted at the laboratory scale under controlled conditions. Scaling up the process to a pilot-scale system—such as a continuous flow adsorption unit or biochar filtration bed—will help evaluate its performance, longevity, and economic feasibility in real treatment plants.
3) Comparison with Other Biochar Feedstocks: Future research can include a comparative study of biochars derived from different agricultural residues such as rice husk, coconut shell, sugarcane bagasse, or corn stover. This would help identify the most effective and regionally available biomass sources for large-scale biochar production with optimized adsorption characteristics.
4) Multi-Pollutant Systems and Real Wastewater Testing: To simulate realistic environmental scenarios, the performance of BPS biochar should be tested in complex wastewater matrices containing not only microplastics but also co-contaminants like heavy metals, dyes, and pharmaceuticals.

REFERENCES

[1] Abdullah, A. A. (2023). Comparative Study on Slow and Fast Pyrolysis for High-Quality Biochar Production. Journal of Renewable Energy Research, 11(2), 210–218.
[2] Ding, N., Jiang, L., Wang, X., Wang, C., Geng, Y., Zhang, J., & Liu, H. (2022). Polyethylene microplastic exposure and concurrent effect with Aeromonas hydrophila infection on zebrafish. Environmental Science and Pollution Research, 29(42), 63964–63972.
[3] Ganie, A. H., Wang, Z., & Sedighi, M. (2021). Adsorptive removal of microplastics using banana pseudostem biochar: Mechanism and efficiency. Environmental Technology & Innovation, 21, 101262.
[4] Ji, M., Giangeri, G., Yu, F., Sessa, F., Liu, C., Sang, W., ... & Campanaro, S. (2023). An integrated metagenomic model to uncover the cooperation between microbes and magnetic biochar during microplastics degradation in paddy soil. Journal of Hazardous Materials, 458, 131950.
[5] Lehmann, J., & Joseph, S. (2006). Biochar for environmental management: An introduction. In J. Lehmann & S. Joseph (Eds.), Biochar for Environmental Management (pp. 1–12). Earthscan.
[6] Li, J., Chen, X., Yu, S., & Cui, M. (2023). Removal of pristine and aged microplastics from water by magnetic biochar: Adsorption and magnetization. Science of The Total Environment, 875, 162647.
[7] Liu, S., Li, J., Xu, S., Wang, M., Zhang, Y., & Xue, X. (2019). A modified method for enhancing adsorption capability of banana pseudostem biochar towards methylene blue at low temperature. Bioresource Technology, 282, 48–55.
[8] Omindi, O. G. (2016). Optimizing slow pyrolysis of banana wastes using response surface methodology to enhance bio-infrastructure products yield (Doctoral dissertation, Makerere University).
[9] Siipola, V., Pflugmacher, S., Romar, H., Wendling, L., & Koukkari, P. (2020). Low-cost biochar adsorbents for water purification including microplastics removal. Applied Sciences, 10(3), 788.
[10] Streitwieser, D. A., Villamil, D. O., Gutierrez, E., Salazar, S., Mora, J. R., & Bejarano, M. L. (2021). Fast pyrolysis as a valorization mechanism for banana rachis and low-density polyethylene waste. Chemical Engineering & Technology, 44(11), 2092–2099.
[11] Wang, Z., Sedighi, M., & Lea-Langton, A. (2020). Filtration of microplastic spheres by biochar: Removal efficiency and immobilisation mechanisms. Water Research, 184, 116165.
[12] Zhao, Z., Wang, B., Theng, B. K. G., Lee, X., Zhang, X., Chen, M., & Xu, P. (2022). Removal performance, mechanisms, and influencing factors of biochar for air pollutants: A critical review. Biochar, 4(1), 30.