

ANAEROBIC PET MICROPLASTIC FERMENTATION AND BIOELECTRICITY GENERATION USING MICROBIAL FUEL CELL COCULTURES

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INTRODUCTION: Plastic pollution and energy recovery are often treated as separate challenges. Plastics are highly durable, hydrophobic, and crystalline, making them ideal for disposable products but resistant to natural degradation, allowing waste to persist for decades (Pilapitiya and Ratnayake, 2024). Most single-use plastics fragment into micro- and nanoplastics, posing environmental and health risks, yet they also represent a low-cost carbon resource. Biological systems offer a promising solution, as microbes can metabolically degrade plastics into simpler compounds. While aerobic PET degradation is slow due to high crystallinity and low enzymatic activity, anaerobic conditions may induce alternative degradation pathways (Kalathil et al., 2022). This study investigates whether a coculture of *Ideonella sakaiensis* and *Shewanella oneidensis* can degrade PET microplastics in a microbial fuel cell, converting them into metabolites and electricity.

MATERIALS & METHODS: The anaerobic fermentation of PET in a microbial fuel cell was evaluated using FTIR, weight-loss measurements, and scanning electron microscopy. Electrochemical performance and soluble COD were monitored to assess microbial activity, while degradation products were identified and quantified using HPLC and GC-MS to elucidate PET degradation pathways.

RESULTS: Over a 40-day period, three microbial fuel cell systems were evaluated: *Shewanella oneidensis* monoculture, *Ideonella sakaiensis* monoculture, and their coculture. The *S. oneidensis* monoculture achieved 9.2% PET biodegradation, producing acetic acid and generating a power density of 1.01 mW/m². In contrast, *I. sakaiensis* degraded 35.2% of PET, producing acetic acid and ethanol with a power density of 1.17 mW/m². The coculture showed moderate PET degradation (16.4%) and yielded a power density of 0.202 mW/m². SEM analysis revealed that control PET exhibited minimal surface changes, whereas PET exposed to microbial treatments developed pronounced pits, cracks, and fissures, along with extensive biofilm formation, confirming active depolymerisation and microbial attachment. *S. oneidensis* surfaces displayed microbial colonies and debris, whereas *I. sakaiensis* surfaces were highly porous and brittle. Soluble COD measurements supported these trends, with the highest values in *I. sakaiensis* monoculture (433.36 mg/L), followed by *S. oneidensis* (328.8 mg/L) and coculture (303.15 mg/L), compared to the control (44.85 mg/L). FTIR analysis indicated carbonyl oxidation, ester bond hydrolysis, and cleavage of aromatic linkages, with hydroxyl and amine exposure confirming microbial contribution. Overall, *I. sakaiensis* anaerobically ferments PET into metabolites while generating electricity, and *S. oneidensis* oxidises acetate to current. Coculture performance was lower, highlighting interspecies interactions that can limit the efficiency of MFC-based PET bioremediation and energy recovery.

CONCLUSION: This study demonstrates that *Ideonella sakaiensis* can anaerobically degrade PET microplastics into ethanol and acetate while generating electricity, a previously unreported electrochemical activity. *Shewanella oneidensis* also contributed to PET degradation. Coculture revealed antagonistic interactions, highlighting that microbial dynamics can limit efficiency, yet microbial fuel cells remain promising for PET remediation and energy recovery.

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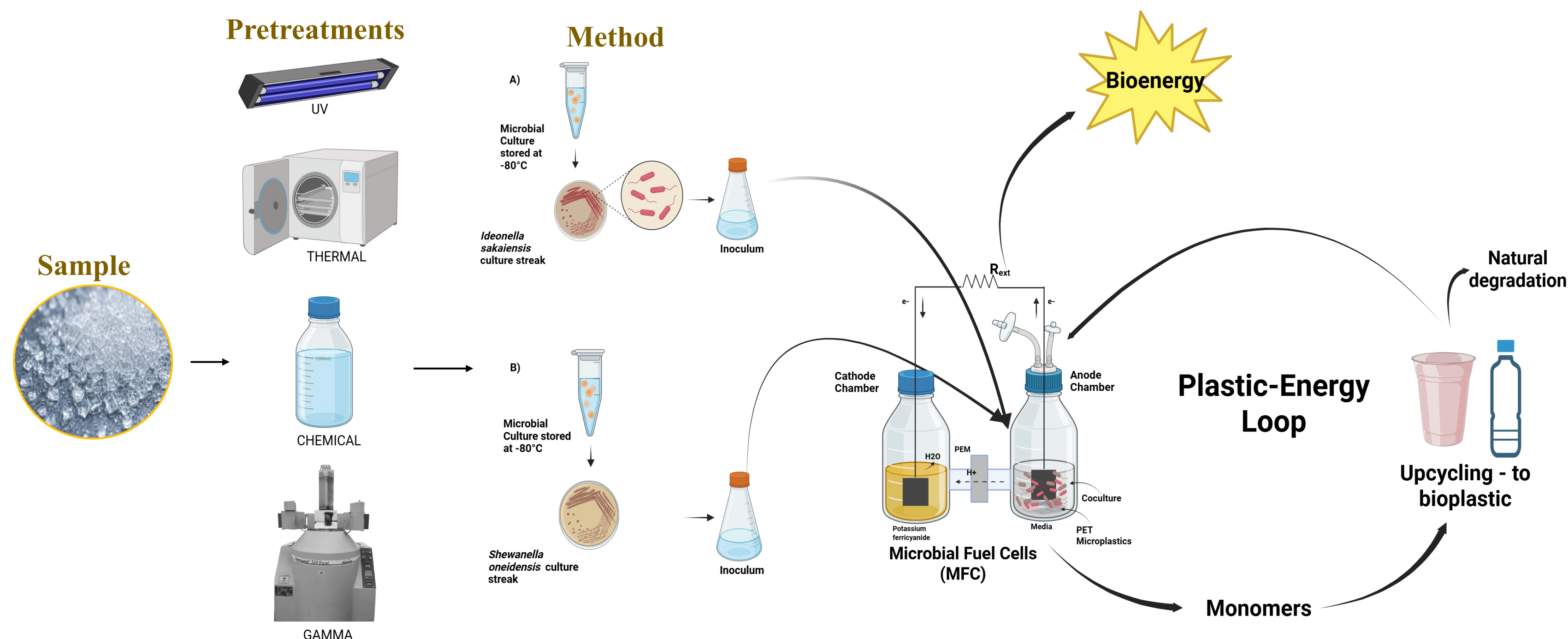
INTRODUCTION

- Plastics exhibit high durability, stability, hydrophobicity and crystallinity. These characteristics make plastics ideal for disposable products but, at the same time, limit their natural degradation, allowing them to persist in the environment for decades or even centuries as plastic waste (Pilapitiya and Ratnayake, 2024). Driven by escalating global demand, inadequate recycling infrastructure, and pervasive environmental leakage, plastic volumes are projected to triple by 2040 (UNEP, 2022).
- Consequently, plastic debris has detrimental impacts on both the environment and human well-being, making it a concerning issue (Pilapitiya and Ratnayake, 2024).
- Among plastics, Polyethylene terephthalate (PET) is a major source of microplastics in water, difficult to biodegrade due to intrinsic properties such as high molecular weight, crystallinity, and limited microbial accessibility that slow enzymatic hydrolysis (Thomsen, Almdal and Meyer, 2023).
- By harnessing the combined activity of electrogenic and plastic-degrading bacteria, microbial fuel cells (MFCs) offer a carbon-neutral strategy for addressing micro- and nanoplastic pollution while simultaneously enabling plastic biodegradation and electricity generation (Kumar, Baghel and Jujjavarapu, 2025).

AIM

The aim of this study was to investigate the effect of thermal, chemical, UV, and gamma irradiation pretreatments on the biodegradation of PET plastics by a co-culture of *Shewanella oneidensis* and *Ideonella sakaiensis* in microbial fuel cell systems.

METHODOLOGY

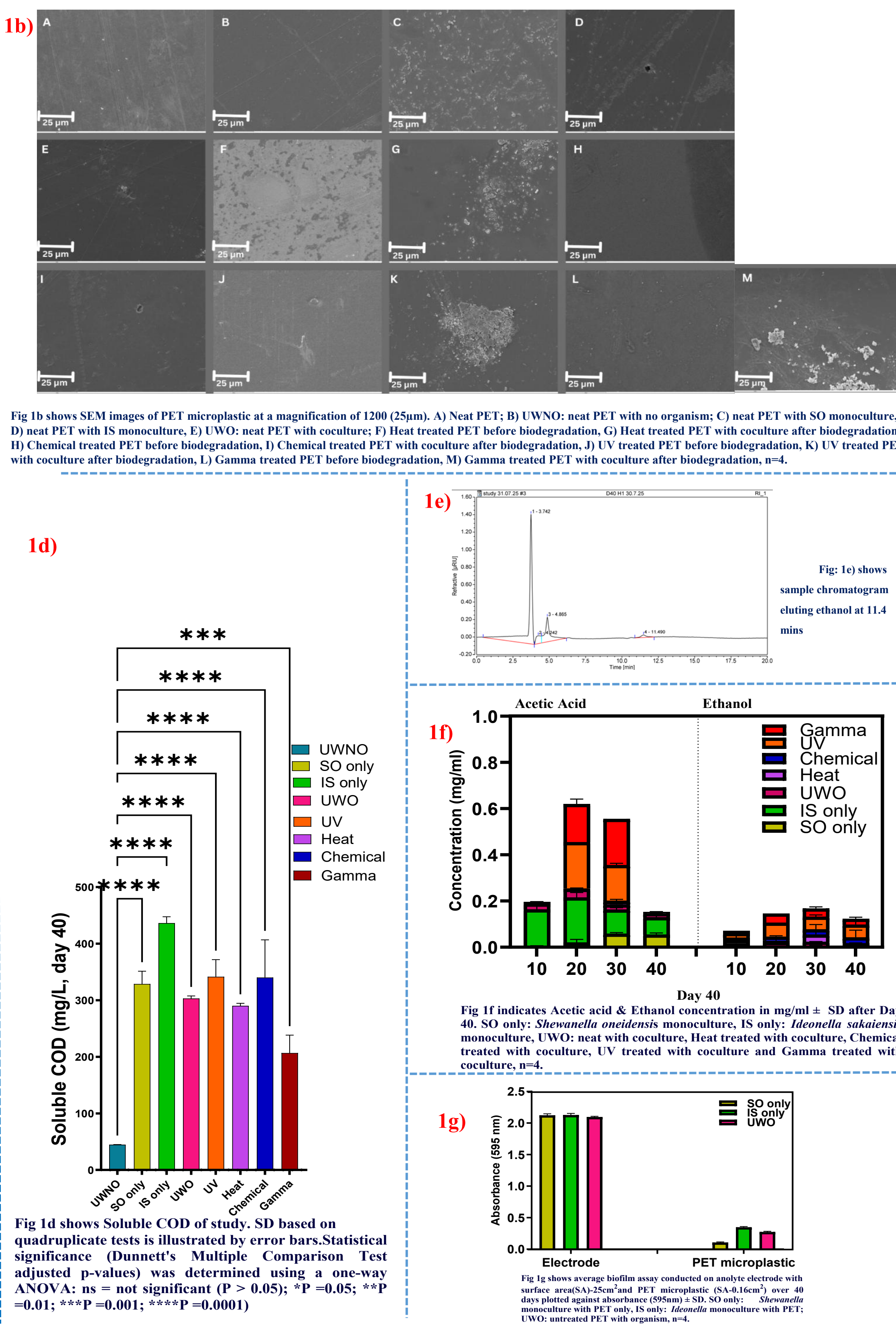
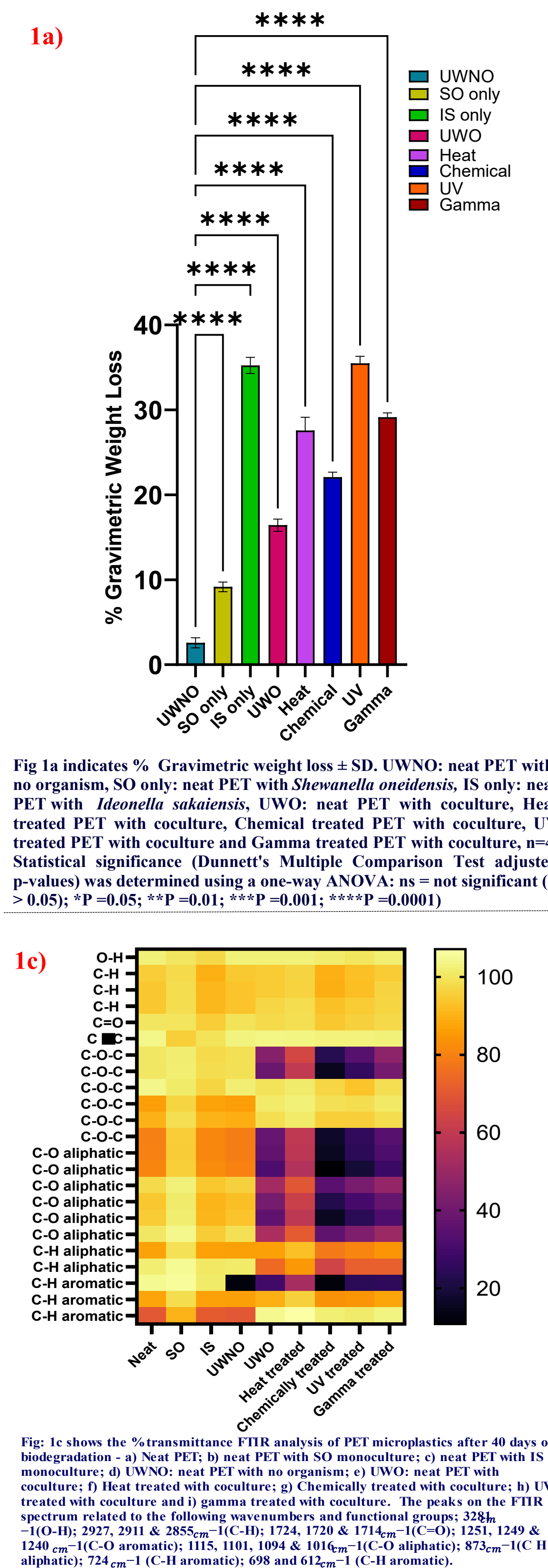


DISCUSSION

- The MFCs showed greater biodegradation with pretreated PET. Pre-treatments, especially **UV and Gamma, oxidize and fragment PET**, making it more susceptible to microbial coculture, resulting in the **greatest biodegradation** compared with untreated controls except the neat PET MFC with *Ideonella sakaiensis*.
- Electrical power generation** was observed in all MFCs, with closed-circuit voltages ranging from 65 to 141 mV across a 2200 Ω external resistor and a 25 cm² anode. Among the treatments, **gamma-pretreated PET** produced the **highest power density (1.66 mW m⁻²)**, followed by UV-pretreated PET (**1.14 mW m⁻²**) and untreated (neat) PET inoculated with *Ideonella sakaiensis* (**1.17 mW m⁻²**) highlighting its role as an electroactive bacteria.
- HPLC and GC-FID detected PET degradation products, including ethanol and acetic acid, while FTIR and SEM analyses confirmed structural and surface alterations of the PET. Biofilm formation on PET and electrodes** supports its role in coupled biodegradation and electricity generation.
- UV treated PET** showed highest biodegradation rate of about 35.4% wherein **gamma treated PET** showed a biodegradation rate of only 29.1%. *Ideonella sakaiensis* also gave a biodegradation rate of 35.2%.
- The electroactive bacterium *Shewanella oneidensis* showed minimal PET biodegradation (9.2% w/w) and thick microbial colonisation in SEM images, underscoring the need for further investigation into its role in plastic biodegradation.
- This study highlights the use of UV pretreatment in enhancing the rapid biodegradation of PET microplastics whereas gamma pretreatment for increased power output in a microbial fuel cell-oriented anaerobic environment using a microbial coculture with concomitant electricity recovery.

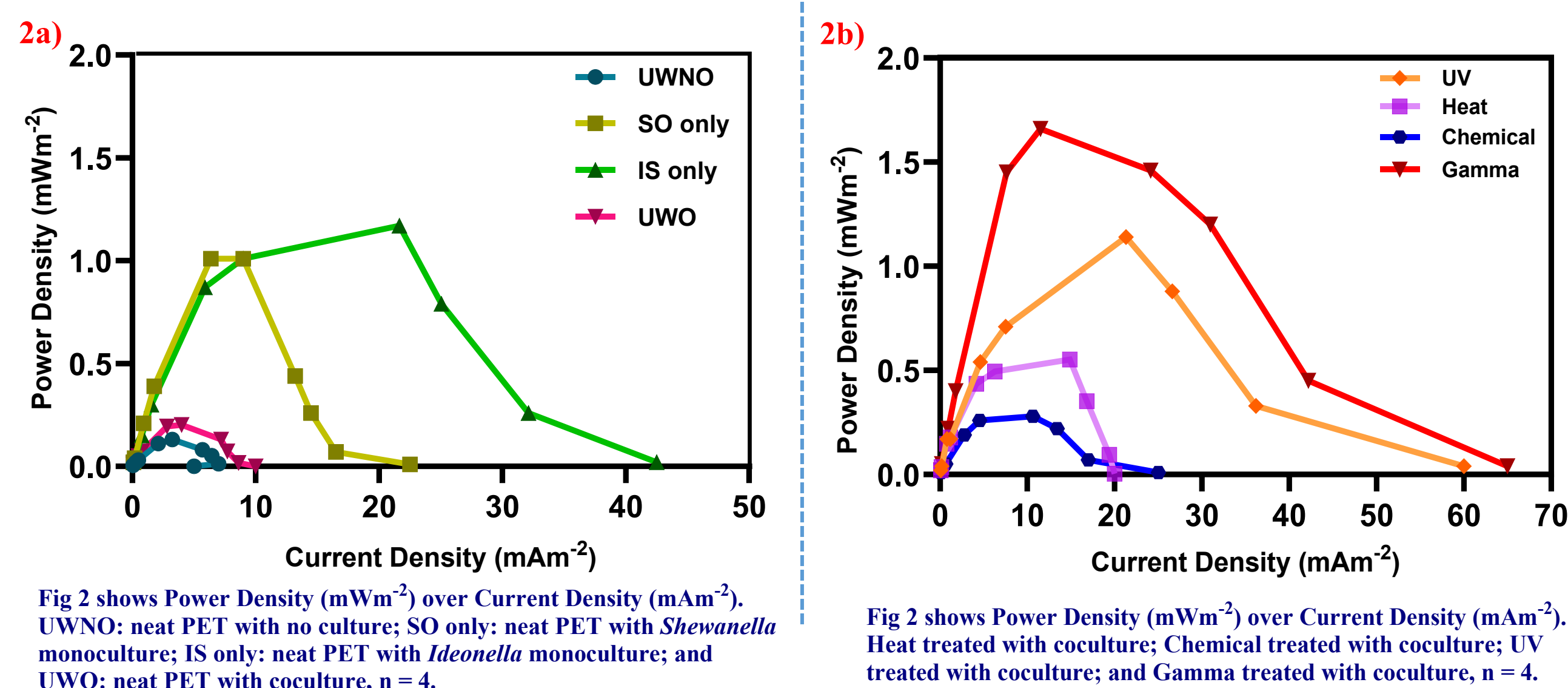
RESULTS

1) BIODEGRADATION EVALUATION IN MFC:



RESULTS continued....

2) ELECTROCHEMICAL PERFORMANCE ANALYSIS:



CONCLUSION

This study evaluated the effect of pretreatments on microplastic biodegradation. All microbial fuel cells (MFCs) with pretreated PET showed biodegradation, with **UV-treated PET achieving the highest and significant weight loss of 34.5% (20.7 mg of 60 mg) with power density 1.14 mWm⁻², surface alterations, oxidative cleavage of ester linkages (C=O, C-O) with ring disruption (aromatic C-H signals) and highest metabolite production (acetic acid and ethanol) in 40 days.** In contrast, **Gamma-pretreatment produced highest power density among all systems at 1.66 mW m⁻².** Meanwhile, the MFC inoculated with *Ideonella sakaiensis* and neat PET achieved 35.2% biodegradation and a power density of 1.17 mW m⁻². **Overall, UV pretreatment enhanced PET biodegradation, metabolite production and bioenergy recovery in anaerobic MFC systems using microbial coculture whereas gamma irradiation primarily improved power output.**

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