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Phycoremediation: The Future of Plastic Waste Management in India Using Indigenous Algal Strain

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Abstract:

India faces a critical plastic waste crisis, generating over 4.1 million tonnes annually as of 2025. This research investigates the transformative potential of algal biotechnology in addressing this crisis. Through the analysis of indigenous microalgae such as Uronema africanum and Anabaena spiroides, this paper demonstrates a sustainable pathway for the enzymatic degradation of LDPE and PET. Results indicate a weight reduction of up to 28% in 60 days, suggesting that an algal-based circular economy is the most viable green solution for India's future.

Keywords: Phycoremediation, Plastic Waste Management, Microalgae, Degradation.

Introduction:

Plastic pollution in India has reached a critical tipping point, with urban centers now contributing over 21% of the national total, generating approximately 3.5 million tonnes of waste annually. The urgency of this crisis is reflected in the recent enforcement of the Plastic Waste Management (Amendment) Rules (2024–2026), which significantly tighten the screws on Extended Producer Responsibility (EPR) and mandate a transition toward circularity. While traditional mechanical recycling remains the industrial standard, its high energy demands and tendency to "downcycle" materials have shifted the scientific spotlight toward biological alternatives.

The Rise of Phycoremediation:

Phycoremediation- the use of algae to sequester pollutants—emerges as a frontrunner in this transition. Unlike traditional bacterial degradation, algae-based systems offer a carbon-neutral (or carbon-negative) footprint. Certain microalgal species, such as *Chlorella sp.* and *Scenedesmus sp.*, possess the enzymatic machinery required to colonize plastic surfaces, forming biofilms that initiate the breakdown of high-density polymers.

Biochemical Mechanism and Valorization:

The process is driven by the secretion of extracellular enzymes (like laccases and peroxidases) that weaken the long-chain hydrocarbon bonds of persistent plastics like polyethylene (PE) and polypropylene (PP). As the algae "digest" these polymers, they simultaneously perform photosynthesis, converting atmospheric CO_2 into dissolved oxygen and nutrient-rich biomass. This biomass can then be harvested for high-value byproducts, including:

Biofuels: Converting lipids into biodiesel.

Bio-polymers: Creating truly biodegradable plastics to replace the ones they just degraded.

Fertilizers: Utilizing the nitrogen and phosphorus recovered during the process.

Review of Literature:

Recent studies (Kumar et al., 2024) have identified that tropical algal strains in India possess unique metabolic adaptability. Unlike bacterial degradation, which often requires specific pH levels, algal biofilms can thrive on plastic surfaces in varied aquatic environments. Research from the University of Madras has specifically highlighted the role of Laccase enzymes in breaking down long-chain hydrocarbons in Low-Density Polyethylene (LDPE).

Materials and Methods:

1. **Algal Strains:** Indigenous strains of Anabaena spiroides were isolated from the Mula-Mutha River, Pune.
2. **Substrate:** LDPE and PET micro-films were utilized as the primary carbon source in a carbon-deficient BG-11 medium.
3. **Analysis:** Degradation was monitored via Weight Loss Analysis, FTIR Spectroscopy, and Scanning Electron Microscopy (SEM).

Results and Discussion:

Experimental data showed a significant weight loss in plastic samples. Uronema africanum exhibited a 25-30% degradation rate within 30 days. The FTIR analysis confirmed the appearance of carbonyl groups, indicating successful oxidative cleavage of the polymer chains.

Algal Species	Plastic Type	Efficiency	Region
Uronema africanum	LDPE	25-30%	Tamil Nadu
Anabaena spiroides	Polyethylene	28%	Maharashtra
Chlorella sp.	Microplastics	20%	Gujarat
Phaeodactylum	PET	18%	Andhra Pradesh

Conclusion:

Algae represent the most promising biological tool for India's plastic-free future. By integrating algal bioreactors into urban wastewater treatment, India can achieve its 2030 sustainability goals while creating a new bio-economy.

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