A Burning Reason: Developing and Testing Bio-Based Flame Retardants Derived From Agricultural Waste and Confirming Ecotoxicological Safety Through a Multigenerational Epigenetic Study on Daphnia magna

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With 2.25 million tons of annual flame retardant production, phosphorus flame retardants cause aquatic ecosystem disruption and eutrophication. Agricultural waste disposal causes 6% of global greenhouse gas emissions. This study developed bio-based flame retardants from banana pseudostem, young green coconut tissue, and coconut button tissue, using burn tests to evaluate performance on cotton fibers, cotton fabric, and dry Spanish moss for potential textile and wildfire prevention applications. Polyphenol and potassium (char-forming micronutrients) presence was confirmed in tissue samples before preparing banana sap and coconut extract, with 5% acetic acid extraction of polyphenols. Ecotoxicity was compared to that of ammonium polyphosphate (APP) flame retardant using a multigenerational epigenetic study on aquatic model Daphnia magna, assessing microfiber-mediated chronic exposure effects at sub-lethal treatment doses, simulating real world re-release conditions. Population and DNA methylation changes were tracked across 5 generations (3 exposure, 2 recovery), using a colorimetric ELISA assay to quantify global 5-methylcytosine percentage. Burn tests showed reduced flammability in all treatment groups. Coconut extract demonstrated highest efficiency, with near 0 burn rate and flame time, and under 3% mass loss in all materials. Untreated materials showed 100% mass loss. In the Daphnia magna study, banana sap fostered the healthiest growth with a stable population and DNA methylation levels similar to the control, followed by coconut extract, which showed initially acidity stress before recovery. Both bio-based treatments induced less stress than APP, demonstrating agro-waste's potential as an effective, low-cost, eco-friendly alternative to phosphorus flame retardants.

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