A Burning Reason: Exploring the Flame Retardancy Potential of Agricultural Waste Products and Testing their Ecotoxicological Safety on *Daphnia Magna*

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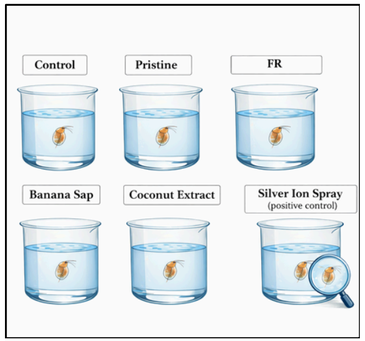
Introduction

- Traditional flame-retardant chemicals pose significant environmental concerns when they end up in wastewater streams and other areas of the environment, negatively impacting aquatic life, and posing risks such as eutrophication, in water streams.
- Agro-waste (agricultural waste) disposal causes nearly 6% of all global greenhouse gas emissions, due to how much is produced every year and the limited ways in which it is reused.
- Banana pseudostems, young green coconut husks, and unfertilized naturally dropped coconut buttons—largely untapped agro-wastes—offer potential to be developed into sustainable bio-based flame retardants.
- This study explores their use as raw materials for developing bio-based flame retardants, and assesses their ecotoxicological safety on aquatic model organism *Daphnia magna*, evaluating population, physiological responses, and heritable stress-induced epigenetic changes.

Experiment Design

- **Part 1 - Agro-waste Extracts:** Young green coconut mesocarp, coconut buttons, and banana stem were processed to obtain polyphenol-rich extracts and evaluated for flame-retardant properties on cotton fibers, cotton fabric, and dried Spanish moss.
- **Part 2 - Daphnia culture experiment:** 6 experimental groups of *Daphnia magna* were grown in exposures represented in the picture. The following conditions were kept controlled: spring water, ~21 °C, 16-hour light cycle. The first two generations assessed exposure and the last two generations assessed recovery and lasting impact.



Variables Measured: Population counts, physiological observations (heart rate and eye movement under a microscope), and DNA extraction followed by global methylation analysis using a colorimetric ELISA test were used to evaluate biological and epigenetic effects.

Results

Material	Burn Rate Reduction (%)	Treated Burn Rate (g/sec)	Mass Loss (%)
Cotton Fibers	50	0.005	2.4
Cotton Fabric	100	~0	~0
Spanish Moss	~83	0.005	2.9

Part 1 - Burn test Result

Young Green Coconut extract significantly reduced flammability across all materials. Burn rate decreased by **50% in cotton fibers**, **100% in cotton fabric**, and **~83% in Spanish moss** compared to untreated samples, with treated samples also showing very low mass loss (2.4%, ~0%, and 2.9%, respectively).

Part 2 - Daphnia Result

Population: Highest in Banana Sap, lowest in insoluble ammonium polyphosphate. Soluble ammonium polyphosphate spray showed early rise then sharp decline.

Heart Rate: Similar across groups; highest in banana sap F2, lowest in positive control (silver ion spray).

- **Eye Movements in Response to Light:** Normal in all groups except silver ion spray (positive control group).

DNA Methylation: Pristine: Hypermethylation in F4; Silver Ion Spray: Hypermethylation in F4 (less than pristine); Soluble APP: Normal at F0 → strong hypomethylation by F3; Banana: Hypomethylation in F0–F1; Coconut: Mild hypomethylation across generations

Interpretation/Conclusions

- Agro-waste from young green coconut, banana sap, and coconut button showed potential as flame retardants, with young green coconut extract performing best; its high potassium content likely formed potassium acetate with acetic acid, promoting char formation, reducing heat transfer, and slowing combustion.
- In the Daphnia magna study, banana sap–coated fibers likely supported providing stable food that promoted rapid population growth, while heart rates and eye responses remained normal in all treatment groups, indicating no physiological stress or neurotoxicity, unlike the positive control exposed to silver ion spray. Epigenetically, slight hypomethylation occurred in banana sap, coconut extract, and flame-retardant groups, suggesting minimal disruption, whereas hypermethylation in pristine fibers and the positive control reflected nutritional or metal-induced stress, with early stress effects persisting across generations.
- **This study proves banana and green coconut waste can create environmentally safer, sustainable flame retardants while reducing landfill burden.**

Future Development: Implement effective milling methods (e.g., ball milling) to grind coconut tissue—the material that showed the best flame retardancy—into the finest material possible. This could enable a simpler, solvent-free process that reduces the potential environmental toxicity of solvents, and allows farmers to perform the process directly in the field, allowing fresh agro-waste to be repurposed efficiently.