

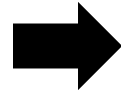
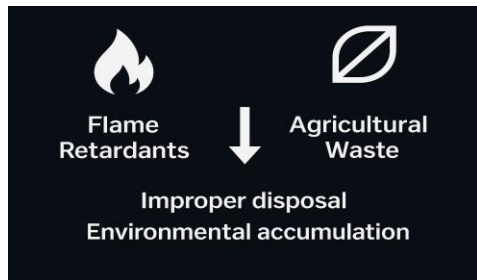
A Burning Reason: Exploring the Flame
Retardancy Potential of Agricultural Waste
Products and Testing their Ecotoxicological
Safety on *Daphnia Magna*

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Introduction



Agricultural waste is primarily disposed of through combustion, regularly releasing greenhouse gases into the air



Coconut Button

Photograph taken by the student



Coconut buttons are small, immature coconuts prematurely dropped from the tree in a cycle known as "button drop". Despite happening seasonally, they have never been used for any purpose, and are disposed of immediately through combustion, in order to avoid pest infestations. Repurposing them can prevent the environmental burden of burning them, and provide a sustainable source for bio-based flame retardants.

Research Goals:

- Developing bio-based flame retardants derived from three unexplored agricultural waste products: banana pseudostems, young green coconut sclerenchyma tissue, and coconut button tissue, testing their potential applications in the areas of textiles and wildfire prevention.
- Assessing the ecotoxicological safety of these flame retardants in comparison with that of a commercial phosphorus-based flame retardant (ammonium polyphosphate), using a model organism for toxicity.

Hypothesis:

- Flame retardants derived from banana pseudostems, young green coconut tissue, and coconut button tissue will demonstrate effective flame retardancy because of their high polyphenol and potassium content, while exhibiting relatively low ecotoxicity compared to ammonium polyphosphate.

Qualitative: Maceration of samples and tissue extraction using 91% isopropyl alcohol and did Ferric Chloride Test for Polyphenol presence.

Sample Analysis

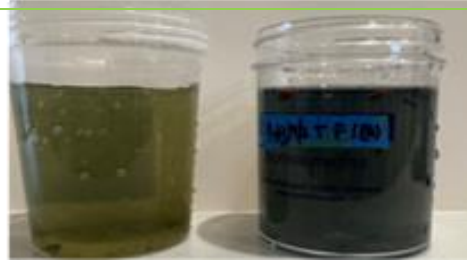


Photo taken by the student

Quantitative: Plant tissue samples were analyzed at a local agricultural laboratory to quantify NPK levels, particularly potassium (K), which may contribute to flame retardancy.

Banana stem is succulent, so it was processed into **sap**.



Photos taken by student

Coconut mesocarp is fibrous, so it was processed into an **extract**.

- Loaded cotton **fibers, cotton fabric, and dried Spanish moss** to evaluate the effectiveness of the prepared sap and extract.

Burn Test: Performed candle burn tests on dried samples, measuring ignition time, flame time, and pilot time, and calculating burn rate and mass loss percentage

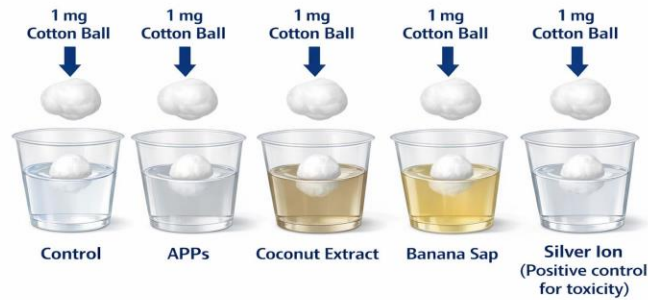
Hydroponic Test: Conducted a hydroponic growth test using radish seeds to assess the bioavailability of compounds in the sap and extract because NPK levels measured in tissue analysis may not be fully present in the sap or extract—and to better understand the observed flame suppression.



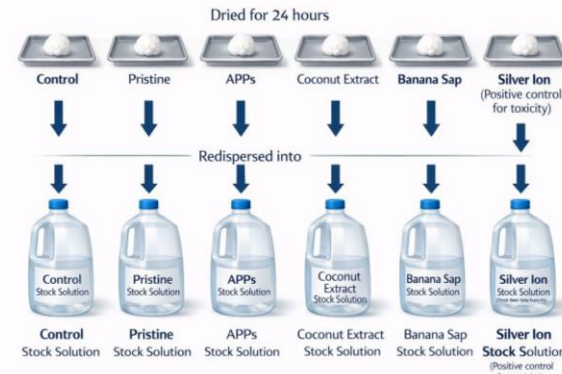
Photo taken by student

- Daphnia magna* were exposed to cotton microfibers treated with banana sap, coconut extract, and soluble ammonium polyphosphate (APP) alongside pristine fibers (material control group), silver ions (positive toxicity control), with a control group grown in spring water.

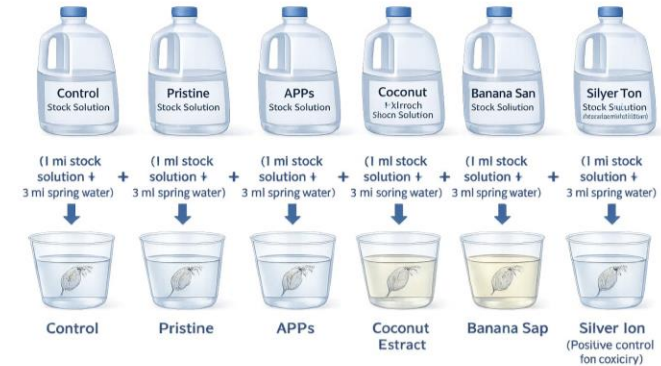
Step 1: Loading the Fibers



Step 2: Fiber Redispersal



Step 3: Preparing the exposure



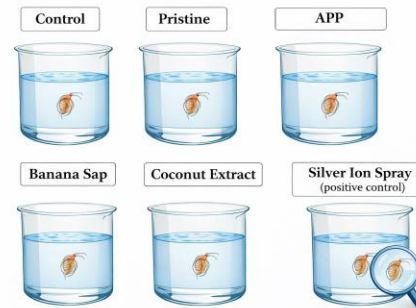
2. Multi-generational epigenetic *Daphnia Magna* Study

Heart Rate

Swim patterns

Eye Responses

Population Dynamics



Graphic Created by student using co-pilot



DNA isolation

Precipitation method

Methylation Study

Colorimetric ELISA assay to quantify percent global 5-methylcytosine (5-mC) levels

Exposed generations: F0-F1-F2

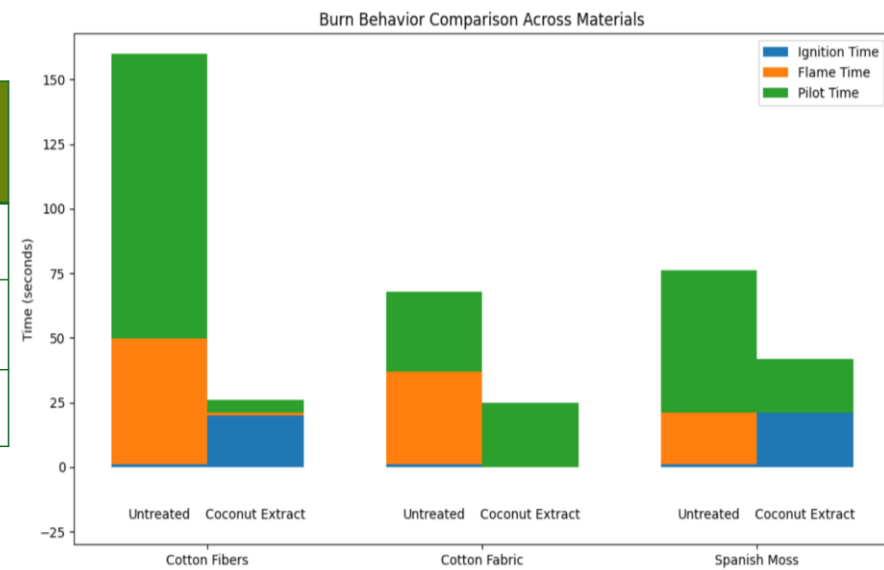
Recovery generations: F3-F4

Results: Burn Tests

Burn tests on cotton fabric indicate that the green coconut extract worked the best in reducing the flammability of the material with a burn rate of $\sim 0\text{g/sec}$ with mass loss of $\sim 0\%$ **reducing the flammability of cotton fabric by 100% compared to the untreated fabric.** All tested bio-based flame retardants successfully suppressed sustained flaming, restricting combustion to smoldering only.

Burn test results were the result of 10 replications of the test, conducted for reproducibility of results

Material	Untreated Burn Rate (g/s)	Treated Burn Rate (g/s)	Burn Rate Reduction (%)	Untreated Mass Loss (%)	Treated Mass Loss (%)
Cotton Fibers	0.01	0.005	50%	100	2.4
Cotton Fabric	0.02	0	100%	100	0
Spanish Moss	0.03	0.005	83.3%	100	2.9



Plant tissue and extract analysis

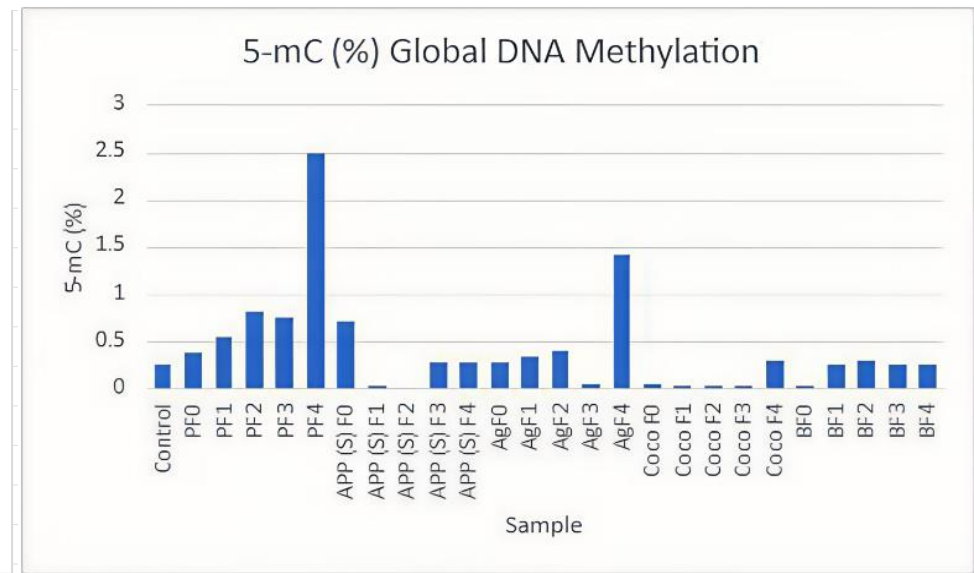
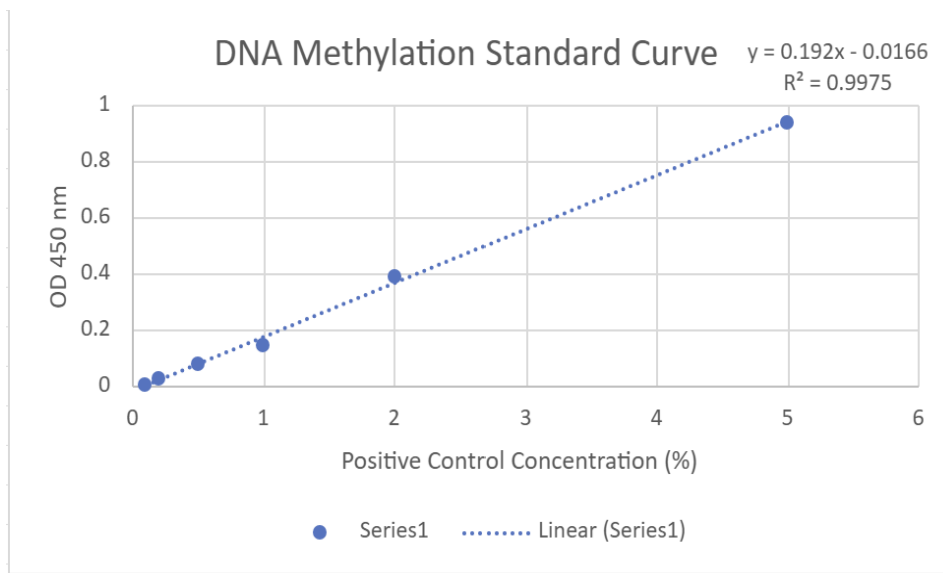
Plant sample	Nitrogen(N)%	Phosphorus (P)%	Potassium(K)%
Banana Stem	0.558	0.195	4.545
Coconut button	1.115	0.207	2.746
Young Green Coconut	0.56	0.16	1.76



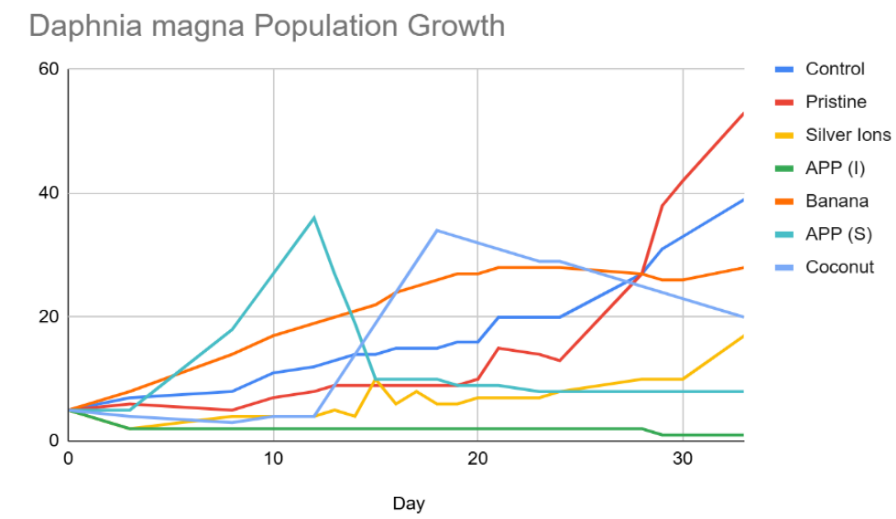
Plant Sample	Root Lengths(cm)
Control	7
APP(s)	7.6
Banana Sap	7
Coconut Extract	29

Cherry Belle radish root growth varied by treatment, with coconut extract producing the strongest roots (likely due to potassium), while soluble APP promoted larger leaves (likely from nitrogen). This shows that bioavailable NPK—not total composition, helps explain both flame-retardant behavior and Daphnia growth effects.

Results



ELISA results showed low control/baseline methylation (~0.25–0.85%). Soluble APP caused transient hypomethylation (F1–F2), while banana sap showed stable, near-control methylation levels. Coconut extract showed early hypomethylation with recovery by the F4 generation. Pristine and silver ion groups showed progressive hypermethylation in F4, indicating heritable epigenetic change.



F0 starting population for all groups: n=5

Banana sap supported stable near self-sustaining growth comparable to the negative control group. Coconut extract grew rapidly and then began to drop, then grew again, as seen in the extended growth graph. Both banana and coconut grew at the same rate, past the ~30-day observation period. Pristine cotton fibers fostered steady growth. Soluble APP peaked before declining, silver ions remained low, and insoluble APP showed acute toxicity, with nearly the entire population dying within a few days of exposure.

Interpretation & Discussion

Agro-Waste to Flame-retardants

Young green coconut extract showed the strongest flame retardancy (≤ 0.005 g/sec burn rate, $< 3\%$ mass loss), effectively limiting combustion to smoldering. Its performance is likely driven by polyphenol and potassium-derived char formation, supported by increased ignition time and reduced burn rate. Results were validated through consistent reproducibility across all repeated trials ($n=10$), indicating strong experimental reliability.

Daphnia magna Study

Banana sap: Supported steady population growth and stable methylation, requiring minimal feeding—indicating a self-sustaining, nutrient-rich system. The initial drop in methylation in the F0 generation could have been an immediate response to salinity changes caused by the dissolved salts in the sap, as hypomethylation is typically a response to immediate environmental stressors rather than a heritable change. The organisms in this treatment group were also bigger in size, signaling a healthier population caused by nourishment by the banana sap.

Coconut extract: Caused early stress (population drop, hypomethylation) but recovered by F4 after return to control conditions. Initial hypomethylation was likely an immediate response to changes in pH, as acetic acid used for polyphenol extraction could have caused excess acidity despite being pH balanced before treatment.

Soluble APP: Triggered extreme hypomethylation (down to 0%) and algal overgrowth in the F2 generation, followed by a rapid population crash after the F2 generation, likely due to oxygen depletion from excess algae growth.

Pristine & Silver ions: Both showed progressive hypermethylation across generations, caused by epigenetic priming (leftover methylation marks strengthening the response in successive generations). Pristine fibers likely induced priming through nutrient deficiency, and silver ions from direct toxicity, with consistently low population supporting this. Both groups exhibited a similar pattern indicating chronic toxicity and heritable, stress-induced epigenetic changes.

Conclusion

Agricultural-waste Potential: Banana sap and coconut sclerenchyma tissue extract can be repurposed into effective, bio-based flame retardants for textile and wildfire prevention applications, offering a sustainable alternative to ammonium polyphosphate flame retardant, with coconut extract showing the highest promise due to near complete protection of the underlying materials through formation of a stable char layer.

Safety Comparison: Banana sap has the highest ecological safety towards aquatic life, nourishing and supporting healthy growth. Coconut extract does not induce heritable epigenetic change, may require further pH adjustment and solvent-free extraction methods to prevent transient epigenetic effects. Both natural treatments are safer compared to ammonium polyphosphate, which causes chronic stress (nutrient overload/oxidative stress) in soluble form, and acute toxicity in insoluble form. Natural flame retardants pose significantly less eutrophication risks in water streams.

Broader impact: This approach enables low-cost, farmer-driven production of value-added materials and highlights the importance of epigenetic studies for assessing long-term environmental safety. Due to the simple method of extraction used, the repurposing of agricultural waste can be done on-site at farms themselves, making this a low capital yet sustainable method.

Conclusion

Additional Finding: Pristine cotton microfibers- a prevalent vector for the re-release of flame retardants and other chemicals into water streams- can cause chronic toxicity towards aquatic organisms such as *Daphnia magna*, due to nutritional deficiency caused by ingestion of fibers alone.

Limitations

- Using a global DNA methylation assay like ELISA, does not allow for methylation tracking of individual genes, only changes to the organism's gene expression as a whole.
- Acetic acid extraction of polyphenols from coconut tissue caused the extract pH to be slightly acidic for *Daphnia magna*.

Future Development

As this study showed that solvent-free banana saps have lower ecological health impacts, future work will focus on developing a solvent-free coconut-based flame retardant using more efficient milling methods, such as ball milling, to convert coconut waste into a sustainable alternative with even higher ecotoxicological safety.

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