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Article

Heavy metal and bacterial water filtration using *Moringa oleifera* and coconut shell-activated carbon

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SUMMARY

Scarcity of potable drinking water exposes people to dangerous impurities – i.e., lead, copper, nitrates, and *Escherichia coli* – that contribute to life-threatening health concerns and are subsequently detrimental to the environment. Current, complex water filtration systems, most commonly reverse osmosis (RO) water filtration systems, remove some heavy metals and bacteria, but are chemically based and expensive to install and maintain. *Moringa oleifera*, commonly referred to as moringa, is a vegetable tree that produces leaves and fruit with both antibacterial and filtration properties for the removal of bacteria, sediment, and heavy metals suitable for removing them from water. The purpose of this study was to examine the use of moringa seeds as a filtration material. To conduct this study, we filtered simulated polluted water containing lead oxide, copper, and ammonium nitrate with moringa. Our results showed that moringa seeds were an effective filtration material. However, the filtered water still contained a significant concentration of heavy metals. Therefore, to further purify the water, we added a coconut shell-activated carbon (CSAC) filter, which proved to remove 100% of the residual contaminants. A real-world testing sample from Elm Fork Trinity River water was also tested for both heavy metal elimination and bacterial filtration. Results revealed that after the two-stage filtration, *E. coli* was no longer in detectable range. Our study demonstrates an effective method of heavy metal and bacteria removal from polluted water. Using moringa seed powder and CSAC, this economical, readily available filter can prove to be a more efficient alternative than current RO Systems.

INTRODUCTION

Globally, one in three people do not have access to clean drinking water (1). Water pollution generally occurs when harmful substances like heavy metals, bacteria, and pesticides enter drinking water sources through five main pathways: agricultural pollution, radioactive substances, oil pollution, sewage, and wastewater (2). Long-term consumption of such polluted, untreated surface water leads to the ingestion of harmful contaminants (i.e., lead, copper, nitrates, and *Escherichia coli*) which consequently can result in life-threatening health conditions in humans. These conditions include – but are not limited to – nervous system disorders, gastrointestinal and kidney dysfunction, and vascular damage (3). Despite the scarcity of potable water around the world, current devices and/or methods of water purification are expensive, not readily available to low-income communities, and can be severely toxic to aquatic life (4).

Moringa oleifera (commonly referred to as moringa) is a tree native to South Asia that grows highly nutritious fruit and is used across different cultures as a diet component, medicine, and animal feed (5). Recent studies have shown that *M. oleifera* seeds contain a protein, *M. oleifera* cationic protein (MOCP), that serves as a coagulant to bind to toxins (6,7). The coagulation process – positively charged molecules attracting negatively charged molecules through adsorption to create a larger molecule (floc) – enables the seed to kill bacteria, filter dirt, and remove heavy metals such as copper, zinc, iron, and nickel (8). Commercial, large-scale filters that traditionally use chemical coagulants could instead utilize moringa seeds as a safe, natural, and organic substitute. However, a single drawback – residual solid contaminants – may require moringa to be paired with additional filtration.

Coconut shell-activated carbon (CSAC) is extracted when coconut shells are slowly heated to extremely high temperatures and then activated by using an acidic substance (i.e., lemon). The material uses the process of adsorption to attract compounds and form a small film along the surface of water, from which solid contaminants can be easily disposed (9). As a renewable resource, CSAC can be easily applied to water filtration in combination with moringa seeds and sourced from many countries worldwide. Furthermore, as coconut shells are commonly disregarded as waste, repurposing of waste can provide environmental benefits to tropical and rural areas (10).

Current water filtration systems have many issues ranging from pricing to environmental safety. One of the most common industrial water filtration systems is the reverse osmosis (RO) filtration system (11). This method uses force to push polluted water through a semi-permeable membrane. Although the system removes many contaminants, it also removes healthy minerals that water contains, including potassium, municipally added fluoride, and calcium (12). Furthermore, this water filtration system wastes a significant amount of water by cleaning the filter itself to remove contaminants it contains. During crossflow, water enters the system to rinse out the contaminants inside of the filter; therefore, more than four times of water can be wasted by attempting to clean the system (12). In conclusion, the RO system can cost up to thousands of dollars to install and maintain, making it inaccessible and impractical to many households globally. Similarly, Brita water filters, commonly used inside pitchers, not only fail to remove common heavy metals such as lead and copper but also enable the growth of bacteria by up to 10,000 times the amount of the unfiltered water (13).

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In this study, we aimed to develop a water filtration system using moringa seeds that successfully inhibits bacterial growth and removes toxic compounds from polluted water while remaining economical and reducing waste for households globally. We hypothesized that a *M. oleifera*-based water filtration system can remove toxic heavy metals and bacteria from polluted water to an extent that is comparable to currently used RO systems, thus, delivering filtered, clean water to households across the globe.

RESULTS

To create the optimal filtration method, we designed three separate steps that evaluated the quantity and effectiveness of potential filtration materials: moringa seeds and CSAC. In Test 1, we evaluated the effectiveness of moringa seed and CSAC individually in removing heavy metals. We filtered simulated polluted water, which contained 1101 ppm each of lead, copper, and nitrate to simulate heavily contaminated water for thorough testing of the filters, with 0.02 g/mL, 0.04 g/mL, 0.1 g/mL, and 0.2 g/mL of moringa seed extract for 15 minutes to determine the optimal mass of moringa seed in an extract (**Figure 1**). The moringa seed powder was then filtered out using a Whatman grade 1 paper filter (**Figure 1**). The 0.02 g/mL concentration removed 67% of heavy metals, the 0.04 g/mL concentration removed 86% of heavy metals, the 0.1 g/mL concentration removed 91% of heavy metals, and the 0.2 g/mL concentration removed 94% of heavy metals (**Figure 2**). We chose 0.1 g/mL as the filter standard content weight in the following tests due to its high removal of heavy metals and for economical purposes. However, since the moringa filter only removed an average of 91% of the contaminants, we tested a second stage with CSAC. The CSAC filter was constructed by placing 2.5 g of CSAC powder evenly layered on a Whatman grade 1 paper filter. The results of the CSAC filter showed an average of an 87% reduction in heavy metals, indicating that both filters (moringa seed and CSAC) are necessary.

In Test 2, each the moringa seed filter was combined with the CSAC filter to develop a two-step filtration system. Using our simulated polluted water, we saw that 97% of all heavy metals in stage 1 (moringa seed filter) were removed and 100% of all residual metals in stage 2 (CSAC filter) were removed. A two-tailed *t*-test showed that comparing heavy metal concentrations in simulated water before and after filtration was statistically significant (*p*-value = 0.032080).

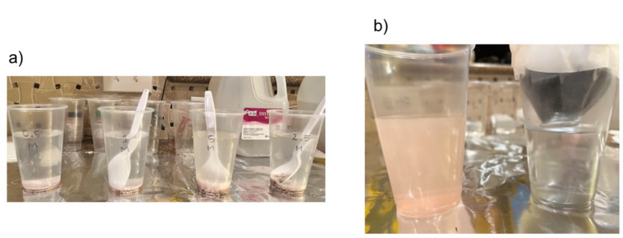

Figure 1. Tests of efficacy of individual filtration materials in simulated water. A) Experimental set-up of Test 1 filtering simulated water by using different quantities of moringa seed powder (0.02 g/mL, 0.04 g/mL, 0.1 g/mL, and 0.2 g/mL from left to right). **B)** Side-by-side comparison of simulated water containing heavy metals and water filtered by the final filtration system.

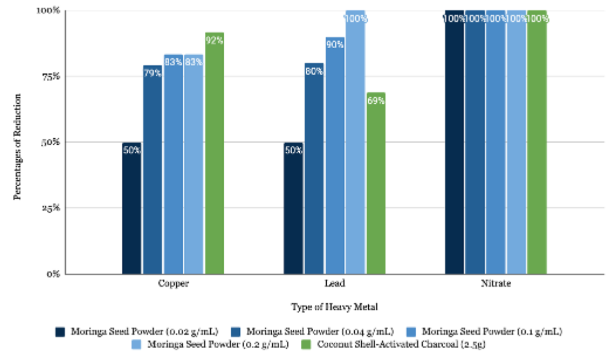

Figure 2. Percent reduction of heavy metals in simulated water with different masses of moringa seed powder in each extract. Results of Test 1 and the CSAC only filter by depicting the percent reduction of copper, lead, and nitrates in simulated polluted water across each moringa powder extract and comparing it to the efficacy of a CSAC filter with 2.5 g of CSAC powder.

In our final experiment, Test 3, we collected water from the Elm Fork of the Trinity River in Irving, TX – a known source of E. coli contaminated water – to test the ability of the final filtration system to remove bacteria and heavy metals (14). In this natural water test, stage 1 removed 91% of all heavy metals and stage 2 removed 100% of all heavy metals from the water (**Figure 3, 4**). Additionally, no *E. coli* was detected after the first stage of filtration (**Table 1**). For direct comparison, in order to validate the test results of the moringa seed and CSAC filter, we tested filtered water from an RO system. Our results showed that there was no trace of heavy metals in the water indicating 100% removal of heavy metals with the final filtration system. A two-tailed *t*-test showed that comparing heavy metal concentrations in river water before and after filtration was statistically significant (*p*-value = 0.02855).

Results showed that all *p*-values were under 0.05, stating that the data is considered statistically significant. Therefore, we concluded that the final filtration system – the moringa seed and CSAC filter – is highly successful in removing heavy metals and bacteria from contaminated water, providing a

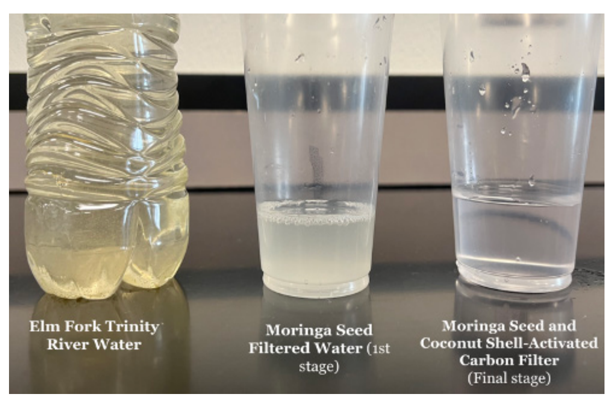

Figure 3. Results at each stage of filtration of the contaminated Elm Fork of the Trinity River using the final filtration system. Side-by-side comparison of Elm Fork Trinity River Water (left), 1st stage filtration by moringa seed powder (middle), and 2nd stage filtration by CSAC (right) as described by the procedures in Test 3.

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	Trial 1	Trial 2	Trial 3
Elm Fork Trinity River Water	Positive	Positive	Positive
Moringa Seed Powder Filter	Negative	Negative	Negative
Moringa Seed Powder and Coconut Shell-Activated Carbon Filter (Final Water)	Negative	Negative	Negative

Table 1. Dual stage Elm Fork Trinity River Water bacteria presence. Bacteria presence in Elm Fork Trinity sampled river water after filtration by moringa seed powder alone and the dual stage moringa seed powder in combination with CSAC. Across all trials, bacteria was undetectable after treatment with moringa seed powder alone and in the dual-stage filtration testing.

method of water filtration using natural processes.

DISCUSSION

The moringa seed and CSAC filter is a natural filter that successfully eliminated 100% of heavy metals and removed *E. coli*. The system is also extremely efficient, and it can be applied to both portable and industrial scales.

There were many obstacles that required procedural modifications throughout the course of experiments. While preparing the moringa seed powder, we initially ground the moringa seeds in a blender instead of a mortar. When running simulated water through the filter, the seed grounds were so fine that they, too, were passing through the filter paper. In subsequent trials, we ground the seeds with a mortar and filtered the seeds out with the filter paper. In addition, in initial stages of testing, coffee filters were used in the CSAC filters, which caused tearing due to the weight of the water-solute mixture. Instead, we substituted coffee filters with the Whatman grade 1 filter paper to help restrict CSAC residue out of filtered water while preventing tears. The pore size of the filter paper (11 μm) was large enough to restrict the moringa seed powder and CSAC powder from filtering into the purified water, but it was not fine enough to filter any heavy metals or bacteria. Most importantly, the biggest obstacle was adding an additional stage which remained efficient. After we discovered that moringa seeds only removed 91% of contaminants, a second filtration system was necessary to filter residual heavy metals, so we added a CSAC filter, which included 2.5 g of CSAC powder on a circular paper filter with a diameter of 150 mm, to the second stage. When testing which amount of CSAC powder was the most successful, we analyzed 5 g of powder to be the most effective. However, to make the filtration system more practical and economical, we chose to use 2.5 g of CSAC powder for the second stage instead, as the primary goal of the second stage was to simply remove residual heavy metals. The two-stage filtration system, moringa seed and CSAC filter demonstrated a 100% success rate of both removing toxic metals and *E. coli* from polluted water (both simulated and sampled).

Current devices or water purification methods, such as RO systems, are extremely expensive or inefficient in communities without power and running water (15, 16). While RO systems, which use semi-permeable membranes to purify water, are the most common water filtration systems, they are very expensive and waste over 15 times the volume of water that is drinkable by the end of the filtration process (12). Alternatively, the filtration system we describe provides a cost-effective and all-natural solution to be used in households. For both the moringa seed and CSAC filters, 0.1 g/mL of solute proved effective in this filtration system. A cost analysis comparing this dual-stage filter to a traditional RO filter revealed that filtration by moringa seed powder and CSAC is more than 5 times cheaper, with a price of $19.96 to install compared to a reverse osmosis system which can range from $100 to $800 to install (17). The breakdown of the filter cost, which filters 100 gallons of water, as tested, before replacing the moringa seed and CSAC, includes $1.00

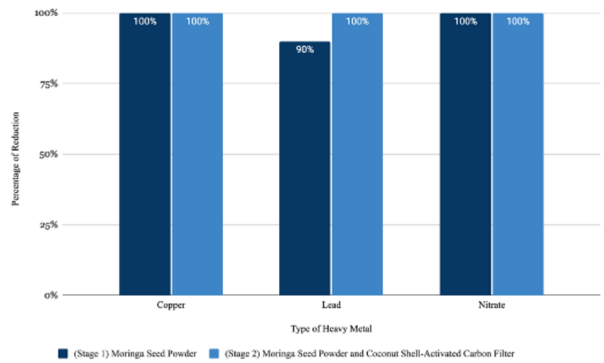

Figure 4. Average percentages of heavy metal reduction by filtering water samples from the Elm Fork of the Trinity River water with the final filtration system. The percent reduction of copper, lead, and nitrates of simulated water at Stage 1 (moringa seed powder filtration) and Stage 2 (CSAC filtration). 0.15 L of river water was filtered through the moringa seed filter (0.1 g/mL) and then the CSAC filter (2.5 g). Across all three metals, 100% of heavy metal residue was removed after the second stage of filtration.

	Influent Water	Effluent Water	Percent Reduction
Copper	17 ppm	<0.07 ppm	>99.85%
Lead	1.01 ppm	<0.07 ppm	>99.37%
Nitrate	171.57 ppm	1.27 ppm	99.26%

Table 2. Test results of a RO filtration system adapted from Express Water. Results of a water test conducted by Express Water to represent the removal of heavy metals and nitrates from water purified by a RO system (16).

	Cost to Filter One Gallon of Water	Wastewater Produced for One Gallon of Clean Water	Removal of Bacteria
Moringa Seed Powder and Coconut Shell-Activated Carbon Filter	$0.02	None	Yes
RO System	$0.03	4L	Yes
Brita Filter	$0.09	None	No

Table 3. Direct comparison of the Moringa Seed Powder and CSAC Filter, RO System, and Brita Filter. Comparison of the cost to filter one gallon of water, waste produced to filter one gallon of water, and whether the filter removes bacteria (13,16,17).

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for 25 g of moringa seeds, $0.50 for one ounce of CSAC, $14.94 for three water tanks (one for each stage of filtration), and $3.52 for the water pipes. In conclusion, we were able to successfully create a water filtration system using moringa seeds and CSAC that is affordable and highly efficient (**Table 3**).

Future research should consider testing the removal of a wider range of common surface water pollutants in varying concentrations to measure the effectiveness of the two-stage system in other contexts. In addition, testing powder from other parts of the moringa plant (i.e., the shell) for filtrate properties could provide increased cost effectiveness of this filtration procedure and prevent waste. The immediate next steps of this research would be to adapt this filter into a compact, portable kit, to ensure directions are clear and the filtration materials are readily available (i.e., filter paper) for distribution globally, and to determine the water flux and therefore efficiency of the filtration system.

MATERIALS AND METHODS

Water sampling of simulated polluted water and river water for heavy metals

Simulated polluted water was used to test the removal of heavy metals by each filtration compound. For standardization of metal concentrations for testing, approximately 1101 ppm of each metal — copper powder (Home Science Tools, CH-CUPOWD), lead oxide (Home Science Tools, CH-PBO), and ammonium nitrate (Home Science Tools, UN1942) — was added to 3 L of distilled water. The container was then stirred to ensure even distribution of metals throughout the mixture. The test strips we then used to measure heavy metal concentrations was based on colorimetric analysis. For Test 3, water was sampled from Elm Fork Trinity River in North Central Texas which has been documented to contain heavy metals and *E. coli* (14).

Test 1: Moringa seed filter with different masses of moringa seed powder

To make the powder, the home-grown dried moringa seeds, which were grown from seeds from Vedic Secrets, were unshelled and the internal white kernel was extracted. Then, using a mortar, the kernel was ground into a semi-fine powder and added to 25 mL of distilled water to create a moringa seed extract at a concentration of 0.02 g/mL, 0.04 g/mL, 0.1 g/mL, and 0.2 g/mL. This extract was then added to 150 mL of polluted water and stirred (**Figure 1**). After 15 minutes, the water was filtered through Whatman grade 1 filter paper and tested for heavy metals using a SaySummer 16-point test kit.

Test 2: Moringa seed and CSAC filter in simulated water

Combining Test 1 and Test 2, this test ran the dual-stage filter. In the first stage, simulated polluted water was filtered through the moringa seed filter which contained a concentration of 0.1 g/mL of moringa seed powder in the extract. Then, for further heavy metal filtration, the water was run through the second stage CSAC filter (2.5 g of solute dispersed over a circular piece of Whatman grade 1 filter paper with a diameter of 150 mm). Finally, the 16-point SaySummer test kit was used to test for residual heavy metals.

Test 3: Moringa seed water and CSAC filter with river water (bacteria test)

Final testing sought to determine the efficacy of the filtration system in removing bacteria. Water from Elm Fork of Trinity River was sampled and tested for bacterial presence using the Watersafe rapid bacteria test. Then, the river water was filtered through the final two-stage filtration system using moringa and CSAC to remove heavy metals and bacteria. The purified water was then tested for heavy metals by the SaySummer 16-point heavy metal test and bacteria by the Watersafe rapid bacteria test to determine the concentration of possible residual pollutants. Using Excel Analysis ToolPak, we used a two tailed *t*-test and descriptive statistics to analyze the data and ensure all metrics were statistically significant. All calculated *p*-values were less than 0.05 and therefore considered statistically significant.

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