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The Optimization of Lead Absorption in Contaminated Water Through Anhydro Galacturonic Acids in Various Citrus Peels

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ABSTRACT: Lead poisoning is a severe health condition that impacts around 240 million people annually worldwide, especially in developing nations and regions such as India, Africa, and South America. Furthermore, fruit peel wastes are found in abundance in underdeveloped nations at low costs and have a chemical makeup that may absorb lead in an environmentally friendly way. It was hypothesized that the pectin concentrations in fruit peels would be directly proportional to the lead absorption, therefore causing grapefruit pectin to absorb the most lead, because more pectin signifies greater availability of the chelating agents that allows the polysaccharide to more effectively bind to lead ions. This study tested a sustainable and cost-effective method to create a filtration system that purifies lead contaminated water through the use of anhydro galacturonic acid from various citrus fruits. Anhydro galacturonic acid, the main component of pectin, extracted from citrus peels was tested for lead adsorption using a percent absorption analysis. Each type of pectin was successful in absorbing a significant percent of lead from the initial solution with respect to the control group; however, grapefruit peels had the greatest percent absorbance for lead since they contained the greatest amount of anhydro galacturonic acid, as the hypothesis predicted.

KEYWORDS: Filtration; Lead Contamination; Water Purification; Pectin; Citrus Peels; Anhydro Galacturonic Acid.

INTRODUCTION

Lead poisoning is one of the most severe and common diseases, accounting for nearly 0.6% of global diseases.[1] Lead, a heavy metal found in the earth's crust, is used in many day-to-day products. Widespread use of lead combined with an increase in globalization has resulted in the environmental contamination of lead in large bodies of water, leading to serious health concerns worldwide. The ramifications of lead poisoning have proliferated exponentially through the collective consumption of the food chain, exposing humans to serious health consequences. With respect to the worldwide epidemic of lead contamination, The World Health Organization estimates that 240 million people around the world are overexposed to dangerous lead concentrations. Of those impacted 99% are found in developing nations in Africa, South America, and some parts of India and account for approximately 853,000 deaths annually.[2] Lead toxicity affects all populations, however, young children are more susceptible to its effects and can suffer from permanent adverse effects to their cognitive development.[2] Adults exposed to toxic levels of lead have a higher risk of developing high blood pressure as well as kidney damage.[3] For these reasons, preventing lead exposure is an important issue in the international public health community; however, this proves to be a difficult task as global production of lead is continuously increasing as nations continue to industrialize.

Current solutions to lead contaminated water come in various forms ranging from gravity filters, reverse osmosis systems, faucet mount filters, to distillers. However, it is important to consider that these technologies are not sustainable in rural communities in developing nations. The use of pectin to bind to lead ions could be a viable form of water filtration in these developing countries, since it is known that pectin has capabilities of binding heavy metal ions. Food products such as some pectin rich fruits and vegetables have been studied for their biosorption capacity, which led to the proposed method of utilizing the pectin in fruit peels to filter lead from water. When considering the environmental sustainability of fruit peels, they are commonly found in underdeveloped nations at low costs and with significant availability. Fruit peels are frequently used in compost or disposed of within these countries, so their utilization as part of our solution would come at no cost. For example, fruit and vegetables make up 39% of food waste in the US.[5] This is why, when considering that the majority of the infected populations are from impoverished communities, sustainable goods such as fruits prove to be promising solutions for lead poisoning. Contaminated water poses a risk to children's development and the health of adults; therefore, it is urgent to find a solution to water pollution. The use of pectin could be the first step to reaching an easily accessible means of filtering lead contaminated water.

The goal of this research project is to create a lead filtration system for environments with lead contaminated water using anhydro galacturonic acid - also known as pectin - found in various citrus fruits. We initially hypothesized that if pectin significantly reduces lead concentration, it can be used as an alternative cost-effective and sustainable filtration system. We also hypothesized that as the pectin concentration of a fruit increases, its ability to absorb lead will also increase due to the heightened amount of chelating agents binding to the metal ions. If pectin from grapefruit, orange, and lemon is placed in a lead solution, it was predicted that the grapefruit pectin would

DOI: 10.36838/v2i3.3

absorb the most lead because it contains the greatest concentration of anhydro galacturonic acid which is 0.65%.[6] Oranges only contain 0.57% while lemons contain 0.63% pectin.[7]

RESULTS AND DISCUSSION

To test the hypothesis, nine oranges, nine lemons, and three grapefruits were peeled and placed in separate pots that contained two liters of water. The pots were boiled and filtered to separate the anhydro galacturonic acid from the peel-water system. Dried peels were added to the pectin solution to increase the surface area and porosity to allow for better absorption of the lead. The pectin was then immersed in lead nitrate for 24 hours to allow for absorbance of the lead ions, and the remaining solution left behind was reacted with potassium iodide. The yellow precipitate, lead iodide, was dried and massed. The change in moles of lead indicated the amount of lead absorbed by the pectin within the fruits, and the average percentage of lead absorbed for each fruit pectin was calculated.

When considering the results of the experiment, the orange pectin absorbed approximately 75.52% of the original lead, lemon pectin absorbed approximately 54.36%, and grapefruit absorbed approximately 77.92%. The pectin from the grapefruit absorbed the greatest percentage of lead, while the orange absorbed the least, excluding the control. The control group absorbed approximately 0% of the original amount of lead, as the amount of lead remained the same before and after the reaction took place. The pectin in each fruit successfully removed lead from the lead nitrate solution, implying that using a pectin-based filtrations system, it can be expected to remove approximately 80% of the lead found in contaminated water (Figure 1).

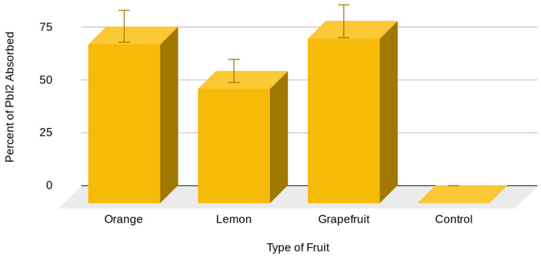

Figure 1. Average percent of PbI_2 absorbed vs type of fruit.

CONCLUSION

In conclusion, the hypothesis that grapefruit pectin would absorb the most lead was supported by the data: the grapefruit was able to remove about 78% of the lead, more than orange and lemon peels. The higher absorption capacity of the grapefruit is due to a greater concentration of pectin present in grapefruit peels compared to the other citrus fruits that were utilized. As stated in the hypothesis, grapefruit has a 0.65% concentration of the sugar which is greater than the concentrations found in orange and lemon. Even though grapefruit had the greatest absorption, orange absorption was close in percentage due to the overlapping of their error bars. Therefore, the absorption of lead using grapefruit and orange was not significantly different. Because of this, the experiment contradicted what was hypothesized based on the level of pectin found in orange and lemon peels. The second highest pectin content based on background research was in lemon which absorbed the least amount of lead (excluding the control). There are multiple hypothetical reasons for this occurrence. One of the reasons could lie in the differences in surface area of each fruit. As surface area increases, the adsorption capacity also increases. Orange peels have been found to have a high surface area through the use of Langmuir Isotherm Models and Freundlich models and demonstrate a high capacity for absorbing lead ions.[8] Another reason that orange was effective at absorbing lead ions could lie in the ripeness of the fruit. In this experiment, ripeness was not measured, but this could be a potential factor in the absorption capability of the fruits. As fruit ripens, there is a "softening" process that occurs. In this scenario, "pectin degrading enzymes such as polygalacturonase, pectin methyl esterase, lyase, and rhamnogalacturonan are the most implicated in fruit-tissue softening."[9] Therefore, ripened fruits contain less pectin due to the higher presence of these enzymes. This indicates that there could have been varying pectin amounts in the fruits, leading to the unexpected higher lead absorption by the orange if the lemons had been riper.

One potential avenue of future research is presented through methylation. The pectin used in the experiment was polymerized to increase the porosity of its surface. The addition of methyl groups from isopropyl alcohol could further increase the ability of the pectin to absorb the lead, as the alcohol contains hydroxyl groups that aid in the chelating agent structure's binding to the positive lead ions. Additionally, this research can be expanded by improving the pectin polymer system. The pectin polymer system absorbed a small amount of the water from the 0.1M lead solution. To better the system, the project hopes to determine how to increase the amount of water coming out of the filter to retain as much of the original water concentration as possible. This could be achieved by maximizing the amount of dried citrus pith used in the filtration system instead of the zest of the fruit peel.

This experiment demonstrates a sustainable and cost-effective solution to lead contamination in many rural parts of the world. The use of waste products such as peels makes it a sustainable resource, as there are billions of tons of peels generated as waste around the world. The fact that fruit pectin is effective in absorbing lead ions proves that this waste can be useful. Many people around the world struggle to afford high maintenance filtration systems, and they often lack access to any clean water. Contaminated water poses a risk to children's development and the health of adults; therefore, it is urgent to find a solution to water pollution. The use of pectin is the first step to reaching an easily accessible means of filtering lead contaminated water, especially in underdeveloped countries. Extracting pectin is not a labor-intensive process and requires very little energy to extract. Hopefully, this project can effectively combat metallic ion contamination.

METHODS

First, we peeled nine small oranges, nine lemons, and three grapefruits, placed them individually in three pots and boiled them with around 2 liters of water each. Once boiling began, we let the pots simmer for 15 minutes and then remove them from the heat. After straining the peels, we preserved the strained liquid in separate containers and baked the dried peels in the oven at 360 degrees for 1 hour. After leaving the baked peels outside to sun dry for 1 week, we blended them to create three powdery substances which were separately stored. In order to prepare the anhydro galacturonic acid solution, we mixed 1 teaspoon of each fruit juice solution with 1 tablespoon of rubbing alcohol. If the alcohol solution formed a solid jellylike mass that could be picked up with a fork, we confirmed that pectin had been created for all three fruits. Next, we labeled 12 250ml beakers (4 per fruit) and transferred 50ml of each pectin solution in the graduated cylinder to the labeled beakers. We then used an electronic balance to measure out 11.25g of each fruit peel and then added that to the respective 250ml beakers while mixing thoroughly with a stirring rod. Each of these pectin solutions were left overnight in a fume hood. Moving on to the next phase of the experiment, we obtained a new batch of 12 150ml beakers, labeled each with the fruit and trial number, placed funnels on top of each, and covered each with a filter paper. Next, we transferred each pectin peel mixture to the filter papers on the respective funnels and created our necessary solutions. In order to create a 0.1M $Pb(NO3)_2$ solution, we added 33.133g (1 mol) of $Pb(NO3)_2$ to a 1L volumetric flask and filled it with distilled water to the 1000ml mark. We created a 0.25 M KI solution by adding 41.5025g (1 mol) of KI to a 1L volumetric flask, and filled it with distilled water to the 1000ml mark. Next, we added 50ml of $Pb(NO3)_2$ to each pectin mixture using the funnel filter paper system, and left the $Pb(NO3)_2$ infused solution overnight. The next day, we added 50ml of KI to each solution using the funnel/filter paper system and left the KI infused solution overnight (leaves a yellow solution). Before beginning the next experimental phase, we obtained 4 new 150ml beakers for the control group and added 50ml of KI and 50ml of $Pb(NO3)_2$ to each beaker, labelling the beakers for each of 4 control trials. We also threw away the pectin/peel mixture that remains on the filter paper, and transferred the yellow solution in each beaker to 16 precleaned 250ml beakers using a new funnel/filter paper system until all of the aqueous KNO3 came out clear in the beaker, leaving behind PbI_2 precipitate in the filters. We made sure to record the weight of the filter papers beforehand. Finally, we discarded the KNO3 in the beakers and placed the 16 funnel/filter systems that contain the PbI_2 residue into their respective 16 watch glasses labelled with fruit and trial number. These watch glasses were put in the oven for 10 hours until the PbI_2 precipitate dried and then we massed out the dried solid in each filter paper in grams using the electronic balance. Moving on to the calculations, we subtracted the mass of the boat and filter paper from the overall resulting mass of each trial. After, we converted each mass to moles of PbI_2, which is equivalent to the moles of lead, since there is 1 mole of Pb for every mole of PbI_2. Next, we subtracted this molar amount for each trial from the initial molar amount of Pb in each beaker, which was 0.005 moles, giving the amount of lead absorbed by the pectin in moles. We converted the moles of lead absorbed for each trial into grams and found the percent absorption by dividing the previously found grams of lead absorbed. Finally, we obtained the average percent of lead absorbed for each fruit and created the graph shown in Figure 1

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