Investigation of Fruit Peels as Green Roof Filter

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Abstract

Due to the leaching of organic matter in green roof substrate, green roofs may decrease the quality of runoff rainwater by increasing concentration of nitrogen, phosphorous and sulphur in the water and thus possibly contributing to eutrophication and acidification in downstream freshwater ecosystem. This paper investigated the efficacy of fruit peel powder in removing undesirable anions from green roof runoff and controlling the acidity of runoff in order to determine its suitability as a green roof filter material. Among the peels selected based on their abundance and studied biosorptive properties, orange and banana showed the capacity for anionic absorption. This capacity is generally proportional to mass of peel used: orange peel is estimated to absorb 14.4±5.4 ppm/g of NO3- while banana peel absorbs 98.8±49.2 ppm/g of SO42-. However, the absorption capacity varies with repeated interaction with runoff. From this study, banana peel was the most favourable material for long-term use as a green roof filter as it was able to absorb NO3- and SO42- after repeated interaction with water. All peels were also able to improve the acidic pH of runoff across all soaking assays.

Keywords

Green roof, Fruit peels, Nutrients, Filter

1. The purpose of the investigation

A green roof is a rooftop covered with vegetation and substrate. Its benefits have been intensively studied and encompass many important environmental impacts and improvements in quality of life [1,2]. However, there is prevalent concern over the impact of green roofs on runoff rainwater quality [3]. Green roofs may be a source of contaminants due to the leaching of organic matter in the substrate which may increase the runoff concentration of nitrogen, phosphorous and sulphur [4]. These can cause eutrophication and acidification in the water channels and catchments, which is detrimental to the survival of aquatic life and can make the water unsuitable for other uses [5]. Thus, there is room for improvement in green roof runoff quality.

Most studies aimed at improving runoff quality have focused on the growing medium to minimise leaching and maximise its ion retaining capacity [6,7]. The addition of a chemical filter layer to green roof systems has yet to be explored. This paper thus aims to engineer such a layer which functions to 1) minimise the amount of contaminants in runoff and 2) control the acidity of runoff within a suitable range for freshwater ecosystem, which is 6 to 8.5 [8]. In addition, it is preferable that this filter is eco-friendly both in production and usage, while remaining low cost.

A potentially suitable filter material would be commonly discarded fruit peels due to their abundance and being completely biodegradable. *Citrus sinensis* (orange), *Musa acuminata* (banana) and *Citrullus lanatus* (watermelon) peels were identified as most suitable since these fruits are among the 5 most commonly produced fruits globally [9] and various studies have shown that their peels possess biosorptive properties towards heavy metals and organic pollutants [10,11,12]. However, few studies have investigated their specific interaction with anionic nutrients - nitrate (NO_3^-), sulphate (SO_4^{2-}) and phosphate (PO_4^{3-}). It has been suggested that loading metal, e.g. Fe and Zr, onto fruit peels greatly enhances their ability to absorb anions [13]. Thus, it is possible that metals naturally found in peels, e.g. 78.10 mg/g potassium in banana and 40.0 mg/g iron in watermelon [14, 15], would exhibit similar enhancement effect. In addition, the use of eggshells to enhance the absorptive properties of peel-based filter was also considered to be potentially effective due to its high calcium content – a relatively safe metal in freshwater ecosystem and a known phosphate-binder [16]. Hence, this paper aims to engineer a green roof filter from commonly discarded fruit peels, by investigating their efficacy in removing undesirable anions from green roof runoffs.

2. Method of the investigation

2.1 Preparation of Peels and Eggshell

The exocarp and mesocarp of orange and banana, as well as the exocarp of watermelon were washed with tap water and heated at 70°C until dry and brittle (1, 2 and 4 days respectively). Eggshells were washed, dried and their membranes were removed. Dried peels and eggshells were grinded separately into powder and sieved to ensure they were less than 1.0 mm^2 in size. For each assay, the peel powder(s) and/or eggshell were weighed out and placed in a teabag.

2.2 Preparation of Stock Solutions

Potassium nitrate, potassium sulphate and potassium phosphate solutions were prepared with deionised water to final concentrations of 10−20 ppm, 120−130 ppm and 20−30 ppm of NO_3^-, SO_4^{2-} and PO_4^{3-} respectively. The anion concentrations were validated using Orion AQ4000 colorimeter. HCl and NaOH were used to standardise the pH to a range of 4.2 to 4.4, tested using Mettler Toledo InLab pH electrode.

2.3 Soaking Assay

For each assay, 50 ml of one stock solution was transferred into a beaker and a teabag with content(s) as shown in Table 1 was soaked in the beaker for 15 minutes. An empty teabag was used as a control. The pH and concentration of the specific ion in the filtrate were then tested using the pH electrode and colorimeter respectively. There were three phases of soaking assays with different masses of peels and repeated soakings as detailed in Table 1 below.

Table 1: Summary of Soaking Assays

Phase 1: Preliminary Investigation of Absorptive Properties of Different Fruit Peels
Soaking assays were done on three types of filter contents: orange, banana and watermelon peels. Each teabag contained 1.0 g of one peel powder and was soaked once.
Phase 2: Detailed Study of Selected Peels
Soaking assays were done on two types of filter contents: orange and banana peels. Each teabag contained 0.5 g or 1.0 g of one peel powder and was soaked three times.
Phase 3: Further Study on Combined Filter Contents
Soaking assays were done on two types of filter contents: orange peel + banana peel, and orange peel + banana peel + eggshells. Each teabag contained 0.5 g of each peel powder, and where applicable, 1.0 g of eggshells. Each teabag was soaked once.

In Phase 1, the percentage change in concentration of anion was calculated in Equation (1) below.

$$\% \text{ Concentration Change} = \frac{\text{Sample} - \text{Control}}{\text{Control}} \times 100 \qquad (1)$$

The results obtained were used to identify selected peels with the ability to 1) absorb at least one anion, and 2) increase pH of filtrate towards acceptable freshwater range, 3) without releasing comparatively high percentage of other anions. Selected peels were then studied to investigate whether a consistent effect is observed when 1) a different mass of peels was used and 2) the peels were soaked multiple times. Each teabag was dried at room temperature overnight between soaking. The specific absorption capacity of each peel was calculated using Equation (2) below.

$$\text{Specific Absorption Capacity} = \frac{\text{Sample} - \text{Control}}{\text{Mass of Peel Powder Used}} \qquad (2)$$

Finally, the combined effect of selected peels were investigated and the results were compared to that from Phase 2 to determine if the peels exhibit the same properties when used together. This was done by calculating predicted concentration changes assuming they would exhibit the same independent properties. The results were then analysed with statistical t-test (one-tail).

3. Results of the experiment

3.1 Preliminary Investigation of Different Fruit Peels

In Figure 3.1, orange peel significantly decreased the concentration of NO_3^- by 73.2% ($p<0.05$) while banana peel reduced SO_4^{2-} concentration by 70.7% ($p<0.05$). Hence, it is hypothesised that orange and banana peels can act as NO_3^- and SO_4^{2-} filters respectively. Nagarajaiah and Prakash in 2011 also corroborated that banana peels leached NO_3^- and PO_4^{3-} [17]. On the other hand, watermelon performed most poorly, showing significant increase in concentration of all 3 anions ($p<0.05$) − NO_3^- by ten-fold, SO_4^{2-} by 69.5%, and PO_4^{3-} by 64.7%. In terms of pH of filtrates, all peels showed a significant increase from the standardised pH of the stock solutions ($p<0.05$). Orange showed the least pH increase to a mean of 4.83 while watermelon was most effective in neutralising the filtrate, reaching mean pH of 6.41. This pH increase is corroborated by previous studies which showed that banana peel compost tended to be alkaline [18] and the pH of orange peel compost increased over time [19].

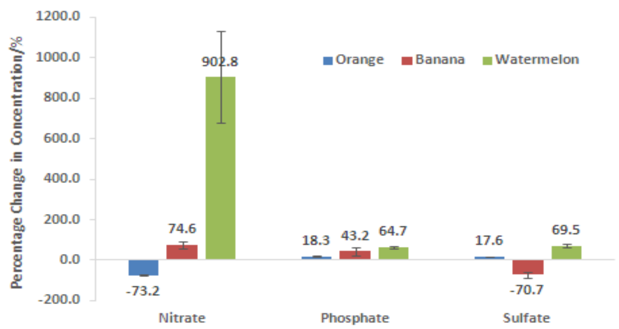

Figure 3.1: The change in concentration of ions from soaking assays of orange, banana and watermelon peels. All changes were significant (p<0.05).

Overall, orange and banana peels have shown desirable results as potential absorbent for the studied anions − having absorbed at least 1 anion by a significant proportion and increased the pH of filtrate towards the desired range. Therefore, they were selected for in-depth study.

3.2 Detailed Study of Selected Peels

The specific absorption capacities of 0.5 g and 1.0 g of each selected peel were calculated for each anion. A significant difference between these values implies that the absorption or leaching of that ion is not proportional to the mass of peel used. For both orange and banana peels, there were no significant difference in the specific absorption capacities for all anions ($p>0.05$) when different masses of peel were used as shown in Figure 3.2. However, SO_4^{2-} leached less per gram of orange peel when 1.0 g is used compared to 0.5 g ($p<0.05$). Therefore, except for SO_4^{2-} interaction with orange peel, the absorption and leaching of the anions were proportional to the mass of peel powder used. Orange peel is estimated to absorb 14.4±5.4 ppm/g of NO_3^- while banana peel absorbs estimatedly 98.8±49.2 ppm/g of SO_4^{2-}. With these constants of proportionality, it may be possible to determine a suitable mass of peel needed for the filter in accordance to the estimated concentration of anions in the runoff. Also, this has to be weighed against the need to keep the filter lightweight due to the weight loading limitation of green roofs.

Between repeated soaking assays, the absorption capacity of orange peel for NO_3^- decreased significantly ($p<0.05$), from 11.1 ppm to 3.1 ppm as shown in Figure 3.3. This is unfavourable for the intended long term use of orange peel as filter material since it may only be effective during its first few interaction with runoff. Nevertheless, there was no significant difference in the leaching of PO_4^{3-} and SO_4^{2-} throughout the repeated soakings ($p>0.05$). It is possible that orange peel will not release greater proportion of undesirable anions with repeated interaction with runoff, as opposed to the expected increase in leaching when fruit peel decompose over time. This can be validated by testing the filter in situ over longer periods. In terms of pH level, the increase in pH is much smaller in subsequent soaking assays for all three anions ($p<0.05$), suggesting a decrease in pH control efficacy of orange peel. Hence, in terms of both anion absorption and pH control function, orange peel performs less favourably as a filter material after every repeated soaking and may be unsuitable for use in the long run.

For banana peels, the absorption capacity of SO_4^{2-} decreases significantly between repeated soaking assays ($p<0.05$), from 93.1 ppm to 31.1 ppm. This suggests that banana peel may not act as an effective SO_4^{2-} filter for long term use. Yet, there was also a significant decrease in the leaching of NO_3^- throughout the repeated soaking assays ($p<0.05$) from 9.3 ppm/g in the first soaking to 1.0 ppm in the second soaking. In fact, the third NO_3^- soaking assay showed a significant decrease in concentration as compared to control, by 2.5 ppm ($p<0.05$), suggesting that banana peel may absorb NO_3^- after repeated interaction with water. On the other hand, the percentage increase in PO_4^{3-} generally decreased between subsequent soaking from more than 15 ppm to 2.5 ppm ($p<0.05$). This is favourable to the intended function of the peel as green roof filter as it releases less PO_4^{3-} in the long run. Also, all filtrates show increased pH level from the standardised stock solutions ($p<0.05$) and between consecutive soaking. Thus, banana peel generally continued to perform well as a filter material after repeated interaction with runoff.

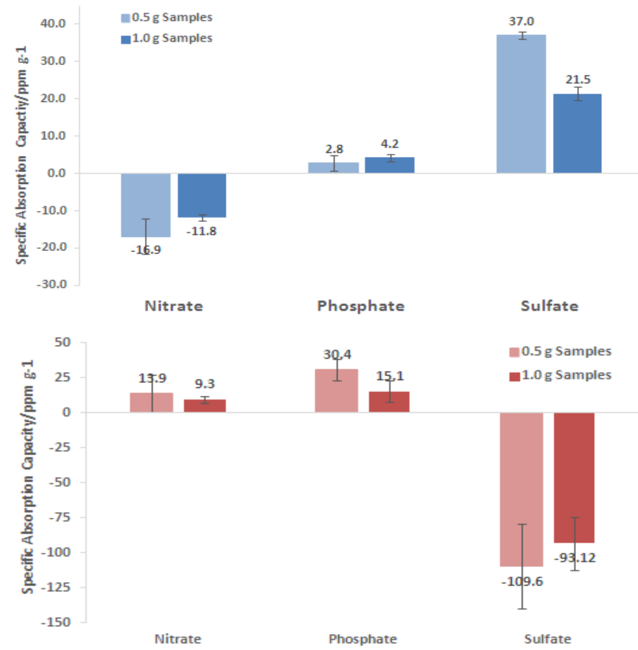

Figure 3.2: The specific absorption capacities of orange (top) and banana (bottom) peels for the first soaking assay

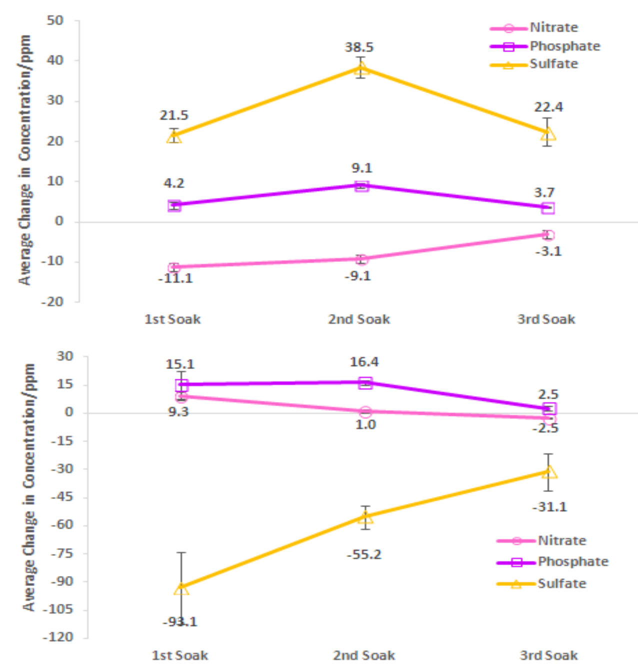

Figure 3.3: Graph showing the absorption capacities for repeated soaking assays of 1.0 g of orange (top) and banana (bottom) peels

3.3 Further Study on Combined Filter Contents

In Figure 3.4, the filtrate of banana and orange combination (BO) soaking assay performed poorly, showing a significant increase in concentration of NO_3^- and PO_4^{3-} ($p<0.05$). Nevertheless, the results compared to the predicted values also showed that the combinative effect of soaking the multiple filter contents together was similar to the effects of each individual content being soaked separately ($p>0.05$), suggesting that the peel powders act independently when interacting with the anions and do not interact with each other. Thus their overall absorption capacities can be adjusted and made more favourable by changing the proportion by mass of each peel in the filter content.

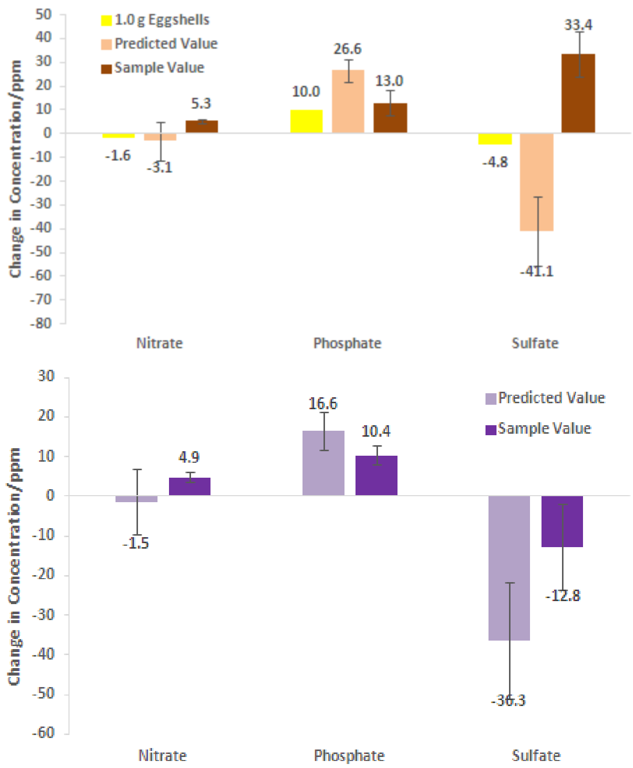

Figure 3.4: The change in anion concentration for soaking assays of orange and banana peels (0.5 g each) combination (BO) (top); as well as orange (0.5 g), banana (0.5 g) and eggshell (1.0 g) combination (BOE) (bottom); with predicted concentration change as calculated from Phase 2 results and eggshell (1.0 g) soaking assay for reference.

When comparing BOE to BO, it appears that adding eggshells to the filter causes the concentration of SO_4^{2-} to increase significantly ($p<0.05$) and there was no change in the concentration of NO_3^- and PO_4^{3-} ($p>0.05$), contrary to previous studies that showed eggshell acting as phosphate binder [16]. The results thus suggest that eggshell is a poor additive for green roof filter. It should be noted that the control (eggshell alone) showed a decrease in concentration of NO_3^- and SO_4^{2-}, though this was not observed when fruit peels were present in the filter. Also, the results generally differ from the predicted values ($p<0.05$ for PO_4^{3-} and SO_4^{2-}), hence the combined effect of soaking the eggshells with the peels was different from the effects of each abovementioned filter content being soaked separately. This may be due to interaction between peels and eggshell which affected their overall absorption capacities.

All combination filtrates showed significant increase in pH level ($p<0.05$). BO, however, showed much less increase from 4.3 to a mean of 5.33, as compared to BOE whose filtrate pH increased up to 6.04. This corroborates with previous studies which showed Ca, which makes up 90% of eggshells, being able to neutralise H^+ ions to cause a rise in pH level [16].

4. Conclusion and Recommendations for Future Work

This paper studied the efficacy of fruit peel powder in removing undesirable anions from runoff and controlling runoff acidity, to determine its suitability as a green roof filter material (Summary Table in Appendix A). Among the three peels studied, orange and banana peels showed the capacity for anion absorption which is generally proportional to the mass of peel used but varies with repeated interaction with runoff. From this study, banana peel was the most favourable material for long-term use as it was able to absorb NO_3^- and SO_4^{2-} after repeated interaction with water. All peels also improved the acidity of runoff across all soaking assays.

Nonetheless, none of the individual peels were able to absorb PO_4^{3-} and the addition of eggshell as a phosphate-binder did not cause a decrease in PO_4^{3-} concentration. Thus, there is room for future investigation involving other phosphate-binders as filter additives in order to enhance the efficacy of the green roof filter. In addition, further studies can be conducted on the specific mechanism for the chemical interaction of the different individual peels with runoff. Overall, there is great potential in engineering a green roof filter from commonly discarded fruit peels to improve the quality of green roof runoff.

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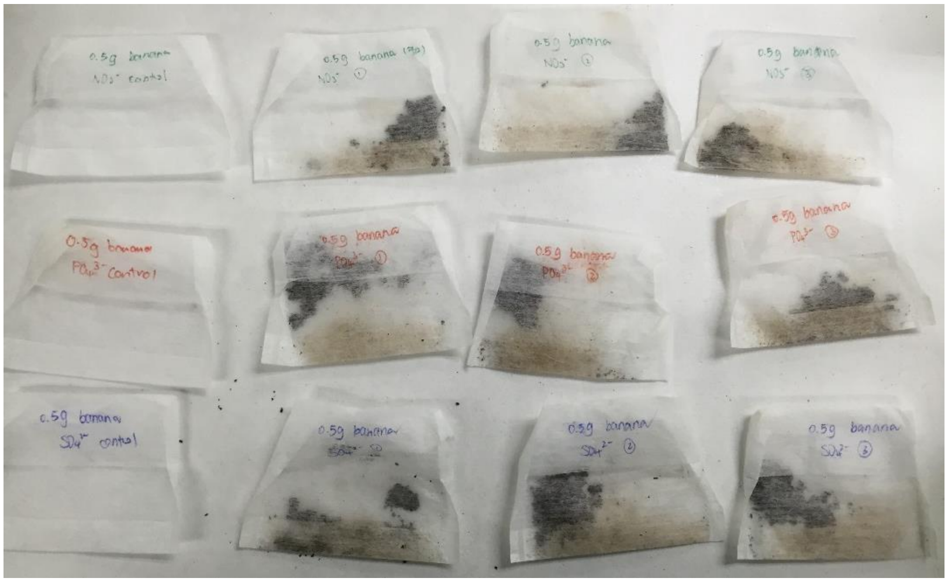
Appendix A – Summary Table

	Orange	**Banana**	**Banana and Orange**	**Banana, Orange and Eggshells**
Pros	Able to improve pH Able to absorb NO_3^- Release of PO_4^{3-} and SO_4^{2-} did not increase with repeated use	Able to improve pH Able to absorb SO_4^{2-} Release of PO_4^{3-} did not increase with repeated use. May absorb NO_3^- after repeated use	Able to improve pH Able to absorb NO_3^- and SO_4^{2-}	Able to improve pH
Cons	Released PO_4^{3-} and SO_4^{2-} Absorption of NO_3^- decreased with repeated use	Released NO_3^- and PO_4^{3-} Absorption of SO_4^{2} decreased with repeated use	Released PO_4^{3-}	Released NO_3^-, PO_4^{3-} and SO_4^{2-}

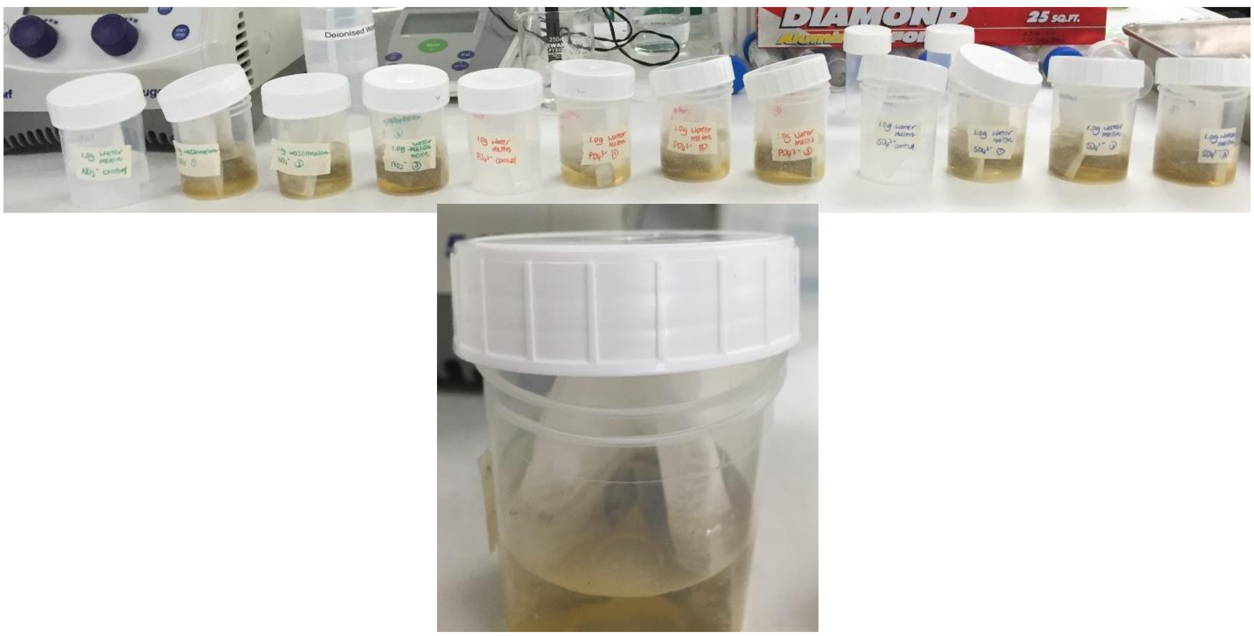
Appendix B – Method and Materials

Grinded watermelon peel and sieving of watermelon peel powder

From left to right: grinded orange peel powder, banana peel powder and watermelon peel powder



Teabag samples


Soaking of teabags