applied sciences

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Brown Coconut Husks as Media Within an Anaerobic Filter for Improving On-Site Wastewater Treatment

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Abstract: Many small communities rely on on-site wastewater treatment systems such as septic tanks; however, there are concerns regarding the level of wastewater treatment being achieved. Appropriate solutions for these communities are needed to upgrade existing septic tanks. Anaerobic filters are a potential solution, which can be added downstream of the septic tank and operate by containing media which allow a biofilm to form. Ideally, this media would be easily accessible and affordable. In this work, the use of brown coconut husks is investigated, and it is found that 68% of the chemical oxygen demand (COD) can be removed by these systems. Nutrient levels were also monitored in the effluent to determine whether the leaching of nutrients from the coconut husks is a concern. It was found that initially some nitrogen and phosphorus had leached but these were washed out of the reactor very quickly and had a minimal impact on the effluent concentrations. Examination of the coconut husks after 10 months of operation showed no signs of the coconut husks beginning to break down, suggesting that the use of coconut husks as media in anaerobic filters should be investigated further.

Keywords: anaerobic filter; coconut husks; eutrophication; on-site wastewater treatment; septic tanks

Academic Editors: Marco Carnevale Miino, Luz Marina Ruíz and Miguel Ángel Gómez

Received: 10 January 2025
Revised: 5 February 2025
Accepted: 10 February 2025
Published: 13 February 2025

Citation: Brown, N.; Edwards, J.; Yarita, S.; Chia, S. Brown Coconut Husks as Media Within an Anaerobic Filter for Improving On-Site Wastewater Treatment. *Appl. Sci.* **2025**, *15*, 1944. https://doi.org/10.3390/app15041944

1. Introduction

Communities and individual households which do not have access to centralized wastewater treatment plants are responsible for their own wastewater treatment via on-site systems such as septic tanks. It was estimated in 2017 that 1.5 billion people use septic tanks around the world [1]. Onsite wastewater treatment systems are common across the Pacific Islands [2–4]. In some countries like the Kingdom of Tonga, there is no centralized wastewater treatment system, so households utilize on-site treatment with 94% of households using septic tanks [5].

One of the challenges with septic tanks is that they rely on individual households for maintenance, and they are typically built below ground so it can be challenging to know how well they are performing. If sludge is not regularly removed, it builds up, which reduces the volume available for treatment and therefore reduces the hydraulic retention time (HRT). Septic tanks can also become undersized if the number of occupants within a household increases. There have been some concerns about how effective treatment is and whether septic tanks are a potential source of pollution for waterways [2,4,6,7]. It is important that any process that improves the treatment performance of septic tanks is appropriate for the communities and households which require them. Low maintenance and affordability are two key considerations. One proposed solution to enhance the system involves the construction of an anaerobic filter downstream of the septic tank [8,9]. The benefit of an anaerobic filter is that the biomass is retained on the surface of media, which makes the system less susceptible to washout as a result of changes in flowrate from an individual household [8], as would be the case in Tonga. The combination of a septic tank and an anaerobic filter has been used at full scale in Brazil [10].

A key component of an anaerobic filter is the media which the biofilm attaches to [11]. From a treatment point of view, the media needs to provide a large surface area for biofilm development and be inert or organic material would leach, which would reduce treatment efficiency. Anaerobic filters can be at risk of blocking [11], so the physical size and shape of the media are important in facilitating the movement of wastewater through the filter bed. Ideally, the media would be readily available locally and affordable. A variety of media can be used, including inert materials such as lava stones [12] or plastic media [13,14], but it is also possible to use crop residuals such as walnut shells [15] and coconut husks [16–18]. Coir fiber has also been used as an attachment medium [19]. Several studies conducted in Brazil have demonstrated that green coconut husks (*Cocos nucifera*) can serve as a suitable surface for the biofilm to attach to [16–18]. This is a potential solution for Tonga where there is an abundance of coconut husks. However, in countries like Tonga, the majority of coconuts are harvested when they are brown rather than green. Brown husks are older, fully ripened, and have fallen to the ground (making them easier to harvest), having lower moisture content (35% [20]). Green husks, on the other hand, are younger and have higher moisture content (86% [20]), having remained attached to the trees. Brown et al., [20] compared the performance of green and brown coconut husks in anaerobic filters and found that brown coconut husks removed more chemical oxygen demand (COD) from the wastewater. Further evaluation found that green coconut husks leached more COD than brown coconut husks, which explains this finding [20]. However, the data presented were only collected over two months of operation, so a more extensive study is required. The leaching of COD from coconut husks gives rise to concerns regarding the potential leaching of nutrients from this organic material [20], though this has not been extensively studied. If nutrient levels in the waterway surpass a certain threshold, it can lead to problems like eutrophication, causing the development of algae blooms and the subsequent pollution of waterways. This highlights the importance of determining nutrient concentrations in the post-anaerobic filter effluent.

The primary aim of this work is to operate an anaerobic filter containing brown coconut husks over a longer period of time, which will assess the stability of the reactor more thoroughly and give an indication of likely maintenance requirements. This research uses synthetic wastewater to provide consistency and allow changes in performance to be detected over time. Examination of the coconut husks at the end of the trial may indicate if the pieces of coconut husk have started to break down, which could provide information on how often the coconut husks need to be replaced. An additional area of focus is to determine whether nitrogen and phosphorus may leach from the coconut husk at levels which adversely affect the feasibility of using brown coconut husks within an anaerobic filter. This work will serve as a proof of concept and determine whether more detailed full-scale trials should be conducted. Prior work has shown a significant difference between the performance of green and brown coconut husks [20], so this work is vital to determine the viability of this process in countries where coconuts are predominately harvested when brown.

2. Materials and Methods

2.1. Anaerobic Filter Setup

A laboratory-scale reactor was set up in the same way as previous studies [20] (Figure 1). The reactor had a diameter of 290 mm and height of 360 mm. Perforated plates were placed 60 mm from the bottom of the reactor and 60 mm from the top of the reactor to contain the pieces of coconut husk and prevent blockage of the outlet. The anaerobic filter tank was connected to two effluent collection containers (20 L and 50 L). Another 75 L container was used as a feed tank. The synthetic wastewater was based on Rodgers et al. [21], and it was diluted to reduce the concentration to approximately 300 mgCOD/L to mimic effluent from a septic tank [22]. The components of the synthetic wastewater are shown in Table 1.

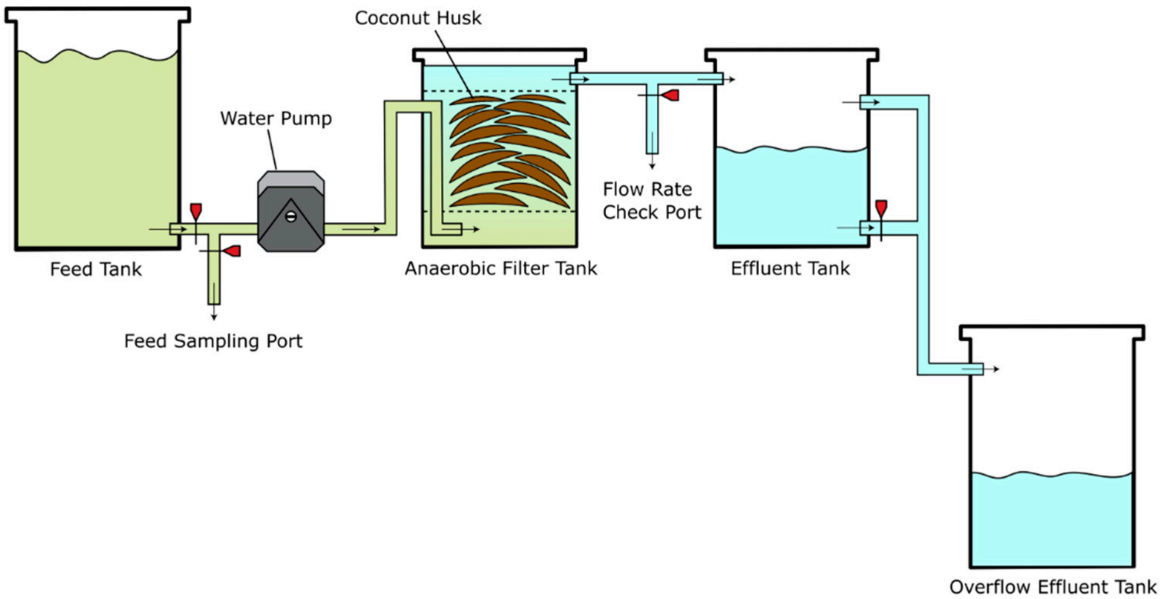

Figure 1. Experimental setup for the laboratory-scale anaerobic filter.

Table 1. Composition of the synthetic wastewater.

Component	Amount Added to 50 L of Water (g)
Glucose	8.15
Yeast extract	0.68
Dried milk	2.72
Urea	0.68
NH_4Cl	1.36
$Na_2HPO_4 \cdot 2H_2O$	2.26
$KHCO_3$	1.13
$NaHCO_3$	2.94
$MgSO_4 \cdot 7H_2O$	1.13
$FeSO_4 \cdot H_2O$	0.05
$CaCl \cdot 6H_2O$	0.01
Bentonite	1.01

The brown coconut husks used in this work were sourced from a coconut farm in the Kingdom of Tonga (*Cocos nucifera*, cultivar Tongan Tall). The coconut husk pieces were one-third to one-quarter of an entire husk. Moisture content measurements were performed, and the brown husks had an average moisture content of 19.8%. The coconut husks were placed in cow manure for 15 minutes to inoculate the reactor with anaerobic bacteria. These husks were then used to fill the anaerobic filter (Figure 1). The total weight of brown coconut husks added to the reactor was 1.371 kg.

In order to mimic wastewater produced from a typical household, the feed pump was run twice daily for one hour (8–9 am and 4–5 pm). This was to simulate the production of wastewater in the morning and evening. The HRT was set at 12 h. The water volume of the anaerobic filter tank was 11 L excluding the coconut husks; therefore, the amount of water pumped each time the pump was run was approximately 11 L, with a total amount of approximately 22 L each day. Initially, the reactor was started on diluted synthetic wastewater to allow the biofilm to become established without overloading. For the first 10 days, the reactor was run using 25% concentration; then, this was increased to 50% until day 25 when the feed was then used at full strength.

2.2. Nutrient Leaching Experiment

The synthetic wastewater contains nutrients, including nitrogen and phosphorus, which could potentially affect the nutrient concentration in the effluent due to various chemical conversions in an anaerobic environment. To eliminate the presence of pre-existing nutrients in the synthetic wastewater, an additional continuous anaerobic filter reactor was set up. This reactor contained brown coconut husks and followed the same setup as the anaerobic filter depicted in Figure 1, except that reverse osmosis (RO) water was used as the feed. The total mass of brown coconut husks used in this reactor was 0.955 kg.

A batch reactor was also run to evaluate nutrient leaching without washout. A 10 L container was used, and one piece of coconut husk (194.7 g) was placed in 6 L of RO water. Samples were taken from the liquid over time, and no additional RO water was added. The container was covered to prevent evaporation.

2.3. Sampling and Analytical Analysis

The continuous reactor feed and effluent were sampled three times per week. The effluent sample was collected from the effluent tank (Figure 1) after the pump had stopped feeding. The effluent tank was emptied and cleaned each morning, and samples were taken in the afternoon after the tank had been well mixed.

Collected water samples were analyzed for COD using AQUAfast Digestion Tubes and an AQUAfast AQ3700 Colorimetry Meter (Thermo Fisher Scientific, Waltham, MA, USA). The pH was recorded. Collected samples from each experiment were analyzed for total phosphorus (TP), total nitrogen (TN), ammonium (NH_4), and nitrate (NO_3). Each nutrient concentration was measured using the Thermo Scientific Orion AQUAfast AQ3700 Colorimetry Meter. Each sample was analyzed in duplicate.

3. Results and Discussion

The anaerobic filter was first evaluated based on COD removal, which is the key parameter of interest. Data on pH were also gathered to give an indication of reactor stability. The nutrient content of the effluent was then examined, and additional experiments were conducted to determine whether nutrients were leaching from the coconut husks.

3.1. COD Removal

The COD results for the feed and effluent samples are shown in Figure 2. During the start-up stage (first 25 days), the synthetic wastewater feed was diluted to allow the biofilm to form without becoming overloaded. This can be seen in Figure 2 where the COD in the feed steps up several times, reaching the full COD concentration of approximately 300 mg/L on day 25.

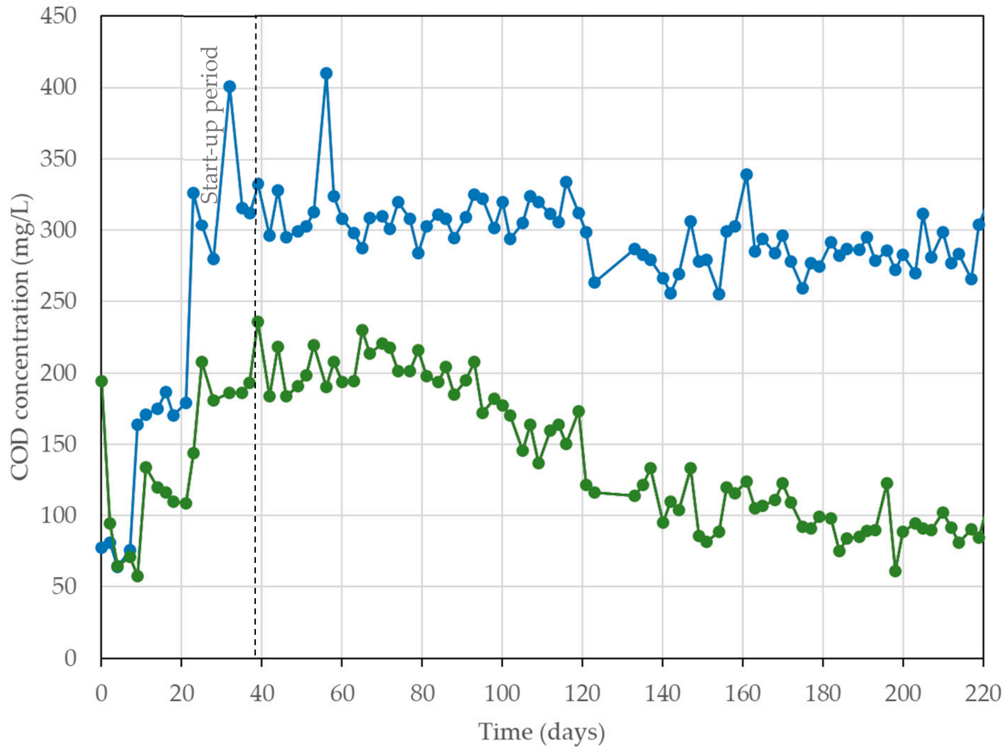

Figure 2. COD concentration in the feed (blue) and effluent (green) of the anaerobic filter.

The COD results are summarized in Figure 3, which shows the average monthly percentage COD removal. For the first four months, the average COD removal was 36%; the COD removal improved, reaching an average of 68% COD removal over the final four months (Figure 3). This improved treatment performance may be due to the establishment of a biofilm on the coconut husks over this period of time. It was reported by Escudié et al. [23] that it can take 4 months to 1 year for anaerobic biofilms to become established, and this agrees with the improved performance seen in Figure 3.

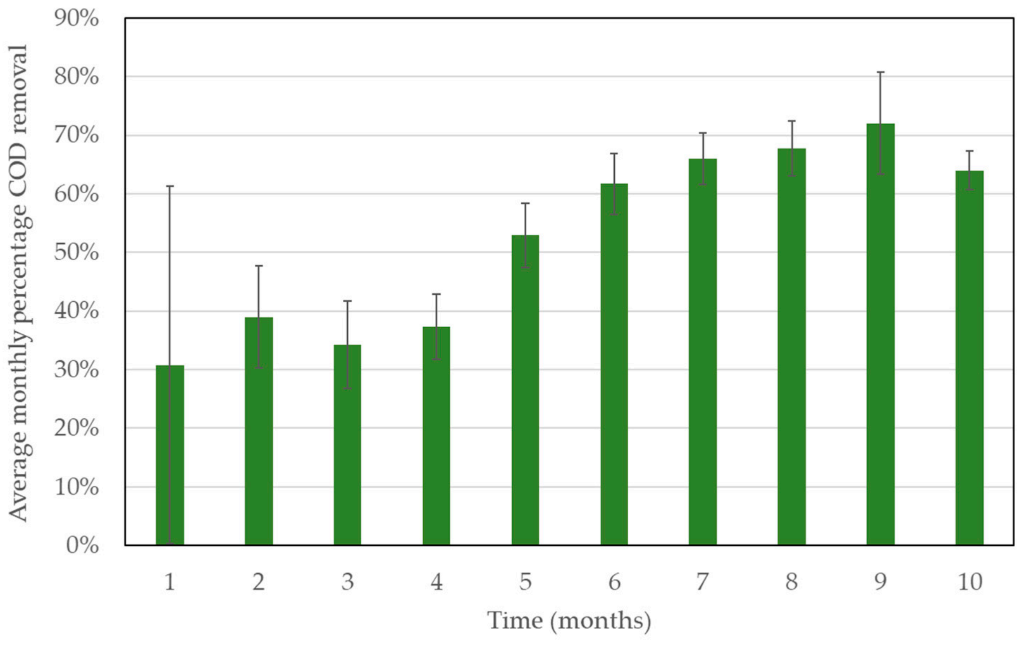

Figure 3. Average monthly percentage COD removal for the anaerobic filter. The error bars show the standard deviations.

The pH was measured to provide an indication of the stability of the reactor. The pH of the feed had a mean of 7.48 and a standard deviation of 0.18. The effluent had a mean of 6.61 and a standard deviation of 0.16. There were no noticeable trends in the pH within the effluent over time, and these values indicate that the reactor was stable throughout its operation.

3.2. Nutrient Levels in the Effluent

The nutrient concentrations in the effluent are influenced by several processes including uptake by the biofilm, biological and chemical processes, which change the form of compounds containing nutrients, and the potential leaching of nutrients from the coconut husks within the filter. Previous research showing COD release from coconut husks [20] suggests that the leaching of nutrients should be investigated.

To reveal changes in nutrient concentrations, the synthetic wastewater feed and the effluent were compared (Figure 4). An increase in the nutrient level in the effluent relative to the feed suggests potential leaching. The forms of nitrogen included total nitrogen, ammonium, and nitrate; however, during the measurements, there was no nitrate detected, so only the total nitrogen and ammonium are shown in Figure 4 along with total phosphorus. Note that the changes in nutrient concentrations in the feed within the first 25 days are due to the start-up procedure.

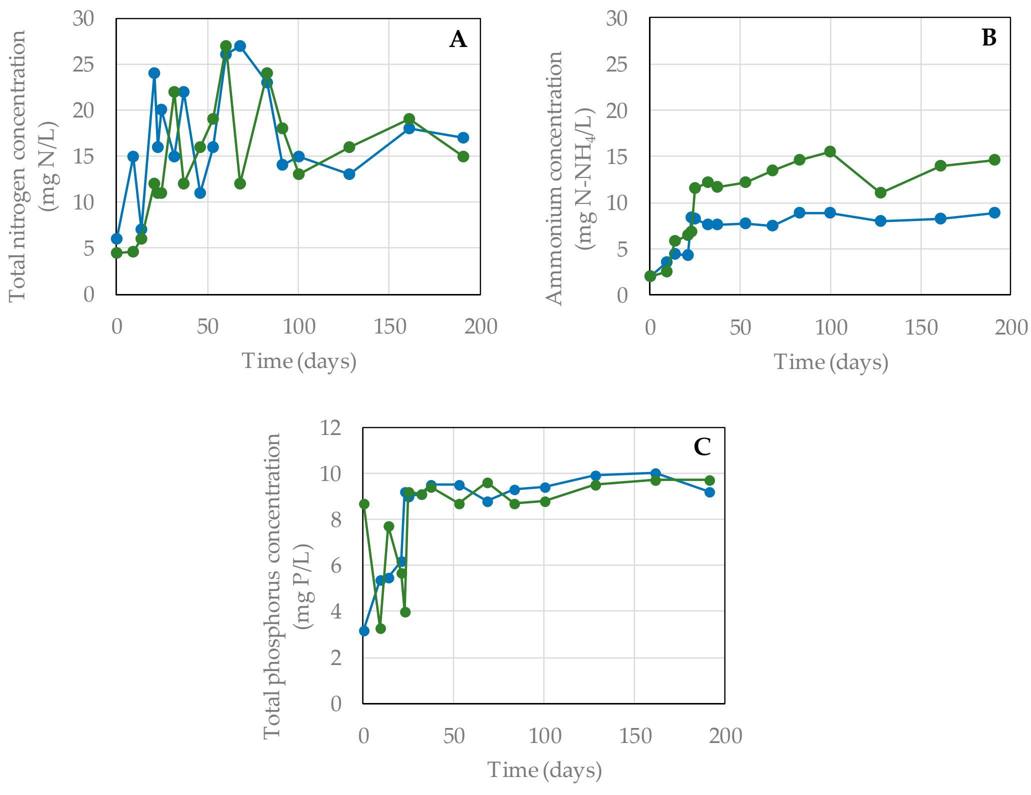

Figure 4. Comparison of total nitrogen (**A**), ammonium (**B**), and total phosphorus (**C**) concentrations in the synthetic wastewater feed (blue) and effluent (green).

The data collected for total nitrogen show variation particularly towards the start of the experiment (Figure 4A). Some of this variation might be due to the washout of cow manure from the inoculation process. It is also possible that any particulate material from the coconut husk pieces was flushed out at the start of the process, which would have been detected in the analysis of total phosphorus and total nitrogen. The ammonium concentration was consistently higher in the effluent of the reactor compared to the feed

(Figure 4B). It is possible that the increase in ammonium is due to the transformation of nitrogen present in the synthetic wastewater into ammonium. The two key nitrogen-containing components in the synthetic wastewater are milk protein in the dried milk and urea [21]. Milk proteins can be broken down into ammino acids, and then, ammonium and urea can hydrolyze into NH_4. However, to confirm this, additional experiments are needed to confirm that leaching from the coconut husks is not occurring.

Figure 4C shows a variable result in total phosphorus levels in the effluent compared to the feed at the beginning of continuous reactor operation and then fairly consistent levels from day 25 onwards. This is likely due to the initial washout of the cow manure, but some leching may also be occurring initially. Once the reactor stabilized, there was very little difference between the feed and effluent concentration (Figure 4C), indicating no significant leaching occurring long-term.

Nutrient Leaching from the Coconut Husk

The presence of nitrogen and phosphorus within the synthetic wastewater may have been masking some leaching from the coconut husk. To eliminate the synthetic wastewater contributing to the nutrient levels, an additional experiment was conducted where RO water was used as the feed using a reactor, which was set up and run in the same way as the first continuous anaerobic filter. This would then determine any leaching of nutrients from the coconut husks. The nutrient levels in the effluent of this reactor are shown in Figure 5.

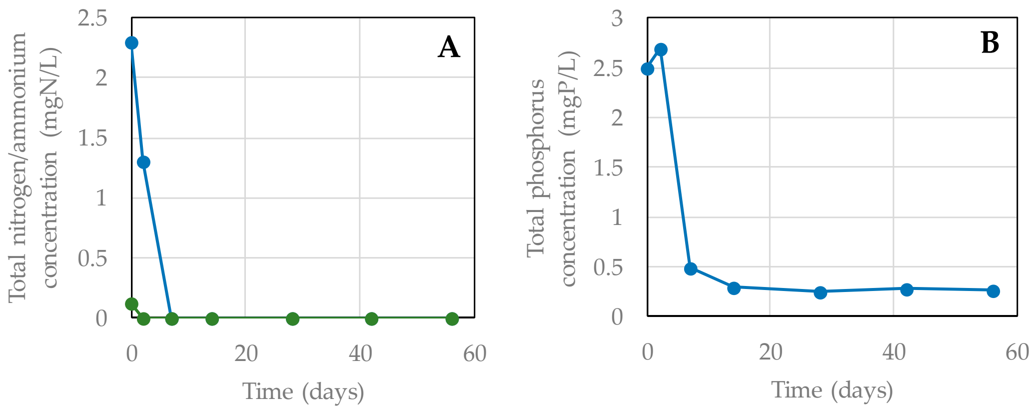

Figure 5. Nitrogen ((**A**), total nitrogen shown in green and ammonium shown in blue) and phosphorus (**B**), total phosphorus shown in blue concentrations in the effluent from the continuous anaerobic filter with RO water as the feed.

Some nitrogen and phosphorus initially leached from the coconut husks, but this was quickly washed out of the reactor (Figure 5). Very little ammonium was detected (Figure 5A), which indicates that the nitrogen being leached is in another form. This finding also suggests that the increase in ammonium shown in Figure 4B was due to nitrogen sources within the synthetic wastewater feed being broken down within the anaerobic filter.

Some phosphorus was initially leached (Figure 5B), but this reduced quickly to a low ongoing amount of phosphorus leaching. This ongoing level of leaching is insignificant compared to the level of phosphorus typically found in domestic wastewater and was not apparent in the reactor, which was fed with synthetic wastewater (Figure 4C). It is interesting to note that the ongoing phosphorus leaching appeared to be relatively consistent over the testing period.

An additional batch experiment was conducted by placing a piece of coconut husk in RO water and monitoring the concentration of total phosphorus in the water over time.

Using a batch experiment means that the phosphorus is not washed out and provides further information on the potential levels of leaching from the coconut husk as shown in Figure 6. The batch experiment was conducted over a longer period of time and shows that the leaching of phosphorus continues over an extended period (Figure 6). At day 120, the phosphorus concentration in the water had reached 16.7 mgP/L, which is equivalent to 0.11 mgP/g dry husk.

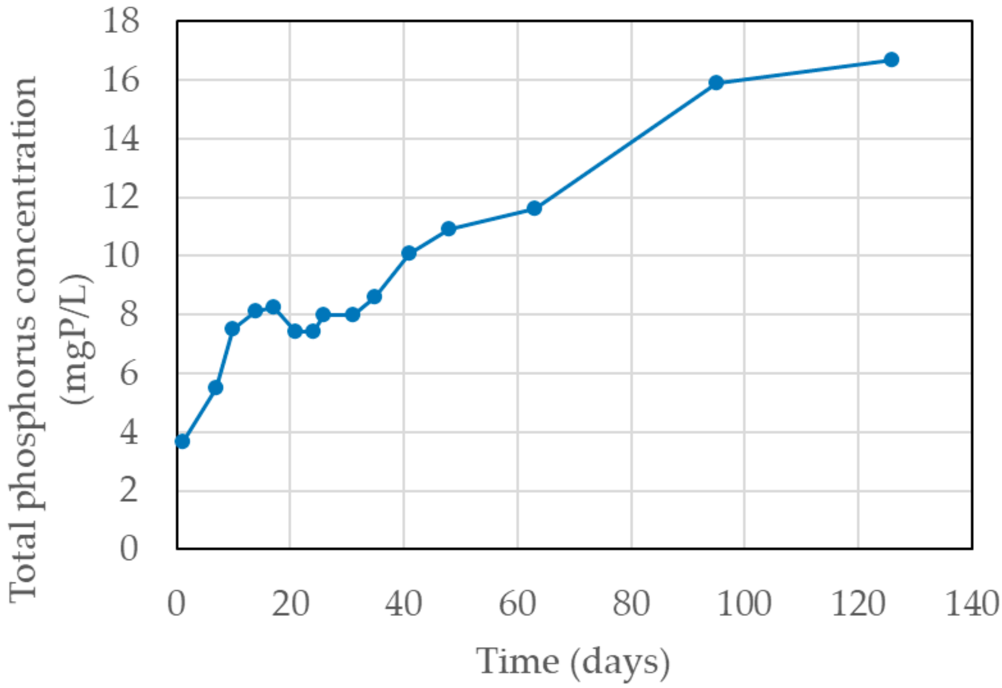

Figure 6. Total phosphorus concentration measured within the batch reactor containing RO water.

The nutrient leaching experiments revealed that the leaching of phosphorus is more significant than the leaching of nitrogen, in line with Torillo and Mihara's [24] findings on the leaching of nitrogen and phosphorus from coconut husks (color and species unspecified). Abad et al. [25] also reported that the available nitrogen content in coconut husks (color and species unspecified) was generally insignificant, in comparison to phosphorus. Torillo and Mihara [24] reported higher values than this study, with nitrogen leaching at 0.1138 mgTN/g husk and phosphorus leaching at 0.3037 mgTP/g husk. It should be noted that Torillo and Mihara [24] used smaller strips of coconut husk, and they were pounded with a hammer to make the pieces more porous, whereas in this study, there was no pretreatment, and the pieces of coconut husk were one-third to one-quarter of an entire coconut husk.

3.3. Condition of the Coconut Husks After 10 Months

On completion of the 10-month experiment, the reactor was opened to observe the biofilm development. The biofilm could be seen on the outside of the coconut husk pieces (Figure 7A) and on the fibers on the underside of the coconut husk (Figure 7B). The pieces of coconut husk were still firm and held their shape. The fibers were examined under the microscope, and they were still intact with biofilm attached to them (Figure 7C).

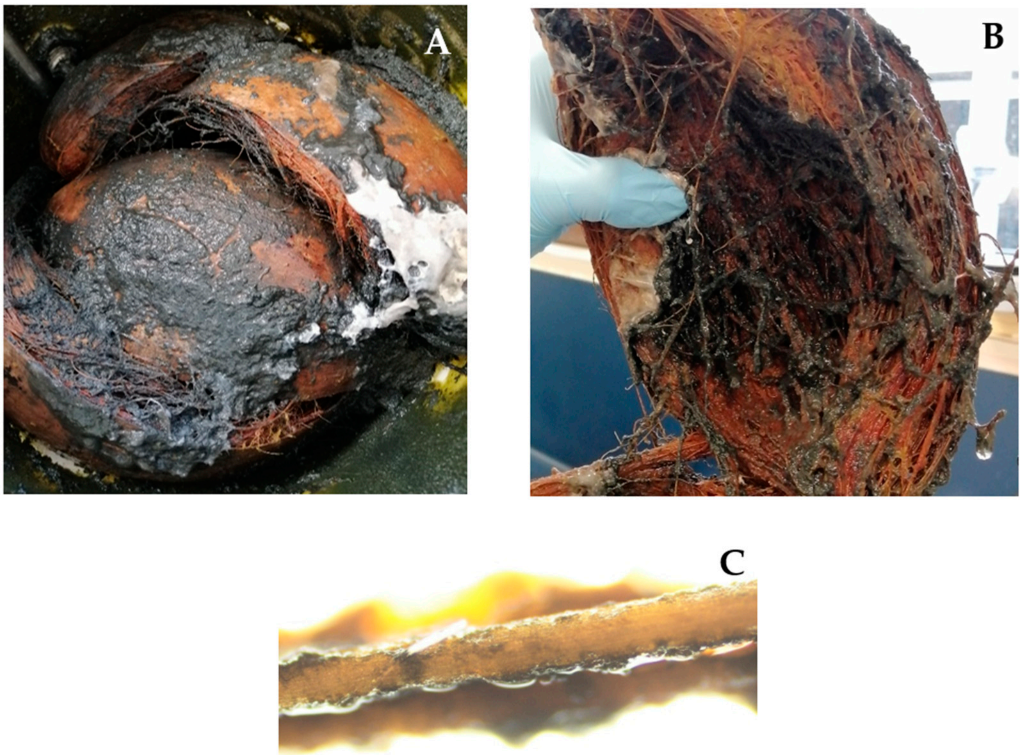

Figure 7. Photographs of the coconut husk at the end of the 10-month reactor trial showing the inside of the reactor once the water had been drained (**A**), the biofilm on a piece of coconut husk (**B**), and a coconut fiber examined under a microscope (**C**).

4. Discussion

When proposing a new appropriate wastewater treatment process, it is important to evaluate the solution based on several aspects. The ability to provide treatment and improve wastewater quality is key, and this is evaluated by measuring the COD removal. Ensuring that there are no adverse effects to the environment is also crucial, so the leaching of nutrients has been tested. Finally, the practical feasibility needs to be considered because if the maintenance requirements are not feasible, then the solution will not improve the situation and may cause more problems. While this study was not conducted for a period long enough to establish the frequency of maintenance, it does provide an indication, and suggestions for future research directions are given later in this section.

Typical COD removal by anaerobic filters containing coconut husks or coconut shells range from 49% to 73% [16–18,20,26], as summarized in Table 2. The exception is Brown et al. [20], where fresh green coconut husks were tested, and due to the leaching of COD from the coconut husks, the resulting removal was only 21%. The dried green coconut husks evaluated by Cruz et al. [16] appear to behave in a similar way to the brown coconut husks (Table 2). The COD removal for this study (Figures 2 and 3) is similar to others reported in the literature (Table 2).

Typically, studies reporting on reactor performance report the overall average, so it is not possible to know whether an improvement in treatment performance over time was observed as seen in this study. By examining the performance over time, it has been revealed that it takes several months for the biofilm to form, with the maximum performance measured after 9 months (Figure 3); however, longer-term trials are required to determine whether performance continues to improve.

Table 2. Summary of studies examining the use of coconut husks or shells in anaerobic filters treating household wastewater.

Coconut Shell or Husk Type	Wastewater Type	Average Feed Concentration (mgCOD/L)	Hydraulic Retention Time (hours)	Percentage COD Removal	Source
Coconut shells	Raw sewage	1105	9	73%	[17]
Coconut shells	Raw sewage	982	9	65%	[26]
Coconut shells	Raw sewage	837	16	63%	[18]
Dried green coconut husks	Raw sewage treated by septic tank	403	16.8	51%	[16]
Fresh green coconut husks	Synthetic wastewater	125	16.8	21%	[20]
Brown coconut husks	Synthetic wastewater	125	16.8	49%	[20]
Brown coconut husks	Synthetic wastewater	250	12	68%	This study

Anaerobic filters serve as a secondary treatment step in household wastewater disposal systems. Their primary function is the removal of COD from wastewater rather than the elimination of nutrients. Consequently, it is anticipated that there will be no observable change in nutrient levels in the effluent following treatment with the anaerobic filter. However, because the brown coconut husks are organic material, it is important to test whether nutrients are leached, which may have a negative impact on the environment. According to the Australian Guideline for Sewerage Systems [27], typical nutrient levels in secondary treatment effluents range from 20 to 50 mg TN/L and 6 to 14 mg TP/L for nitrogen and phosphorus, respectively. Both nitrogen and phosphorus levels in the effluent of this study fall comfortably within this specified range. It is important that these nutrient levels are below the threshold to prevent eutrophication. Often, effluent from septic tanks enters the environment via a leach field, and therefore, the impact to the environment is site-specific, depending on the soil type and the presence of groundwater, and additional treatment systems would be needed if nutrients were a concern. The presence of any sensitive ecosystems such as coral reefs should also be considered [4]. Conversely, if the effluent was used as irrigation water for crops, then the presence of nutrients may be an advantage. It is important to note, however, that cultural considerations need to be carefully investigated with the community before the reuse of treated wastewater occurs.

One key consideration in terms of the feasibility of this solution is the longevity of the filter media. The coconut husks used in this work had not started breaking down after 10 months. It has been suggested in the literature that coconut husks can be used in anaerobic filters for at least 2 years [18]. This suggests that the coconut husks may not need frequent replacement; however, further work would be needed to determine the frequency of maintenance needed.

The findings of this work suggest that the use of brown coconut husks within an anaerobic filter shows potential as an appropriate solution for improving wastewater treatment from septic tanks in countries where coconut husks are abundant. The key limitation of this study is the use of synthetic wastewater. While the use of synthetic wastewater is needed to provide consistency and evaluate treatment over time, future work should move to evaluating this process at a larger scale using household wastewater. This would serve several purposes. The use of wastewater from a household would allow the true variations in daily wastewater use to be evaluated. While this study attempted to mimic daily wastewater production, actual daily and weekly variations need to be evaluated. The presence of pathogens within wastewater would also allow any form of pathogen removal to be determined. The start-up of the reactor could also be evaluated. The anaerobic filter would be receiving wastewater from the septic tank, which contains an anaerobic environment. The constant inoculation of microorganisms from the septic tank may mean that the anaerobic filter would not require inoculation; however, this needs to be tested as inoculation with material such as cow manure may speed up the start-up phase.

Longer-term operation of the reactor is required to establish the frequency of maintenance for the system. This would be dependent on the breakdown of the coconut husks themselves, which may compress and block the filter over time. The formation of biofilms may also build up to the point of causing a blockage. If this occurs, then the filter may need flushing to allow for longer operation. This work should be conducted using household wastewater to provide the most useful information on these key parameters. Finally, the eventual disposal of the coconut husks needs to be evaluated, but this does depend on the final physical characteristics of the coconut husk pieces and cultural considerations. Once this information has been determined, a robust framework should be used to evaluate this technology against alternative solutions, accounting for economic affordability, treatment performance, and environmental sustainability in addition to local stakeholder input to consider social and cultural needs [28].

5. Conclusions

The anaerobic filter using brown coconut husks was able to remove 68% COD after an initial period of start-up when the biofilm would have been forming. It took several months for the biofilm to form with maximum COD removal recorded after 9 months of operation. Throughout this process, the pH remained stable. Nutrient leaching from the coconut husks was evaluated, and while some nitrogen and phosphorus leached initially, this was quickly washed out of the reactor. Low levels of phosphorus were continuously leached over 60 days, but this was not high enough to be detected in the reactor receiving synthetic wastewater due to the concentrations already present within the synthetic wastewater. Examination of the coconut husks at the conclusion of the experiment showed that the fibers were still intact, and pieces of coconut husk were still firm and held their shape. These findings suggest that using brown coconut husks within an anaerobic filter may be an appropriate solution to improving wastewater treatment for households using septic tanks. Further research should move to larger-scale trials using household wastewater.

Author Contributions: Conceptualization, N.B. and J.E.; methodology, N.B., J.E., S.C. and S.Y.; formal analysis, S.C. and S.Y.; investigation, S.C. and S.Y.; data curation, N.B., S.C. and S.Y.; writing—original draft preparation, N.B.; writing—review and editing, N.B., J.E., S.C. and S.Y.; supervision, N.B. and J.E. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The raw data supporting the conclusions of this article will be made available by the authors on request.

Acknowledgments: We would like to acknowledge the Government of the Kingdom of Tonga for providing us with a Tonga Government Research Permit. We would also like to thank our collaborators from the Ministry of Lands and Natural Resources in the Kingdom of Tonga for their advice and support throughout this project.

Conflicts of Interest: The authors declare no conflicts of interest.

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