Feasibility Study for Volatile Fatty Acids (VFAs) Production from Acidogenic Biotreatment of Water Hyacinth: Toward The Concept of Circular Economy for Sustainable Waste Management in Thailand

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A B S T R A C T

Water hyacinth (Eichhornia crassipes) is a invasive plant species and poses a concern in the waterways. Currently, the rapid growth of water hyacinth is managed by collecting it from water and disposing of in disposal areas hich is high cost and ineffective. This study aimed to investigate the technical feasibility of volatile fatty acids (VFA) production from the acidogenic biotreatment of water hyacinths and provide additional insights into the application circular economy concept for the aspects of water hyacinths waste management in Thailand. The water hyacinths mixed with acidogenic inoculum in the ratio of 1:1 w/w of total volatile solids (TVS) was tested in a 15-L of the laboratory-scale acidogenic biotreatment. In the experimental work, the water hyacinths were prepared for feeding into two categories (i) mixed leaves, stems and roots of the water hyacinths (MWH) and (ii) mixed leaves and stems of the water hyacinths (LWH). The results found that the acidogenic biotreatment feeding with the LWH and MWH can produce VFA of more than 1,053 and 2,522 mg CH_3COOH/L, respectively, and the VFA production in the acidogenic biotreatment reactors showed an increasing trend until 6 days for feeding with LWH and 14 days for feeding with MWH. The application of the circular economy concept for converting water hyacinths waste into biorefinery products was discussed in this study.

1. INTRODUCTION

To achieve the environmental sustainability, The circular economy is a key component that can support many Sustainable Development Goals (SDGs), particularly SDG 12. (Responsible consumption and production). Reducing the consumption of raw materials and waste is a major goal of the circular economy, which includes resource recovery, reuse, and recycling [1,2]. Water hyacinth (WH) (Eichhornia crassipes) is known as the common environmental problem in various regions including Thailand. It is a South American floating aquatic weed that is widely distributed in tropical and subtropical regions of the world and is regarded as an invasive alien species. It can reproduce rapidly which consequently invading the waterways, reducing biodiversity and deteriorating water quality [3-7]. Presently, there are several approaches to manage the spread of water hyacinth, such as physical, mechanical, biological and chemical control. However, methods for controlling its growth are not ideal, and control using biological and chemical substances can result in secondary pollution. Other utilizations of WH are mostly spent on craftworks and fertilizers which do not provide much value. However, the growth rate of WH is much higher than the consumption rate. Due to its chemical compositions there are various researches focused on the conversion and management of WH into high value-added functional materials and also reduce waste to landfill. Various applications of WH include using WH for animal feed, biofertilisers, crafts, bioenergy production, phytoremediation, high-value chemical, building material and biopolymers [4-13]. The anaerobic digestion is a process of transformation of biodegradation organic compounds into methane and carbon dioxide using a consortium of microorganism. Hydrolysis, fermentation, also known as acidogenesis (the formation of soluble organic compounds and short-chain organic acids), and methanogenesis (the bacterial conversion of organic acids into methane and carbon dioxide) are the chemical reactions that take place in stages during anaerobic digestion. [14, 15]. Common volatile fatty acids (VFAs) produced in anaerobic digestion process are acetic, propionic, butyric acids and Depending on the anaerobic digestion system's operational conditions, substrate composition, and microbial population, different amounts of VFAs are produced. [16].

In recent years, due to the overuse of fossil fuel, the demand of renewable resources is higher. Due to their considerable potential as a carbon source for numerous downstream industrial uses, including a valuable raw

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material for biogas, biodiesel, and bioplastic, VFAs are significant building block chemicals with rapidly rising market demand [17-20]. To address the issues with waste management, it is necessary to integrate novel waste treatment technologies with value recovery from the waste streams. There have been few, if any, research investigations on the meso acidogenic biotreatment of water hyacinth up to this point [21]. This study aimed to evaluate the technical feasibility of VFA production from the acidogenic biotreatment of WH and propose circular economy solutions for water hyacinth waste management in Thailand.

2. MATERIALS AND METHODS

2.1 Preparation of the water hyacinths

A few samples of water hyacinth (Eichhornia crassipes) were taken from the main canals in Bangkok, Thailand (Fig. 1).

Fig. 1 Water hyacinth (*Eichhornia crassipes*).

For removing the particles, insect larvae grown on the plants and other contamination, the collected water hyacinth samples were washed four times using tap water, then two times with distilled water and were soaked once in 0.25 M ethylene diamine tetra acetic acid (EDTA). The samples were dried for 3-4 hours and cut into small pieces, approximately 1–2 cm. This study signified the importance of the plant parts, and the water hyacinths were prepared as the substrates for feeding into two categories (i) mixed of leaves, stems and roots parts (MWH) at the wet weight ratio of 1:1:1 and (ii) mixed of leaves and stems parts (LWH) with the wet weight ratio of 1:1. The detail of the experiment is summarized in Fig. 2.

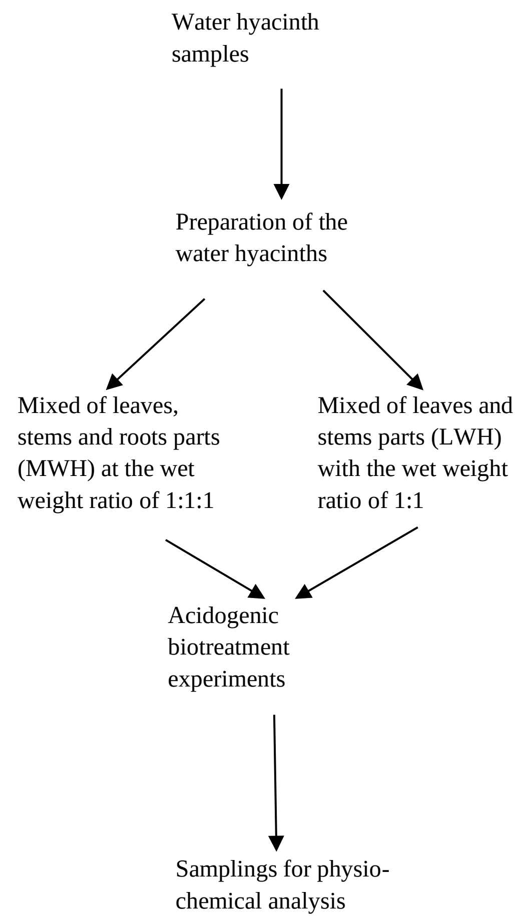


Fig. 2. Detail of the experiment.

2.2 Acidogenic biotreatment experiments

The acidogenic inoculum was prepared from the inoculation sludge collected from the upflow anaerobic sludge blanket of a brewery's industrial wastewater treatment plant. The inoculation sludge was placed in a 15 L- acidogenic bioreactor designed as a cylinder shape, which had a diameter of 0.06 m and a height of 0.03 m (Fig. 3), then purged for 10–15 minutes with nitrogen gas to promote anaerobic condition. The acidogenic inoculum was acclimatized at ambient temperature (30-33 ºC) and manually controlled the pH in the acidic range (< 7.0) for more than 7 days.

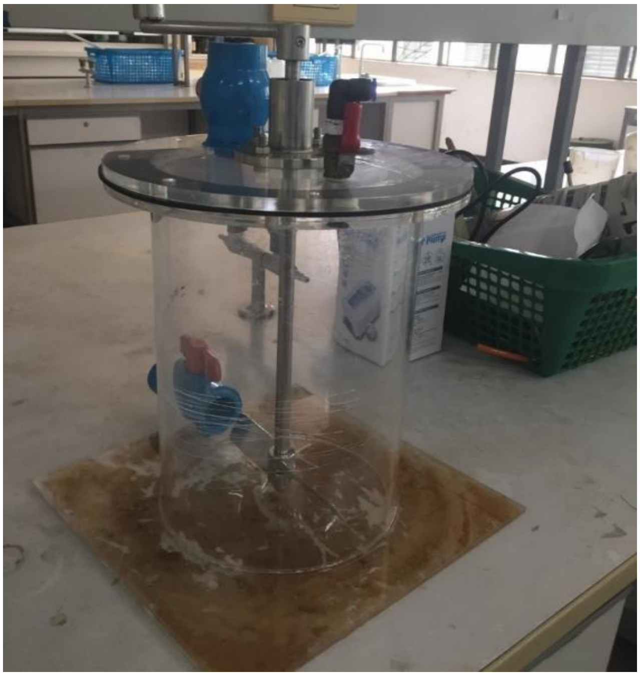


Fig. 3 Acidogenic bioreactor.

The acidogenic inoculum was considered ready for the experiments when its pH was stable for more than two weeks at 4.0-6.0. The MWH and LWH were used as two feeding substrates (sub) in the acidogenic biotreatment experiments. For each batch experiment, the mix of the substrate (about 100 g) and acidogenic inoculum in the ratio of 1:1 w/w of total volatile solids (TVS) was placed in the acidogenic reactor (Fig. 4). Samplings for physio-chemical analysis were done with an operation period of about 15 days (all analyses were done in triplicate).

Fig. 4 Experimental set-up.

The samples were homogeneously mixed using a mixer and collected by grab sampling technique for analyses of pH, chemical oxygen demand (COD), total solids (TS) and TVS according to standard methods [22]. Referred to the Nordmann method [23], The FOS (Flüchtige Organische Säuren) value corresponds to the volatile fatty acids (VFA) concentration in this study, and the TAC (Totales Anorganisches Carbonat) value was the amount of total inorganic carbonate. The data was analyzed statistically and graphically using free and open-source R software. By examining the variance, a statistical difference was found between each trial and the statistical testing (at a 95 percent confidential level) (ANOVA).

3. RESULTS AND DISCUSSION

This study investigated to identify a suitable part of the water hyacinth that can be used to feed the acidogenic biotreatment and the operation time for effective acidogenic biotreatment to convert the water hyacinth to VFA. The initial COD concentration of the MWH was 34,600 mg/L, higher than that of the LWH, which was about 8,000 mg/L. There was not much variation in the COD concentrations in the acidogenic biotreatment reactor, which was about 10,889 to 37,762 mg/L (Fig. 5). The pH values were found in the range of 6.5-7.9 (Fig. 6).

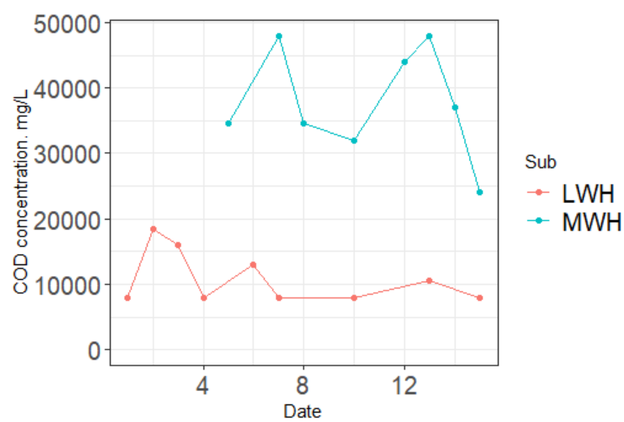


Fig. 5 Time-series analysis of COD.

The TAC and VFA concentrations in the acidogenic biotreatment showed an increasing trend till 6 days for feeding with the LWH and 14 days for feeding with the MWH, respectively. The simultaneous existence of acid-forming processes with widely different microbial abundances inside the acidogenic reactor, which aided the conversion of substrates into the VFA products, was likely the cause of the increasing trend of the VFA concentrations in the acidogenic biotreatment. To achieve better VFA productions, this suggests that the optimum operating time for the acidogenic biotreatment feeding with LWH and MWH could be within about 6-14 days. The relatively high VFA productions (up to 2,522 mg CH_3COOH/ L) in the acidogenic biotreatment reactor with the feeding of MWH suggests a high potential to use as biorefinery resource generation from the acidogenic biotreatment. The production rates between LWH and MWL were about 10.53 mg of VFA/g of LWH and 25.22 mg of VFA /g of MWH and It could be hypothesized that the MWH contained a high biodegradable substrate, converting it into more VFA products under acid-forming reactions. The decline of VFA and COD after 14 days of operation in the reactor of MWH can be observed. This might be due to the occurrence of other microbial activities and identifying the individual VFAs and microbial communities to investigate the in-depth mechanism for acidogenic biotreatments is strongly recommended.

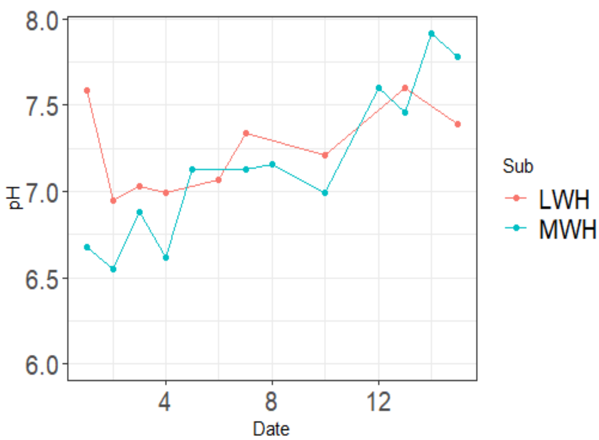
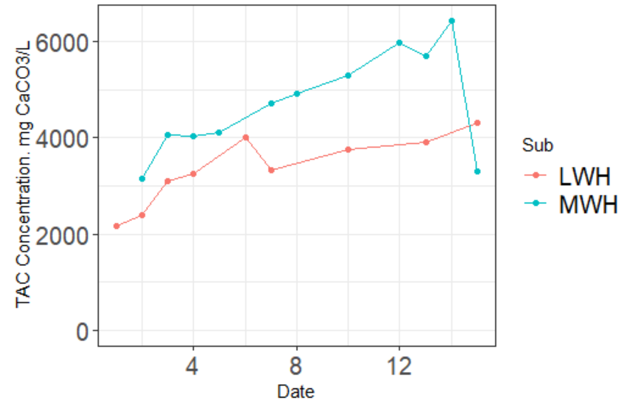


Fig. 6 Time-series analysis of pH.

The VFA/TAC ratios can indicate the stability of acidogenic biological treatment. Fig. 7 showed that the VFA/TAC ratios were found in the recommended values to operate, which were less than 0.4 [24]. It is hypothesized that the MHW was suitable for the converting the complex organic substance by the acid-forming bacteria and promoting the acido-acetogenesis reactions in the system. In addition, The production of carbon dioxide from the degradation processes by microbes has been appreciated as a significant contributor to the increse of TAC accumulation during the operation period.

Better degradation and support for microbial hydrolysis and acidogenesis to produce VFA could result from these microbes' acclimatization and growth [25-29]. Further studies to analyze the microbial communities in the acidogenic biotreatment are strongly recommended.



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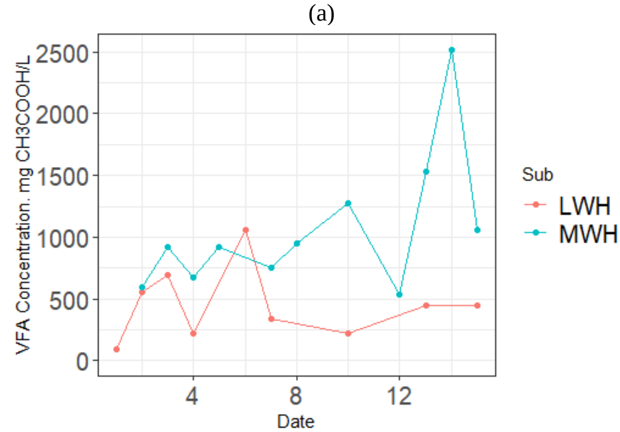

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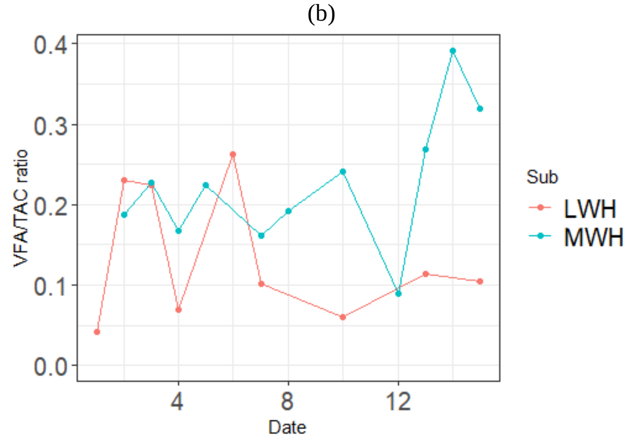
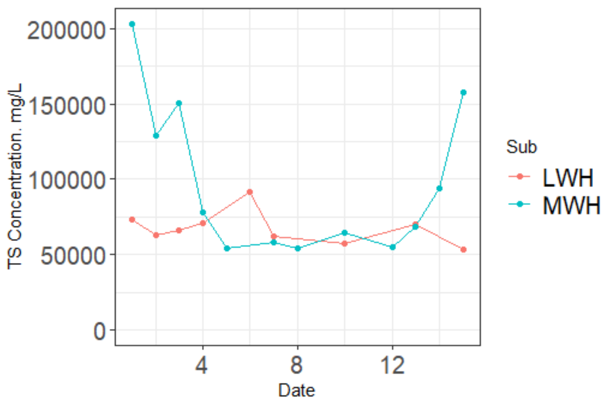


(c)

Fig. 7. Time-series analysis of (a) TAC, (b) VFA and (c) VFA/TAC ratio.

Due to the plant part containing hardly biodegradable material (such as in the stem or leave), the concentrations of TVS and TS in both the reactors feeding with MWH and LWH were not much degraded and found to have the same trend. The concentrations of TVS and TS of the reactors were found in the ranges of 53,183-91,387 mg/L and 54,490-203,207 mg/L, respectively. The TVS/TS ratios were found in the same magnitude, being about 0.3-0.4 (Fig. 8).



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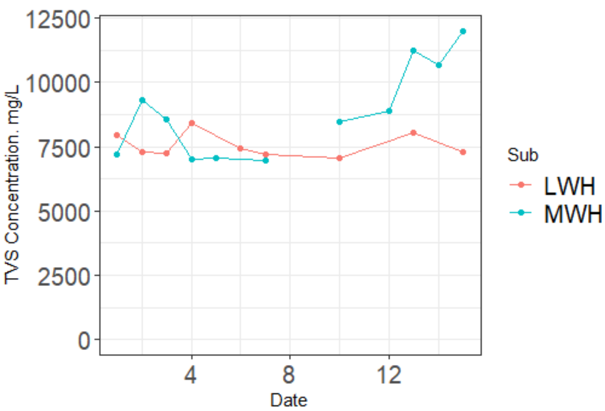

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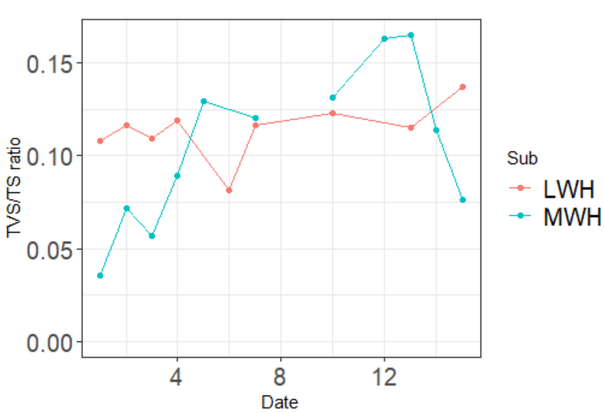
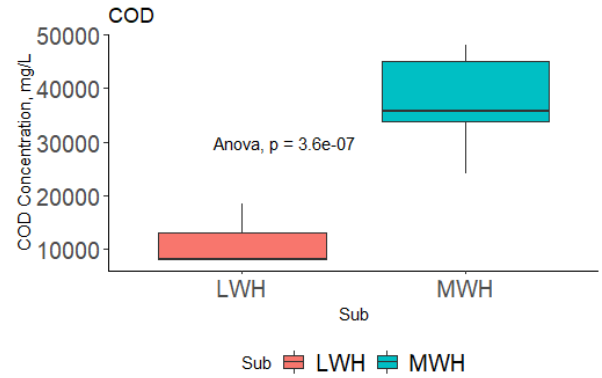


(c)

Fig. 8. Time-series analysis of (a) TS, (b) TVS and (c) TVS/TS ratio.

Statistical analysis for variation in the effluent concentrations of COD, TAC and VFA revealed a significant difference ($p<0.05$) between the two substrates (Fig. 9). There was no significant difference ($p>0.05$) among the pH, TVS and TS data. This finding points to the acidogenic bacteria's potential to effectively break down complex organic chemicals, particularly those found in MWH, into soluble intermediate products like VFA that can be used in the circular bioeconomy's subsequent application processes.



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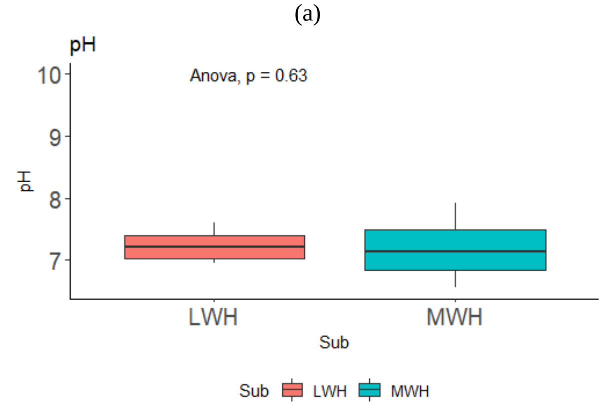

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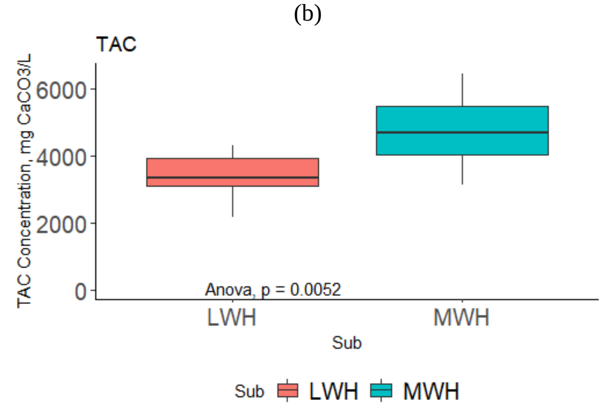

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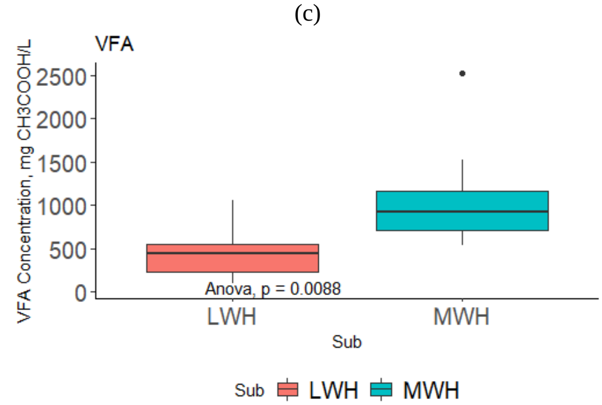

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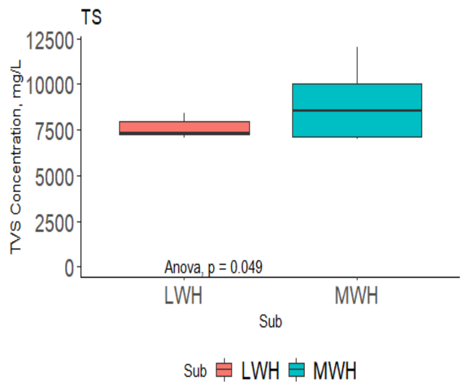

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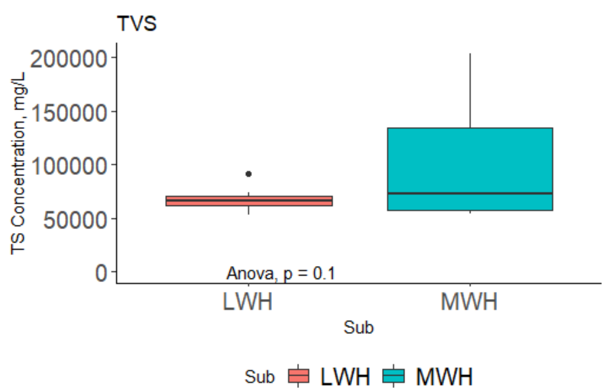

(f)

Fig. 9. Boxplots of (a) COD, (b) pH, (c) TAC, (d) VFA, (e) TVS and (f)TS.

4. CONCLUSION

According to the study's findings, the main conclusions:

1. The average COD concentrations of the acidogenic biotreatment feeding with the LWH and the MWH were not much varied during the operation period.

2. The acidogenic biotreatment of the LWH and the MWH can produce VFA at a maximum of about 1,053 and 2,522 mg CH_3COOH/L, respectively, with the optimum operating time of 6 days for the unit feeding with LWH and 14 days for the unit feeding with MWH.

3. The relatively high VFA productions in the acidogenic biotreatment reactor with the feeding of MWH suggests a high potential to use as a biorefinery resource material

4. The concentrations of TVS and TS of the acidogenic biotreatment units were in the range of 53,183-91,387 mg/L and 54,490-203,207 mg/L

5. The WH material can be used as the potential materials in producing soluble intermediate products such as VFA, and is suitable for further application of circular bio-economy.

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