# Food Waste and Empty Fruit Bunches (EFB) Characterization for Production of Biogas by Anaerobic Co-digestion

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***Abstract*** **— Both of food waste and empty fruit bunches (EFB) are kinds of wasted material that highly potential to be used as a feedstock in composting process of anaerobic digestion. As the composition of these two biomasses consist rich of organic and biodegradable matter, which highly recommended for anaerobic digestion producing biogas production. In anaerobic digestion, feedstock characterization as carbon and nitrogen ratio (C/N ratio), carbohydrate, protein and lipid composition in FW, cellulose, hemicellulose and lignin composition in EFB, play an important role in determining the quantity and yield of biogas production. In this study, C/N ratio was determined by using elemental analyzer meanwhile carbohydrates, protein and lipid composition of food waste and cellulose, hemicellulose and lignin composition of EFB was determined by several analytical methods. By analyze the characteristic of the food waste and EFB, it can theoretically determine and proved in further study, whether the combination of these two biomasses are capable of producing high quantity and yield of biogas which potentially can be used as alternative sources of currently natural gases. Average C/N ratio of food waste obtained was ideal, 11.87 meanwhile C/N ratio of EFB obtained was relatively high, which is not suitable for single digestion and need to be combined with other substrate that have low C/N ratio, where is food waste give it an ideal combination. Carbohydrate, protein and lipid composition of food waste resulting on balance composition especially on Food Waste Type B which is mostly contain of bread. Cellulose, hemicellulose and lignin composition of EFB was also favor for digestion process as it showed low composition of lignin.**

***Keywords — Food Waste, Empty Fruit Bunches, Characterization, Biogas, Anaerobic Digestion***

## I. INTRODUCTION

Food waste is a type of biomass are being produced at an increasing rate due to the growing economic and population, rising living standard and expansion variety of food production. Food waste is part of the organic fraction of municipal solid waste (MSW), possesses the highest fraction in the overall MSW composition at approximately 37% [1]. According to a review by [1] and [2], the daily production of MWS in Malaysia is approximately 0.5 to 0.8 kg per person per day, and is expected to reach the 9 million tons per year mark by the year 2020. Hence, as food waste is the highest composition in this MSW, the amount of food waste is also expected to be in large numbers.

In term of agricultural waste, empty fruit bunches (EFB), is another type of biomass which can be found in abundance in Malaysia. This is because Malaysia is the second largest palm oil producer in the world, next to Indonesia, providing around 43% of the global annual palm oil supply, or 15.88 million tons of palm oil per year [3]. From this amount, approximately 4.42 metric tons of fresh EFB per hectare of palm oil plantation is produced annually [4].

An effective mechanisms or system must be created to minimize, control and dispose all those kinds of waste. Nowadays, the only solution is by disposing and eliminating the waste at landfill even it is the least preferred waste treatment method in the hierarchy of solid waste management [5] due to high in cost and also contribute on environmental problem such as air pollution due to the uncontrolled emissions of greenhouse gases, especially methane $CH_4$, and groundwater pollution due to the landfill leachate produced from landfills which do not have a proper monitoring system.

On the other side, fossil fuel is being widely used in almost every country, however fossil energy is a non-renewable energy which mean it will run out at the end the day. Furthermore, a statistic show that global energy demand is rising rapidly which put as human in pressure to come out with a solution before fossil fuels are totally depleted [6]. Therefore, by considering all the problems stated, biogas production via anaerobic digestion seem to be the best way to overcome all those problems.

Anaerobic digestion (AD) is a biochemical process which utilizes organic and biodegradable materials as its main feedstock, and converts them to biogas, where this process takes place in the absence of oxygen [7]. Anaerobic digestion possesses a great potential in the renewable energy field, as its main product is biogas; a mixture of gases, mainly methane $CH_4$ and low compositions of carbon dioxide $CO_2$, and small traces of hydrogen sulfide $H_2S$, depending on the composition of the feedstock used in the process [8]. This process consists of four main reactions; first reaction is hydrolysis, followed by acidogenesis, then acetogenesis, and the final reaction is known as methanogenesis [9], in which each reaction has its specific parameters as specific temperature and pH that play an important role for the final biogas production. This biogas has similar characteristics to the currently used conventional natural gas, and thus can be used as an alternative source of fuel to replace natural gas, and fed to boilers and turbines for electricity generation [10]. Also, this process is sustainable, as the raw materials required for anaerobic digestion is mainly biomasses or biodegradable materials, in which these materials can be found in abundance, and available continuously, such materials include food waste, the organic fraction of municipal solid waste (OFMSW), and agricultural waste, such as paddy husk, sugarcane bagasse, and EFB especially from palm oil plantations.

In additional, anaerobic digestion operates at low temperatures; 30ºC to 60ºC, much lower as compared to other processes which derive energy from biomass such as incineration (850ºC) and gasification (650ºC to 1200ºC) [11], hence requiring lesser energy requirement for anaerobic digester operation. An anaerobic digestion system can also be defined as a bio-refinery system, as it uses a sustainable process to convert biomass to useful products; whether single product or multiple products [12]. Since anaerobic digesters require lower energy consumption for operation due to low operating temperature, this condition favors the energy-bio-refinery interaction, in which less energy is required to be used by a process which produces energy itself, hence reducing the trade-off which arises from using bio-refinery technology for renewable energy production.

To obtain high biogas production, process stability, and high efficiency in anaerobic digestion process can be challenging, as this biochemical conversion process is sensitive, thus easily affected by various factors. These factors range from materials used as the reaction feedstock, to operating parameters in terms of temperature [7], [13], [14], where anaerobic digestion is normally operated at either mesophilic temperature (30ºC to 40ºC) or thermophilic temperature (50ºC to 60ºC). Other operating parameters studied for optimum anaerobic digestion include pH of reaction [15], feedstock loading rate, mode of operation, whether single-stage or multi-stage reactors [14], [16], [17], feedstock pretreatment [18], [19], and salinity [20].

However, most of recent researches have mainly focused on the feedstock used, in which two different feedstock were utilized in the reactor, better known as co-digestion [21], as different feedstock used will result in different outcomes from the anaerobic digestion process. In addition, even when using the same type of feedstock, but from different regions, it will give different impact on the digestion process, hence producing different biogas results. Co-digestion of two different feedstock, usually one being food waste while the second one being an agricultural waste, at specified ratios, has been said to help improve biogas production, as the mixing of two different feedstock provided better nutrients balance for microorganisms involved during the degradation process in anaerobic digestion. Therefore, this study will observe the effect of anaerobic co-digestion of Malaysian local food waste with agricultural waste; empty fruit bunches (EFB), to determine whether the combination of these two biomasses will give higher biogas production, compared to single-digestion, in which the biogas can then be further utilized for energy derivation and electricity production [9].

Several past researches have observed that using two feedstock for anaerobic co-digestion favored higher biogas yield. Firstly, a research by [22] reported a 48% increase in biogas when spent coffee grounds were mixed with cow manure, as compared to using only cow manure. Secondly, a study by [7] showed that co-digesting kitchen waste and cow manure obtained higher biogas production than single digestion of those two feedstock alone. Another research by [23] found that co-digestion of chicken manure and Napier grass led to higher methane production, as well as better process stability. One other research on co-digestion by [24] also found that mixing the organic fraction of municipal solid waste, which is mostly food waste, with two different agricultural wastes, cattle slurry and cow manure, managed to increase biogas productivity and provided better stability of the anaerobic digestion process itself as well, compared to using only the organic fraction of MSW as a single feedstock. A recent and close research by [25], which used Malaysian local household waste as a feedstock, also showed similar results, when the household waste was mixed, or co-digested with cow manure; methane production was higher for co-digestion, as compared to single digestion of feedstock, as using two feedstock contributed to more synergistic interactions between the components in the reactor.

Besides, co-digesting two or more different feedstock in anaerobic digestion at different ratios also give an impact on the overall biogas productivity. Referring to the study by [23], chicken manure and Napier grass were co-digested at different ratios, and it was discovered that an equal ratio (1:1) of the two feedstock produced the highest volume of cumulative biogas after 48 days of operation, as compared to using ratio of 3:1 and 1:3 with respect to chicken manure to Napier grass. Another research by [26] who carried out anaerobic co-digestion of food waste and cattle manure found that when the two feedstock were mixed at three different ratios, the C/N ratio, biogas production and methane yield varied for all three cases, in which a ratio of food waste to cattle manure of 2:1 led to the highest value of biogas production and methane yield.

Precisely, food waste compositions varies according to region, as each region differs in terms of climate, food trends, and food processing techniques, in which this gives an impact on the C/N ratio of the food waste. In other words, food waste taken from different places or regions, even within the same country, will give a different C/N ratio, even if the type of food analyzed is similar or within the same category. For instance, a research on food waste anaerobic digestion in India found that the C/N ratio was high, at 44.21 [18], while another study found that food waste collected from several provinces in China had C/N ratios between 9.7 and 18.1 [27], and in Singapore, the collected food waste possessed a C/N ratio of 21.5 [19]. However, in Malaysia, there is limited research on the characterization of Malaysian local food waste. The previously stated study by [25] on household waste, which is mainly food waste, only studied several parameters such as C/N ratio (11.0), moisture content (84.5%) and other standard parameters (VS, TS and pH). Specific characterization such as determination of carbohydrates, proteins, and lipids content of local food waste in Malaysia has yet to be carried out. Characterization on EFB from Malaysia's palm oil mills has been studied by [28], however the study was focused more on using the EFB for pyrolysis to produce bio-oil[29], [30], and not to produce biogas via anaerobic digestion. Though pyrolysis has similar operating conditions with anaerobic digestion, where both processes are carried out in the absence of air or oxygen, these two processes differ greatly in terms of operating temperature, where pyrolysis operates at much higher temperatures than anaerobic digestion.

Hence, the main concern of this study is to study the composition of the two feedstock used in this research; food waste and EFB, mainly carbon (C) and nitrogen (N), for determining the C/N ratio. C/N ratio is one of the important aspects in anaerobic digestion [26], as it involves nutrient supply for the microorganisms present in the process. Feedstock composition is also one of the main factors that affects the efficiency anaerobic digestion process in terms of process stability and biogas production, besides other operating parameters. Unbalanced compositions of nutrients in the food waste, particularly carbohydrates, protein and lipids, could also lead to an inappropriate C/N ratio [27], which leads to operational problems in the anaerobic digester, thus less biogas production. The optimum C/N ratio for food waste in an anaerobic digester is around 10 to 20 [31], while [32] found that a C/N ratio from 13.9 up to 19.6 for food waste also favors efficient anaerobic digestion of the food waste with another feedstock.

EFB is considered as a lignocellulosic material, as it consists of mainly cellulose, hemicellulose, and lignin, and the compositions of these three materials play an important role in determining the efficiency of the anaerobic digestion process. A research finding by [33] found that the lignocellulosic composition of EFB, which is low in lignin and high in cellulose, favored higher methane yield as compared to other palm oil wastes, such as decanter cake (DC) and palm press fiber (PPF), which had higher contents of lignin. In the structure of lignocellulosic materials, as shown in Fig. 1, the cellulose is bounded by the lignin structure, which acts as a shield for the cellulose and hemicellulose as well. The lignin structure possesses a high resistance towards microbial attacks, which is necessary in anaerobic digestion for the decomposition of cellulose into glucose in hydrolysis; one of the crucial steps in the overall digestion process. Hence, high lignin content will hinder access to the cellulose. Cellulose is the main component in EFB that will undergo degradation steps to yield high glucose during hydrolysis, which at the end of the day, will be converted to methane, or biogas during the digestion process. Hence, higher lignin leads to lower glucose conversion from cellulose, and will cause lesser biogas to be produced.

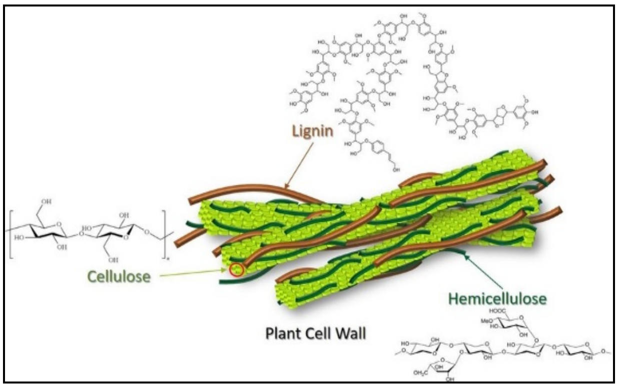


**Fig. 1 - Structure of Lignocellulosic Biomass**

Therefore, it is vital to determine the characteristics of the feedstock (both food waste and EFB), before it can be used as co-substrates for anaerobic digestion, to observe whether it can lead to high biogas yield or otherwise. Hence, this study is carried out to further observe the characteristics of food waste, together with EFB, to be utilized as feedstock in anaerobic digestion, for biogas production.

## II. METHODOLOGY

### A. *Sampling and Pre-treatment Processes*

The food waste was collected from the food cafés at the Faculty of Chemical Engineering UiTM Shah Alam, where the waste was segregated to remove plastics, papers, bones and any other recyclables and unwanted inorganic substances present in the waste. These materials were discarded as mechanical pre-treatment, grinding and drying of these materials are difficult. Furthermore, during the actual anaerobic digestion process, these materials cannot be included in the reactor as they are highly resistant towards degradation and will affect the overall biogas results. The segregated food waste consisted of basically rice, chicken, bread and pastries, with small traces of fish residues, vegetables leftovers and other local food residues. The food waste was subjected to two forms of physical pre-treatment; drying and grinding. The food waste was first grinded using food blender to reduce the overall size of the waste, and dried at 105ºC in a drying oven, to remove moisture content which could alter the results of elemental analysis. The dried food waste was then grinded once more to powder form. Three types of food wastes were prepared, known as Food Waste Types A, B, and C, where food waste types were classified according to meal times; breakfast and lunch. The classification of the food wastes used in this study is summarized in Table 1.

***Table 1: Classification of Food Wastes***

| ***Type of FW*** | Classification | Major Compositions |
|---|---|---|
| ***FW Type A*** | Lunch Session | Rice, Chicken, Fish |
| ***FW Type B*** | Breakfast Session | Bread, Pastries |
| ***FW Type C*** | Equal Combination of Type A & B | Rice, Chicken, Fish, Bread, Pastries |

EFB was provided by Felda Palm Industries Sdn Bhd (FPI), under Felda Global Ventures Holdings Bhd (FGV), Malaysia's leading global agribusiness, where the EFB was in pellet form. The EFB was also subjected to physical pre-treatment prior to characterization. The EFB were grinded into powder form, and further dried at 105ºC in a drying oven to remove any remaining moisture contents. Similar to food waste, duplicate samples of EFB were prepared for characterization.

### B. *Elemental Analysis*

Elemental Analyzer (CHNS-O Analyzer) was used for analysis of the two feedstock involved in this study. This was to determine the percentage compositions of these feedstock, in terms of carbon (C), hydrogen (H), nitrogen (N), and sulfur (S). From the elemental analysis, the carbon-to-nitrogen ratio or C/N ratio was then calculated, as this ratio is one of the main concern in this study.

### C. *Food Waste (FW) Nutrients Analysis*

For food waste, besides the C/N ratio, nutrients analysis was also carried out. The nutrients characterization of the food waste was carried out by determining the compositions of three main nutrients; carbohydrates, proteins, and lipids. The compositions of these three nutrient components in the food waste give an impact on the efficiency of the anaerobic digestion process. Three different tests were carried out, one for each component. For carbohydrate content determination, the phenol-sulfuric acid method was used, where the food waste was mixed with phenol and concentrated sulfuric acid at ratio of 1:5 for phenol to sulfuric acid.

For proteins content, the Lowry's method was used. Both these methods utilized UV-Vis Spectrophotometer for measuring the absorbance of the diluted FW samples at 490 nm and 660 nm for carbohydrates and proteins, respectively. The carbohydrates and proteins content were determined via calibration curve prepared in the methods; glucose calibration curve for carbohydrates, and Bovine Serum Albumin (BSA) standard protein calibration curve for proteins. As for lipids determination, the chloroform-methanol extraction method was used, where the food waste sample was mixed with chloroform and methanol at ratio of 2:1 respectively, and the lipids content was determined by weight difference before and after carrying out the steps in the method. A flowchart of these methods is shown in Fig. 2.

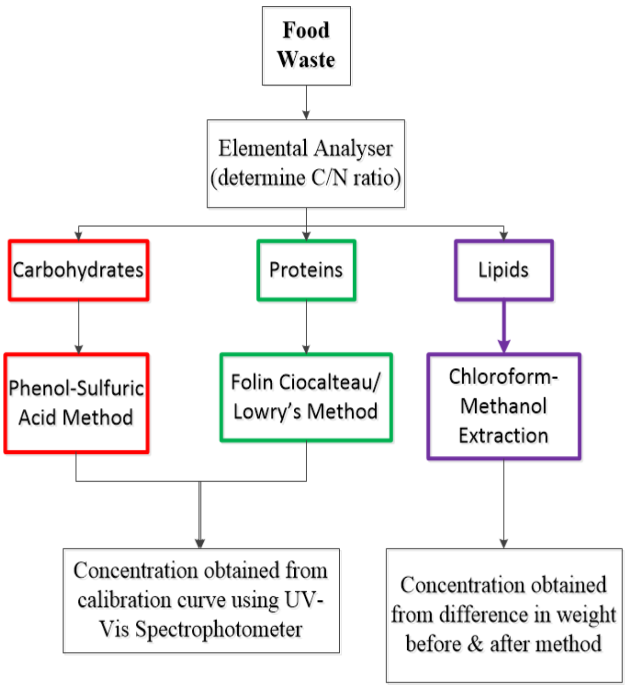

**Fig. 2 - Methodology flowchart for carbohydrates, proteins, and lipids content determination in food waste.**

### D. *Empty Fruit Bunches (EFB) Lignocellolusic Analysis*

For EFB, the lignocellulosic composition; cellulose, hemicellulose, and lignin, were also determined besides the C/N ratio from TGA. The compositions of these three components, together with extractives and ash content, were determined using a procedure by Ayeni, Adeeyo, Oresegun, & Oladimeji, (2015).

The sample was first extracted via Soxhlet extraction to determine extractives content. Soxhlet extraction was carried out using acetone as the solvent. 4 g of pre-dried and pre-grinded EFB was placed into the cellulose thimble. 150 ml of acetone solvent was used, for an extraction time of 4 hours, at 70ºC. After extraction, the saturated solvent was discarded, and the EFB sample in the cellulose thimble was air-dried and cooled to room temperature, followed by further drying in a convection oven at 105ºC, until constant weight of EFB was obtained. The difference in weight before extraction and after drying was the extractives content.

2.5 g of the extractives-free sample was then treated with 500 mol/m3 NaOH solution and boiled in water bath for 3.5 hours. After the mixture was cooled to room temperature, vacuum filtration was carried out. The filter cake from the filtration was then washed with distilled water until a neutral pH was obtained. After washing, the filtered solids were oven-dried at 105ºC until constant weight was achieved; for hemicellulose content determination by difference in weight before NaOH treatment and after drying.

300 mg of the extractives-free sample was also used in a different test for lignin content determination, where the sample was subjected for treatment with 3 ml of 72% sulfuric acid H2SO4 for 2 hours at room temperature, with 30-minute intervals for shaking to allow complete initial hydrolysis of the sample.

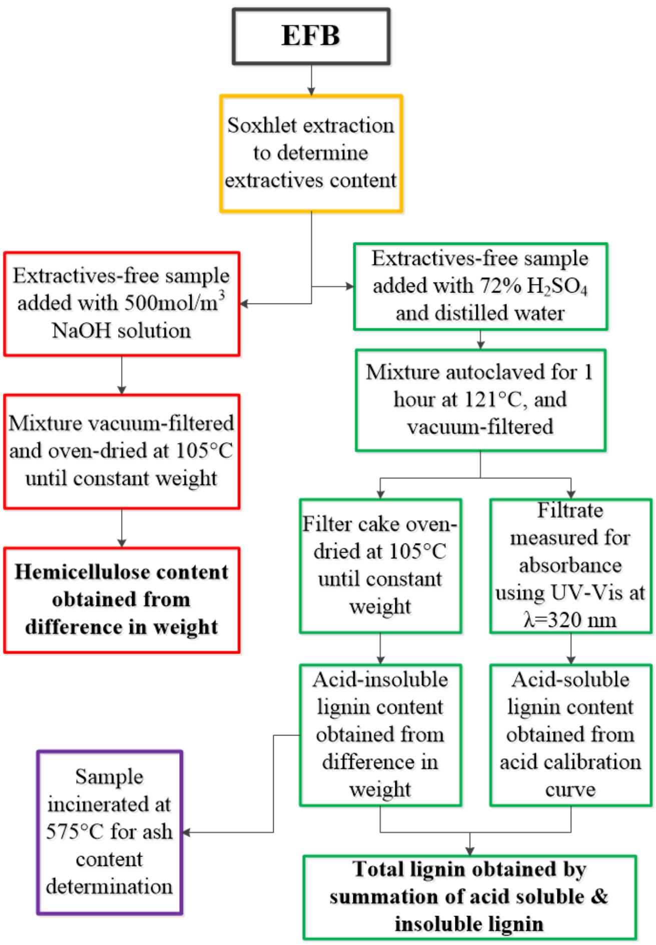


**Fig. 3 - Methodology flowchart for cellulose, hemicellulose, lignin, extractives, and ash content determination in empty fruit bunches**

Once initial hydrolysis was completed, the mixture was added with 84 ml of distilled water, then autoclaved at 121ºC for 1 hour, followed by vacuum filtration. The filter cake obtained from the filtration was then further dried to constant weight at 105ºC for insoluble-lignin content, also by difference in weight, before acid treatment and after drying. The dried sample was then further incinerated at 575ºC for ash content determination. The filtrate on the other hand, was measured for its absorbance using UV-Vis Spectrophotometer at wavelength 320 nm, for soluble-lignin content. The overall lignin content was obtained by adding the insoluble and soluble lignin content values. Cellulose content was obtained by difference, based on the assumption that the EFB only contained cellulose, hemicellulose, lignin, extractives, and ash. A flowchart of this procedure is shown in Fig. 3.

## III. RESULTS AND DISCUSSION

### A. *Elemental Analysis*

Percentage composition of carbon (C), hydrogen (H), nitrogen (N) and sulfur (S) was obtained for Food Waste Types A, B, C and EFB, all type of feedstock were analyzed for three time and the average result is shown in Table 2.

***Table 2: Elemental Analysis Results for FW and EFB***

| *Feed stock* | C (%) | H (%) | N (%) | S (%) | C/N ratio |
|---|---|---|---|---|---|
| ***Food Waste Type A (Average)*** | 80.30 | 10.24 | 9.46 | 0.00 | 8.49 |
| ***Food Waste Type B (Average)*** | 75.39 | 17.93 | 6.67 | 0.00 | 11.3 |
| ***Food Waste Type C (Average)*** | 79.08 | 15.93 | 4.99 | 0.00 | 15.83 |
| ***EFB (Average)*** | 78.26 | 16.30 | 5.44 | 0.00 | 15.40 |

From the results of elemental analysis, the C/N ratios for all feedstock were successfully obtained, as shown in Table 2. For food waste, the C/N ratio ranged of 8.49 to 15.83, giving an average of 11.87. The ratio of Food Waste Types B and C, 11.3 and 15.83 respectively, were within the optimum range specified by [31], which is 10 to 20, as well as [34], which specified optimum range of food waste for anaerobic digestion between 10 to 30. The ratio for Food Waste Type A, 8.49, however is not within this range. However, this ratio was within the range of the optimum C/N ratio range for food waste as defined by [27], which is between 9.7 and 18.1.

Food Waste Type A was taken from lunch session from the food café, and contained mostly rice, and residues of fish and chicken. Also, Food Waste Type A contained the highest amount of nitrogen N, compared to Food Waste Types B and C, which correlates with the low C/N ratio value. A review by [35] observed that digesters which used feedstock with low C/N ratio due to imbalance of nitrogen and carbon, lead to high ammonia concentrations. High concentrations of ammonia results in negative effects towards anaerobic digestion, due to the inhibition of ammonia, specifically on the methanogens, which in result, reduces methane production. Higher C/N ratios, as shown in Food Waste Types B and C, are more ideal, as it provides a better balanced nutrient content, and can prevent the inhibitory effect of ammonia in the digester [36], hence less inhibition on methanogens, which will result in higher biogas yield. However, too high C/N ratio will lead to nitrogen deficiency, hence causing an imbalance amount of nutrients for anaerobic bacteria to carry out the steps in anaerobic digestion, hence disrupting the final biogas production step; methanogenesis.

As for EFB, the C/N ratio was similar to food waste, due to the fact that EFB contains a high percentage of carbon, and a low percentage of nitrogen as well. Previous researches on EFB analysis however did not show similar results in terms of carbon and nitrogen content; 45.64% C and 0.35% N [37], and 50.01% C and 1.9% N [38]. This is most likely due to differences in methods used for EFB compositional analysis, as the method used in this study neglected the oxygen content. Furthermore, the steps used during EFB sample preparation may also have led to the addition of nitrogen content in the EFB sample.

This C/N ratio hence makes EFB less desirable to be used as a single feedstock in anaerobic digestion for high biogas production, as it will lead to imbalance in nutrients required during the digestion process. Hence, to obtain high biogas yield from anaerobic digestion of EFB, it is necessary for the EFB to be mixed with another type of feedstock, preferably one with a lower C/N ratio, to provide a better nutrients balance in the digester system. Since the food waste analyzed in this study possess slightly lower C/N ratios, average of 11.87, mixing food waste with EFB, at a certain ratio, is suitable to provide a more optimum C/N ratio during anaerobic digestion, which will in return, give higher biogas productivity.

### *B. Food Waste (FW) Nutrient Analysis*

Nutrient analysis for food waste was carried out and the result of weight percentage of carbohydrate, protein and lipid was obtained for all Food Waste Type as shown in Table 3.

***Table 3 – Food Waste Analysis for Carbohydrates, Proteins, & Lipids***

| ***Type of Food Waste*** | Carbohydrates (wt%) | Proteins (wt%) | Lipid (wt%) |
|---|---|---|---|
| ***Food Waste Type A*** | 3.10 | 8.00 | 6.81 |
| ***Food Waste Type B*** | 7.61 | 5.18 | 5.67 |
| ***Food Waste Type C*** | 9.19 | 4.55 | 5.05 |

From nutrients analysis of the food wastes, the compositions of carbohydrates, proteins, and lipids for all three types of food waste were obtained, as shown in Table 3. Food Waste Type A, which had the lowest C/N ratio at 8.49, was found to have the lowest amount of carbohydrates, and highest amount of proteins and lipids, compared to the other two types of food waste. On the other hand, Food Waste Type C, which possessed the highest C/N ratio at 15.83, gave the highest carbohydrates content, and lowest protein and lipid content; the exact opposite of Food Waste Type A. Carbohydrates, proteins, and lipids have a theoretical molecular formula of $(CH_2O)_n$¬, $C_3H_7NO_2$, and $C_{57}H_{104}O_6$ respectively [39], where each of these components have their own effect on anaerobic digestion. Materials which possess a high level of carbohydrates, will lead to a high C/N ratio, as shown in Food Waste Type C. However, C/N ratios that are too high will cause an imbalance in the nutrients contents. As for proteins, materials containing too high levels of this substance will lead to the formation of ammonia in the digester, due to the high content of nitrogen which is derived from the protein. This can be seen in Food Waste Type A, where the protein content was highest compared to Food Waste Types B and C. This also explains the fact that the C/N ratio for Food Waste Type A was the lowest compared to the other two food wastes. Too high ammonia levels in the digester is not favorable for anaerobic digestion, as ammonia inhibits methanogens activity during methanogenesis step; the final step in the process, hence reduces final methane yield. The lipid contents in all three food wastes did not deviate far from each other, and are at moderate levels. However, a too high lipid level can also lead to a reduction in methane yield, due to the formation of long chain fatty acids (LCFA), which results in a similar condition with the case of high ammonia formation; inhibition on the methanogens activity for methanogenesis [27]. Hence, a balanced composition of these three elements is necessary, to provide an optimum condition for anaerobic digestion to take place, to produce high levels of biogas; particularly methane gas. Out of the three types of food waste analyzed in this study, Food Waste Type B shows the best potential to be used for anaerobic digestion, since the levels of all three elements; carbohydrates, proteins, and lipids in Food Waste Type B is the most optimum, that is, the levels are not too high, and not too low. Food Waste Type A possesses a high protein content, which can lead to ammonia inhibition during anaerobic digestion. This high protein content also explains the relatively low, and out of optimum range, C/N ratio of Food Waste Type A, since proteins contains nitrogen, contributed by the amino group in proteins. As for Food Waste Type C, although the C/N ratio is within optimum range, it possesses the highest C/N ratio, and this can be explained by the high carbohydrates content in this food waste type, where high levels of carbohydrates can cause an imbalance and limitations in nutrients contents required for microbial activity during anaerobic digestion.

### *C. Empty Fruit Bunches (EFB) Lignocellulosic Analysis*

Lignocellulosic analysis for EFB was carried out and the result of weight percentage of cellulose, hemicellulose and lignin was obtained. The analysis was repeated for 2 times with different sample but from same region. The average value was calculated as shown in Table 4.

***Table 4 – EFB Analysis for Lignocellulosic Compositions***

| ***Component*** | Cellulose (wt%) | Hemicellulose (wt%) | Lignin (wt%) | Extractives (wt%) |
|---|---|---|---|---|
| ***EFB 1*** | 63.14 | 15.60 | 6.63 | 14.63 |
| ***EFB 2*** | 64.75 | 14.00 | 6.88 | 14.38 |
| ***EFB 3*** | 64.09 | 15.10 | 6.00 | 14.81 |
| ***Average*** | 63.99 | 14.90 | 6.50 | 14.61 |

From the lignocellulosic analysis of EFB for cellulose, hemicellulose, and lignin compositions, it was observed that, from Table 4, the pattern of the compositions of these three elements in EFB were similar. For all three EFB samples analyzed, the highest composition was cellulose, ranging from 63.14% to 64.75%, average on 63.99%, followed by hemicellulose (14% to 15.6%) with average 14.90%, and finally lignin (6% to 6.88%) and average of 6.50%. The results also were not within ranges from past literatures, in terms of hemicellulose and lignin; 21.9%-33% for hemicellulose, 10%-36.6% for lignin, and was within the top limit for cellulose range, at 63% [40]. This is most likely due to differences in EFB lignocellulosic composition determination methods. In this study, extractives content were determined prior to the three main components in lignocellulosic biomass; cellulose, hemicellulose and lignin. The extractives content were first determined via Soxhlet extraction, and the solid residues after the extraction process was used for determination of hemicellulose and lignin, hence the EFB sample used for the analysis of these two components were using extractives-free EFB, instead of original EFB. Also, there was no specific analysis carried out for cellulose determination, as the cellulose contents recorded in this study were simply determined by difference; total initial weight of EFB sample, deducted by amount of extractives, hemicellulose and lignin, in which for each of these three components, different procedures were carried out; Soxhlet extraction for extractives, NaOH treatment for hemicellulose, and $H_2SO_4$ treatment for lignin. Therefore, the amount of cellulose was completely dependent on the results of these three procedures.

In short, in the EFB, cellulose content is the highest, followed by hemicellulose and extractives or oils, and lignin having the lowest content. This composition of the EFB makes it favorable to be used as one of the feedstock in anaerobic digestion, since cellulose is the main component that will be hydrolyzed to glucose during hydrolysis step; the first and most crucial step in anaerobic digestion. The glucose will then be further converted to acetate during acetogenesis, and finally to methane during methanogenesis; the final step in digestion. Hence, high cellulose content increases the tendency of cellulose being converted to glucose, and finally methane gas. In the lignocellulosic structure of EFB as shown in Fig. 1, the lignin is the component that provides structural support to the material, and thus possesses high impermeability and resistance towards microbial attack [41], [42]. In addition, the lignin acts as a protective layer, shielding the cellulose and hemicellulose, blocking it from microbial attacks. Hence, these characteristics of the lignin hinders microbes from reaching the cellulose for degradation to its final methane product, thus lowering the methane yield during digestion process [33]. Therefore, a low level of lignin, as shown in the EFB analysis in this study, can enable easier penetration, and less resistance for the microbes towards the cellulose, allowing degradation process of the cellulose to glucose, acetate and eventually methane gas, thus increasing methane and biogas productivity.

## IV. Conclusion

In conclusion, the characterization of food waste and empty fruit bunches (EFB) to be used in anaerobic digestion for biogas production, has been managed to be carried out. From Elemental Analyzer analysis, C/N ratios for all food waste types and EFB were obtained. C/N ratio ranging from 8.49 to 15.83 for food waste was obtained, where C/N ratio for food waste was overall within optimum range for high biogas production. For EFB, the C/N ratio are ranges of 107.56 to 212.9, where these values are relatively high, thus requires co-digestion with low C/N ratio feedstock for high biogas yield. Further analysis of food wastes in this study showed that Food Waste Type B, which consists of mainly bread residues, gave the most balanced compositions of the three components; carbohydrates, proteins, and lipids, in which a balanced composition can provide optimum conditions for anaerobic digestion to produce higher biogas. Further analysis of EFB for cellulose, hemicellulose, and lignin content determination found that the EFB possessed high cellulose content (63.99%), and low lignin content (6.5%), where this condition favors the EFB to be used in anaerobic digestion for high biogas production. By using the food waste, together with EFB in anaerobic digestion, it can resolve various problems related to environment and energy aspects. Using food waste and EFB in high amounts for up-sized scale anaerobic digestion systems can reduce the amount of wastes being disposed of in landfills, hence reducing the negative impacts derived from landfills on the environment, land and water. The main products from anaerobic digestion, biogas, can also be further utilized for renewable energy generation, in which the anaerobic digestion process itself requires less energy consumption, as compared to other processes which also converts biomass into forms of energy.

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