Characterization of food waste and empty fruit bunches (EFB) for anaerobic digestion application

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Abstract. Food waste (FW) and empty fruit bunches (EFB) possess a great potential to be used for anaerobic digestion process, as these two biomasses are rich in biodegradable organic matter, in which its contents play an important role in determining the efficiency of the digestion process. In this study, the elemental compositions, nutrients content, and lignocellulosic content of Malaysia FW and EFB were determined by running several procedures and were compared to past literatures which also used similar feedstock for anaerobic digestion; to determine whether the biomasses used in this study could lead to better performance of anaerobic digestion. Elemental analysis of the FW showed that the C/N ratio ranged from 4.45 to 15.45, within the optimum range as defined by past studies. For EFB, the C/N ratio was similar to FW, making EFB suitable to be mixed with FW for optimum anaerobic digestion conditions. Nutrients analysis of the FW showed that FW Types A and D, rice waste and food waste mixture respectively, possessed the most balanced carbohydrates, proteins and lipids nutrients for optimum digestion. Lignocellulosic analysis of the EFB also proved that its contents were favourable to be used in anaerobic digestion; high cellulose content, low lignin content.

1. Introduction
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 [1]. Such materials include food waste (FW), the organic fraction of municipal solid waste (OFMSW), and agricultural waste, such as paddy husk, sugarcane bagasse, empty fruit bunches (EFB) and palm oil mill effluent (POME) from palm oil plantations. This process consists of four main reactions; first reaction is hydrolysis, followed by acidogenesis, then acetogenesis, and the final reaction is known as methanogenesis [2]. Each reaction has its respective specific conditions in terms of temperature and pH. and play an important role for the final biogas production, specifically the first step, hydrolysis, as this step produces glucose from the feedstock; the main product that will be converted to methane gas at the end of the digestion process. Anaerobic digestion possesses a great potential in the renewable energy field, as its main product is biogas; a mixture of gases, mainly methane CH\textsubscript{4} and carbon dioxide CO\textsubscript{2}, [3]. 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 [4]. Also, this process is sustainable, as the raw materials required for anaerobic digestion is mainly biomass or biodegradable materials, in which these materials can be found in abundance, and available continuously.

In Malaysia, biomass can be found in abundance from various sources, such as food waste, agricultural residues, and palm oil mill wastes such as EFB and POME [5]. Food waste, which is part of the organic fraction of municipal solid waste, possesses the highest fraction in the overall MSW composition at approximately 37% [6]. In addition, MSW in Malaysia can be found in large amounts and is continuously increasing, due to the increasing population and economic growth. According to a review by Kathirvale et al. (2004) [6] and Bong et al. (2016) [7], the daily production of MSW in Malaysia is approximately 0.5 to 0.8 kg per person per day, and is expected to reach the 9 million tonnes 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, and thus can become a reliable source to be utilized in anaerobic digestion.

Furthermore, utilizing food waste as feedstock in anaerobic digestion can help reduce the amount of the waste sent for landfilling; the least preferred waste treatment method in the hierarchy of solid waste management [8], especially in large scale digesters, hence reducing environmental problems related to landfilling. Such problems related to landfilling include 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. Leachate is known as a liquid effluent generated from landfills, mostly due to rainwater percolation through the wastes in the landfill and inherent water and moisture content present in the waste originally [9]. Components present in the leachate include organic matter and ammonia-nitrogen, and toxicity levels in landfill leachates were shown to possess hazardous organic chemicals as well as heavy metals [10]. Uncontrolled leachate flow and discharge from landfills can lead to soil contamination, as well as water pollution, whether contamination in the groundwater, or water bodies such as rivers and lakes due to flow of leachate through the soil.

Empty fruit bunches, or 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 tonnes of palm oil per year [11]. From this amount, approximately 4.42 metric tonnes of fresh EFB per hectare of palm oil plantation is produced per annum [12]. From this statistic, the abundant amount of EFB available in Malaysia makes it suitable to be used as continuous feedstock for anaerobic digestion. 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 [1], [13], [14], where anaerobic digestion is normally operated at either mesophilic temperature (30ºC to 40ºC) or thermophilic temperature (50ºC to 60ºC, or 55ºC up to 70ºC). 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 prior to anaerobic digestion [18], [19], salinity [20], and addition of support materials such as trace elements [21], charcoal [22], and biochar [23] for process enhancement to increase biogas yield.

However, most recent researches have mainly focused on the feedstocks used, in which two different feedstocks were utilized in the reactor, better known as co-digestion [24], as different feedstocks 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 results. Co-digestion of two different feedstocks, usually one being food waste while the second one being an agricultural waste, at specified ratios, has been said to help improve biogas production and process performance, as the mixing of two different feedstocks provided better nutrients balance for microorganisms involved during the degradation process in anaerobic digestion. Therefore, this study will observe the characteristics of Malaysian local food waste with empty fruit bunches (EFB); an agricultural waste, to determine whether these two biomasses will give better
performance in an anaerobic digester compared to using only single biomass feedstock. Furthermore, anaerobic digestion operates at low temperatures; 30°C to 60°C, much lower as compared to other processes which derive energy from biomass such as incineration (850°C) and gasification (650°C to 1200°C) [25], hence requiring lesser energy requirement for anaerobic digester operation. An anaerobic digestion system can also be defined as a biorefinery system, as it uses a sustainable process to convert biomass to useful products; whether single product or multiple products [26].

Several past researches have observed that using two feedstocks for anaerobic co-digestion favoured higher biogas yield. Firstly, a research by Luz et al. (2017) [27] 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 Iqbal et al. (2014) [1] showed that co-digesting kitchen waste and cow manure obtained higher biogas production than single digestion of those two feedstocks alone. Another research by Weerayutsil et al. (2016) [28] 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 Carlini et al. (2015) [29] 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 Khairuddin et al. (2015) [30], 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 feedstocks contributed to more synergistic interactions between the components in the reactor. Furthermore, co-digesting two or more different feedstocks in anaerobic digestion at different ratios also give an impact on the overall efficiency and biogas productivity. Referring to the study by Weerayutsil et al. (2016) [28], chicken manure and Napier grass were co-digested at different ratios, and it was discovered that an equal ratio (1:1) of the two feedstocks 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 Zhang et al. (2013) [31] who carried out anaerobic co-digestion of food waste and cattle manure found that when the two feedstocks 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.

Hence, the main concern of this study is to study the compositions of the two feedstocks used in this research; FW and EFB, mainly carbon C and nitrogen N content, for determining the C/N ratio. C/N ratio is one of the important aspects in AD [31], 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 [32], which leads to operational problems in the anaerobic digester, thus less biogas production. The optimum C/N ratio for FW in an anaerobic digester is around 10 to 20 [33], while Kumar et al. (2010) [34] found that a C/N ratio from 13.9 up to 19.6 for FW also favours efficient anaerobic digestion of the FW 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 Chaikitkaew et al. (2015) [35] found that the lignocellulosic composition of EFB, which is low in lignin and high in cellulose, favoured higher methane yield as compared to other palm oil wastes, such as decanter cake (DC) and palm press fibre (PPF), which had higher contents of lignin. In the structure of lignocellulosic materials, 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, in which the latter is necessary in anaerobic digestion for the decomposition of cellulose into glucose in hydrolysis as 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.

Therefore, it is vital to determine the characteristics of the feedstocks (both FW and EFB), to observe whether it can be used as co-substrates for anaerobic digestion. FW compositions vary 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 FW. In other words, FW taken from different places or regions, even within the same country, will give a different C/N ratio, even if the type of food analysed is similar or within the same category. For instance, a research on FW 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 [32], and in Singapore, the collected FW possessed a C/N ratio of 21.5 [19]. However, in Malaysia, there is limited research on the characterization of Malaysian local FW. The previously stated study by Kairuddin et al. (2015) [30] on household waste, which is mainly FW, 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 FW in Malaysia has yet to be carried out. Characterization on EFB from Malaysia’s palm oil mills has been studied by Abdullah et al. (2011) [36], however the study was focused more on using the EFB for pyrolysis to produce bio-oil [37], [38], 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, this study is carried out to further observe the characteristics of EFB, together with FW, to be utilized as feedstocks in anaerobic digestion.

2. Methodology

2.1 Food waste and empty fruit bunches feedstocks

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 unwanted inorganic substances present in the waste. To reduce the variance of the food waste conditions, the food waste was collected during morning session at the café, every Tuesday, in which the same types of food were taken. The segregated food waste consisted of basically rice, chicken, bread, with small traces of fish 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 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 to powder form using kitchen blender. Four types of food wastes were prepared, known as FW Types A, B, C, and D, where food waste types were classified according to food type; rice, chicken, bread, and a combination of all food types. The classification of the food wastes used in this study is summarized in Table 1. For all food waste types, characterization was carried out in duplicates

| Table 1. Classification of food waste. |
|--------------------------------------|
| Type of FW | Classification | Major Compositions |
|------------|----------------|--------------------|
| FW Type A  | Single Food Type | Rice               |
| FW Type B  | Single Food Type | Bread              |
| FW Type C  | Single Food Type | Chicken            |
| FW Type D  | Combination of Food Types | Rice, Bread, Chicken |

Empty fruit bunches 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 empty fruit
bunches were grinded into powder form, and further dried at 105°C in a drying oven to remove any remaining moisture contents. Similar to food waste, duplicate samples of EFB were prepared for characterization.

2.2 Elemental analysis
Elemental Analyser (CHNS-O Analyser) was used to determine the compositions of the feedstocks, 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.

2.3 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 of 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.

2.4 Empty fruit bunches (EFB) compositions analysis
For empty fruit bunches, 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 et al. (2015) [39]. The sample was first extracted via Soxhlet extraction to determine extractives content. Soxhlet extraction was carried out using acetone as the solvent. In this step, 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 70°C. 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 105°C, until constant weight of EFB was obtained. The difference in weight before extraction and after drying was the extractives content.

After Soxhlet extraction steps have been completed, 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 105°C until constant weight was achieved; for hemicellulose content determination by difference in weight before NaOH treatment and after drying. For lignin content determination, 300 mg of the extractives-free sample was also used. 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. Once initial hydrolysis was completed, the mixture was added with 84 ml of distilled water, then autoclaved at 121°C for 1 hour, followed by vacuum filtration. The filter cake obtained from the filtration was then further dried to constant weight at 105°C for insoluble-lignin content, also by difference in weight, before acid treatment and after drying. 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, and extractives.

3. Result and Discussion

3.1 Elemental analysis results

From the results of elemental analysis, the C/N ratios for all feedstocks were successfully obtained, as shown in Table 2. For food waste, the C/N ratio ranged between 4.45 to 15.45; FW Type A having the highest ratio, while FW Type C the lowest ratio. The ratio of FW Types A and D, 15.45 and 13.36 respectively, were within the optimum range specified by Guo and Dai (2017) [33], which is 10 to 20, as well as Bong et al. (2018) [40], which specified optimum range of food waste for anaerobic digestion between 10 to 30. The ratio for FW Types B and C, 9.78 and 4.45 respectively, however is not within this range. However, FW Type B ratio was within the range of the optimum C/N ratio range for FW as defined by Li et al. (2017) [41], which is between 9.7 and 18.1, although its value is close to the low limit of this range.

FW Type A was an individual food waste type, which was almost purely rice only, unmixed with other foods. Also, FW Type A contained the lowest amount of nitrogen N, compared to the other three FW types, which explained FW Type A possessing the highest C/N ratio as compared to the other three. Rice is a food source which is rich in carbohydrates [42], and hence rich in carbon content. This best explains FW Type A possessing the highest carbon content compared to FW Types B to D, and with FW Type A also possessing the lowest nitrogen content, these two points are reflected by this FW type having the highest C/N ratio at 15.45. 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 step in the process; methanogenesis.

Table 2. Elemental analysis results for FW and EFB.

| Feedstock     | C (%) | H (%) | N (%) | S (%) | C/N ratio |
|---------------|-------|-------|-------|-------|-----------|
| FW Type A (Average) | 76.29 | 18.77 | 4.94  | 0.00  | 15.45     |
| FW Type B (Average)  | 69.57 | 23.31 | 7.11  | 0.00  | 9.78      |
| FW Type C (Average)  | 64.85 | 20.57 | 14.59 | 0.00  | 4.45      |
| FW Type D (Average)  | 74.51 | 19.91 | 5.58  | 0.00  | 13.36     |
| EFB (Average)      | 78.26 | 16.30 | 5.44  | 0.00  | 15.40     |

On the other hand, FW Type C possessed the lowest C/N ratio at 4.45; far from the range of C/N ratio for optimum anaerobic digestion of food waste. FW Type C was also an individual food waste type, which was nearly purely chicken, with small traces of rice. FW Type C is the exact opposite of FW Type A; Type A has highest carbon and lowest nitrogen content, Type C has highest nitrogen and lowest carbon content. Chicken is a food source which is rich in proteins and therefore rich in nitrogen content, hence this best explains the reason behind FW Type C possessing the highest nitrogen content; nearly 15% of overall elemental analysis, compared to the other food wastes. A review by Zhang et al. (2014) [43] observed that digesters which used feedstock with low C/N ratio due to imbalance of nitrogen and carbon, led 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 FW Types A and D, are more ideal, as it provides a more balanced nutrient content, and can prevent the inhibitory effect of ammonia in the digester [44], hence less inhibition on methanogens during the final stage in anaerobic digestion.

As for EFB, the C/N ratio was similar to FW, 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 [45], and 50.01% C and 1.9% N [46]. 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.
3.2 Nutrients analysis of food waste (FW)

From nutrients analysis of the food waste, the compositions of carbohydrates, proteins, and lipids for all four types of food waste were obtained, as shown in Table 3. FW Type A, which had the highest C/N ratio at 15.45, was found to have the second highest amount of carbohydrates, and lowest amount of proteins, compared to the other three types of food waste. On the other hand, FW Type C, which possessed the lowest C/N ratio at 4.45, gave the highest proteins content, and lowest carbohydrates content; the exact opposite of FW Type A. FW Type B, which was bread food waste, possessed the highest concentration of carbohydrates at 206.36 mg/ml, with the second highest concentration of proteins at 97.66 mg/ml, far from FW Type C protein content at 197.43 mg/ml. As for FW Type D, the mixed food waste type, the significant difference which can be seen is that FW Type D possessed the highest lipid content compared to the rest, while carbohydrates and proteins content were similar to FW 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 [47], where each of these components have their own effect on anaerobic digestion. 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 FW Type C, where the protein content was highest compared to the other three. This also explains the fact that the C/N ratio for Type C was the lowest compared to the others. Too high ammonia levels in the digester is not favourable for anaerobic digestion, as ammonia inhibits methanogens activity during methanogenesis step, hence reducing efficiency as less biogas product will be obtained.

| Type of FW | Carbohydrates (mg/ml) | Proteins (mg/ml) | Lipids (%) |
|------------|------------------------|------------------|------------|
| FW Type A  | 138.28                 | 19.75            | 6.73       |
| FW Type B  | 206.36                 | 97.66            | 2.48       |
| FW Type C  | 97.90                  | 197.43           | 7.87       |
| FW Type D  | 137.01                 | 25.68            | 13.04      |

The lipid contents in FW Types A to C were at low to moderate levels; FW Type B, bread, having the lowest lipid content. FW Type D on the other hand showed higher lipid levels, more than 10%. This is most likely due to the type of food waste used for Type D; mixture of food wastes. In this mixture of food waste, the major components were rice, bread and chicken, together with oily foods and sauces, with residues of eggs. Hence, the more significant presence of oily food contents in Type D as compared to Types A to C is the best explanation. FW Type D had the highest lipid content for the food waste nutrients analysis. High lipid contents can help increase methane production potential, or in other words higher biogas yield [44] during anaerobic digestion. 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 [48]. Hence, a balanced composition of these three elements is necessary, to provide an optimum condition for anaerobic digestion to take place. Out of the four types of food waste analysed in this study, FW Types A, B and D show positive and promising results to be used for anaerobic digestion. On the other hand, FW Type C, which is chicken food waste, may not be suitable to be used as sole feedstock for anaerobic digestion, since nitrogen content is relatively high in this FW type. This is due to the high protein content, which can lead to ammonia inhibition during anaerobic digestion, since proteins contains nitrogen which is contributed by the amino group in proteins. As for FW Type B, the C/N ratio is near with the optimum range and possesses the highest carbohydrates content in this study. However, too high levels of carbohydrates can cause an imbalance and limitations in nutrients contents required for microbial activity during anaerobic digestion.
3.3 Analysis of empty fruit bunches (EFB) compositions
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%, followed by hemicellulose (14% to 15.6%), and finally lignin (6% to 6.88%). 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% [49]. 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 raw untreated 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 H2SO4 treatment for lignin. Therefore, the amount of cellulose was completely dependent on the results of these three procedures.

| 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          |

In short, in the EFB, cellulose content was the highest, followed by hemicellulose and extractives or oils, while lignin having the lowest content. This composition of the EFB makes it favourable to be used as one of the feedstocks in anaerobic digestion, since cellulose is the main component that will be hydrolysed 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 [50], [51]. 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 during digestion process [35]. 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 process efficiency and productivity.

4. Conclusions
In conclusion, the characterization of food waste (FW) and empty fruit bunches (EFB) to be used in anaerobic digestion has been carried out successfully. From Elemental Analyser analysis, C/N ratios for all food waste types and EFB were obtained. C/N ratio ranging from 4.45 to 15.45 for food waste was obtained, where C/N ratio for food waste was overall within optimum. For EFB, the C/N ratio was similar to food waste at 15.40, where these values are suitable for co-digestion with food waste. Further analysis of food wastes in this study showed that Food Waste FW Types A and D, which consisted of mainly rice residues, gave the most balanced compositions of the three nutrients; carbohydrates, proteins, and lipids, in which it can provide optimum conditions for anaerobic digestion. Further analysis of EFB for cellulose, hemicellulose, and lignin content determination found that the EFB possessed high
cellulose content (63.14% to 64.75%), and low lignin content (6.00% to 6.88%), where this condition favours the EFB to be used in anaerobic digestion.

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