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Enhancement on Anaerobic Digestion of Food Waste using Spend Coffee Ground Derived Biochar for Biogas Production

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ABSTRACT

In recent, one of the available energy sources is biogas where it is suitable for necessities of the future with the appropriate application of digestion technology. However, the technology used which is anaerobic digestion (AD) faces some challenges especially for food waste including low biogas productivity due to unstable operation efficiency. In order to overcome this shortcoming, spent coffee ground (SCG) derived biochar is introduced as an additive in AD process to enhance the production. To promote the efficiency of the AD, the optimum condition of biochar dosage, the amount of feedstock and pH value were studied. The experimental findings revealed that 13.528ml/g of biogas yield was achieved under optimum condition of 7g of biochar, 500g of feedstock at pH 7 for 14 days. The characterization analysis of biochar showed that, the carbon content and surface area as well as several functional groups of SCG biochar has led to the enhancement of the biogas production during AD process of food waste. The outcomes shows that the addition of SCG biochar can solve the instability issues of AD process yet increase the production of biogas.

1. Introduction

Globalization has accelerated in recent years and the global energy demand is expected to rise by 48% in the next 20 years due to the increment of industrial activity and technological advancements. Fossil fuel has been powering economies for over 150 years, and currently it supplies about 80% of the world’s energy. However, the usage of fossil fuels also leads to environmental emissions of greenhouse gases (GHGs) and pollutants [1,2]. Therefore, it is critical to find the alternative for fossil fuels to promote the sustainable energy resources.

On the other hand, increased food waste has been as a major problem that might have negative consequences for the environment if it is not adequately treated. Poor food waste management will have a negative influence on the environment [3]. Thus, an effective food waste treatment techniques which able to convert food waste to energy sources such as biogas can be regarded as a potential solution to address all of the issues about fossil fuels and the food waste problem [4,5].

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Biogas is a multilateral renewable energy source that can replace conventional fuels to produce heat and power and can be used as gaseous fuel in automotive applications at the same time. The biogas which produced through anaerobic digestion (AD) process has substantial advantages over other kinds of bioenergy because AD is a cost-effective and ecologically beneficial method [6,7]. However, biogas production via the AD process from food waste also face problem that may lead to anaerobic system failure such as low production due to the limitation in system stability during the process [8,9]. Hence, adding biochar to AD systems can enhances the biogas production and has been proven to reduce as well as eliminate the process limitation [10,11].

Biochar has a lot of advantages where it is environment-friendly, inexpensive and it can be produced from variety sources of biomass. During AD process, the addition of biochar could mitigate the inhibitory which is the main cause of instability of AD system [12]. Besides that, it also can reduce the concentration of inhibitory factors and enhance the growth and metabolic activity of microorganisms [13]. Moreover, the surface functional group structure of biochar can promote the direct interspecies electron transfer (DIET) of microorganisms and strengthen the metabolic pathway of methanogens. However, it should also be noted that the starting biomass is the key factor for the composition of biochar. Biochar carries a significant amount of oxygen and usually contains minerals which contribute to the effectiveness during its application [14].

Along with the current and expanding explorations of biochar, spent coffee grounds (SCG) have attracted much interest for their practical applications [15]. SCG are among the most common biomass wastes with high generation of year [16]. Biochar from SCG exhibits a significant number of O-surface sites, high surface area and a quantity of minerals [17–19]. In addition, preparation steps can also affect the formation of the structure of bio-based carbon materials. The preparation steps can change the functional group properties of the material and make the physical and chemical properties such as specific surface area different [20]. These properties are important in overcome the stability issue of the AD.

Therefore, this study focused on the enhancement of the biogas production from food waste through AD by adding spent coffee ground (SCG) derived biochar. The study aims to study the compatibility of the prepared SGC derived biochar with the enhancement of the biogas produced from food waste. Initially, the SCG derived biochar will be prepared with facile method and further characterized by using Scanning Electron Microscopy (SEM), Brunauer-Emmett-Teller (BET) and Fourier Transform Infrared (FTIR). Then, the performance of biochar as additive in AD of food waste will be investigated by several parametric studies which includes the effect of the dosage of biochar, the amount of feedstock and pH towards the biogas yield. Lastly, the existence of the primary element of biogas was detected through chromatography analysis.

2. Methodology

2.1 Material

The SCG was collected from local coffee shops in Gambang, Pahang. The food waste was collected in the recycle bin from cafeteria near the campus. Then it was stored in a container and refrigerated at 4 °C for further used.

2.2 Preparation of Spent Coffee Ground Derived Biochar

The biochar used in this study was prepared from SCG. Initially, the collected SCG was dried in an oven at 105°C for 24 hours to remove the moisture content. The purpose for removal of the moisture in the sample is to avoid any growth of mold in the sample surface. Then, it was let to cool at ambient temperature. Subsequently, the dried SCG was placed in the furnace for the thermal treatment process at the temperature of 550°C for 3 hours. After cooling, the prepared biochar obtained was kept in desiccator for further use (Figure 1).

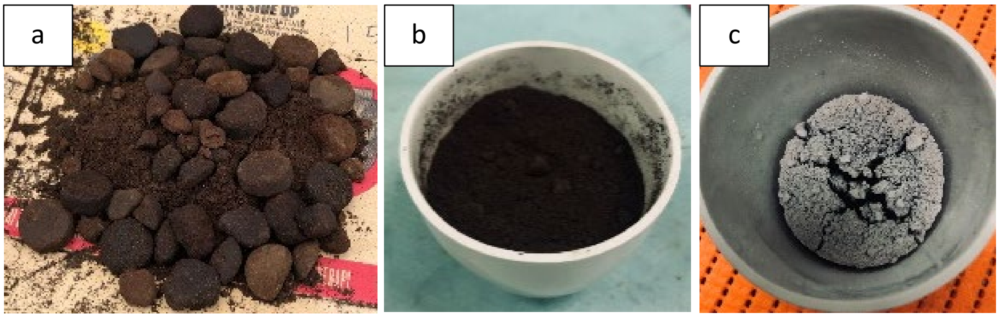

Fig. 1. Spent coffee ground (a) raw (b) after drying and (c) after thermal treatment process

2.3 Characterization of Spent Coffee Ground Derived Biochar
2.3.1 Surface morphology analysis by scanning electron microscopy

The morphology of the biochar was examined by setting up the electron beam energy at 20keV, working distance 10 – 10.5mm, and dead time of X-ray acquisition between 15 and 20% using the scanning electron microscopy with energy-dispersive X-ray spectroscopy (SEM-EDX, Hitachi, Japan). Then, the line-scan analysis was performed to analyze the morphology and content of the biochar.

2.3.2 Surface area analysis by Brunauer-Emmett-Teller (BET) Method

The specific surface area of the biochar was determined using a Tristar 3000 Micromeritics instrument (USA). Initially, the sample was outgassed before measurement at 120°C under N_2 flow for over 1 hour.

2.3.3 Functional group identification by Fourier Transform Infrared (FTIR)

Surface functional group on biochar surface was determined by Fourier Transformed Infrared (FTIR) using Thermo Fishcer Scientific Nicolet iS50 FTIR (USA), where the spectrum for FTIR was in the range of $400cm^{-1}$ to $4000cm^{-1}$ with a resolution factor of $4cm^{-1}$. The data were collected at room temperature by using Potassium Bromide (KBr) pellet technique.

2.4 Performance of Spent Coffee Ground Derived Biochar in Anaerobic Digestion
2.4.1 Preparation of food waste as feedstock

The feedstock that was used for AD in this study is food waste. It was collected from several restaurants in Gambang, Pahang. The food waste consists of carbohydrates and fibers such as leftover rice and bread as well as rotten fruits such as banana and mango. The food waste was processed without any pre-treatment, except the addition of water to dilute the slurry of the feedstock.

2.4.2 Anaerobic digestion of food waste for biogas production

AD reaction was performed in 500 ml glass bottle with 350 ml operating volume. The bottle was seeded with different amount of biochar dosage (1g, 3g, 5g, 7g, and 9g), desired amount of food waste (100g, 200g, 300g, 400g and 500g) for the digestion at different pH (5,6,7,8,9) was prepared in the bottle. A bottle without the biochar was set up as a blank. After filling and sealing the bottle, the bottle was left at atmospheric temperature and pressure for 14 days.

2.4.3 Analysis of anaerobic digestion product calculation

The performance of SCG derived biochar was observed by the total amount of biogas produced in the AD of food waste. The total biogas production was measured by water displacement method by using the following equation:

$$\text{Yield of biogas} = \frac{\text{Volume of dry biogas (ml)}}{\text{Mass of raw materials (g)}} \tag{1}$$

2.4.4 Analysis of biogas compositions through gas chromatography

Online gas chromatography or GC-TCD was performed in a GC-2014 by Shimadzu to analyze the composition of biogas produced from AD process. The operating condition for the GC-TCD was 8ml/min using a carrier gas flow of Helium (He) with column held at 35°C at 5 minutes and ramped to 65°C at rate 20°C min^{-1}. Then, the column was held at 65°C for another 4 minutes. The injector was set to 150°C meanwhile DTCD1 and DTCD2 temperatures were set to 110°C and 60°C respectively.

3. Results and Discussion

3.1 Characterization of Spent Coffee Ground Derived Biochar

3.1.1 Surface morphology of spent coffee ground derived biochar

The SEM images of raw SCG and SCG derived biochar as portrayed in Figure 2. Figure 2(a) and Figure 2(b) show the raw surface of the untreated SCG at two magnification scales which are 200 and 1000. Meanwhile, Figure 2(c) and Figure 2(d) show the SEM images of biochar after thermal treatment process at the same magnification scales. The corresponding EDX analysis is presented in Table 1. SEM images of the SCG biochar in Figure 2(c) and Figure 2(d) show that the morphology of the pores is bigger than the raw SCG in Figure 2(a) and Figure 2(b). These pores were estimated to be about 5µm. The results show that the raw SCG has 54.52% of carbon meanwhile the SCG that has been treated has 87.76% of carbon. Based on Table 1, EDX analysis for the samples show that the main elements are C and O.

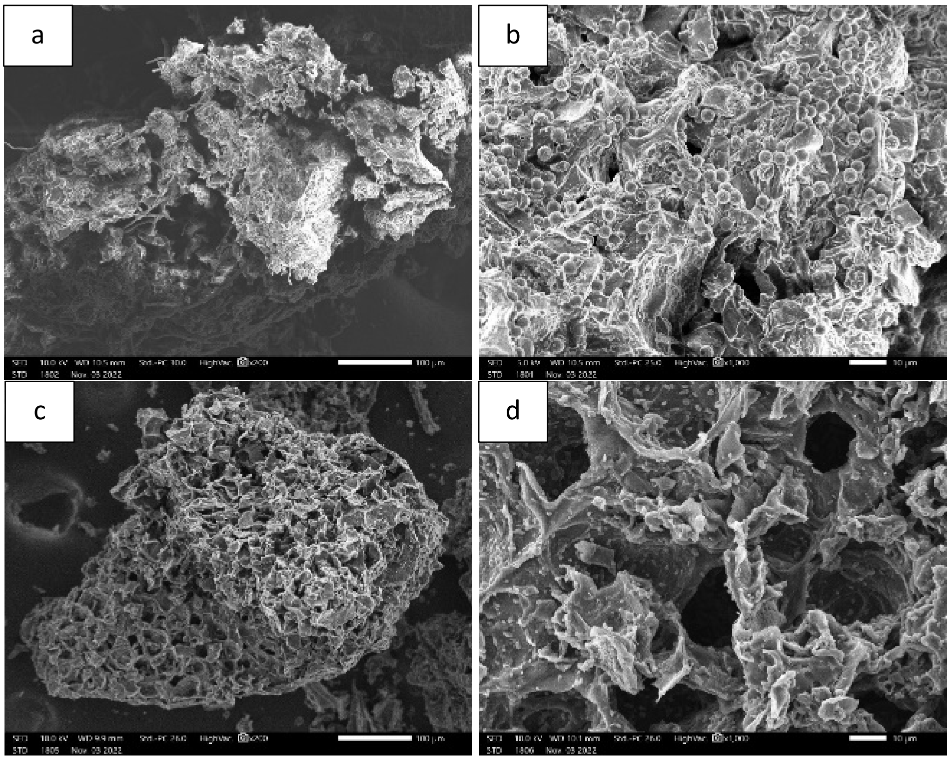

Fig. 2. SEM images (a) raw SCG at 200 magnification scale (b) raw SCG at 1000 magnification scale (c) SCG biochar at 200 magnification scale and (d) SCG biochar at 1000 magnification scale

Table 1
EDX analysis of raw SCG and SCG biochar

Samples	Elements	Mass (%)	Atomic (%)
Raw SCG	C	16.40	74.10
	O	4.24	17.80
SCG biochar	C	3.53	3.57
	O	68.30	1.11

3.1.2 Textural properties of spent coffee ground derived biochar

BET analysis output of the raw SCG and SCG derived biochar are shown in Table 2. The obtained data show that the BET surface area of raw SCG is 9.1960 m^2/g, compared to 15.3282 m^2/g for SCG derived biochar. The surface area increases significantly due to the thermal treatment process of SCG. The release of a huge quantity of volatile matter results in biochar with high porosity with various pore structures and low density [21]. The obtained data revealed the presence of one type of pore in both samples which is mesopores (pore size is 2 – 50 nm). The average pore width of SCG derived biochar was a bit higher compared to the raw SCG. The average pore width of raw SCG and SCG derived biochar were 46.187 Å (4.6187 nm) and 47.796 Å (4.7796 nm) respectively. Thus, both samples were categorized as mesopores. The specific surface area of raw SCG is generally larger than that of SCG derived biochar, and such larger specific surface area is suitable for the metabolism and growth activities of methanogens and other microorganism [22].

Table 2
BET analysis of the raw SCG and SCG derived biochar

Parameters	Raw SCG	SCG Biochar
BET Surface Area (m^2/g)	9.1960	15.3282
Total pore volume (cm^3/g)	0.010	0.017
Average pore width (Å)	46.187	47.796

3.1.3 Existence of functional group in spent coffee ground derived biochar

FTIR analysis was used to investigate the function group on the surface of SCG before and after the thermal treatment method. The KBr spectra of the raw SCG and SCG derived biochar are presented in Figure 3. For the raw SCG, the two main peaks were appeared at 3400 and 1600cm^{-1}. The first peak is due to the -OH bond while the second is characterize as C–C bond. However, the SCG derived biochar sample revealed the absence of the peak at 3400cm^{-1} which is associated with the hydrogen-bonded OH from water, considering complete dehydration during thermal treatment method. Typical moieties present in the SCG were also identified as the C–H stretching vibration that was detected at 2916 and 2847cm^{-1}. The peak at 900cm^{-1} is associated with the C–O vibration [16]. The peak stayed the same in the spectrum of the SCG derived biochar at the same wavenumber.

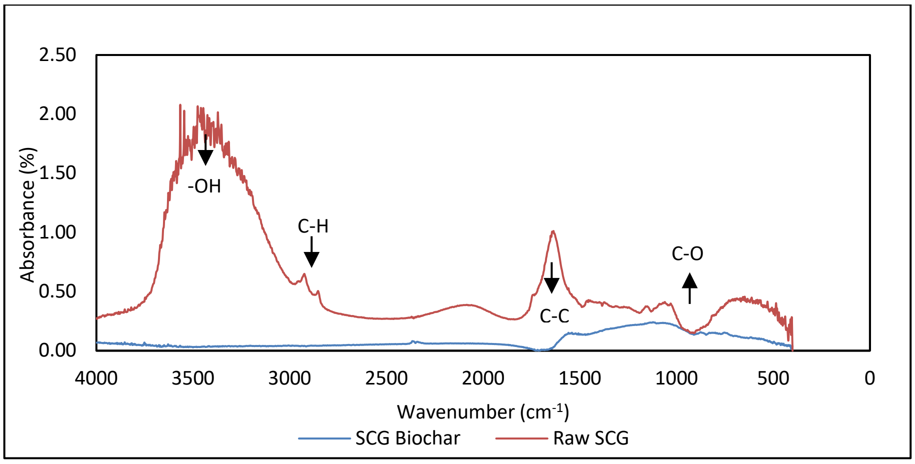

Fig. 3. FTIR analysis of raw SCG and SCG derived biochar

3.2 Parameters Affecting Anaerobic Digestion Process

3.2.1 Effect of the amount of biochar dosage

The parametric effect of the amount of biochar dosage on AD was analysed in five different amounts of biochar dosage which are 1g, 3g, 5g, 7g and 9g. In each anaerobic digester, 500g of food waste mixture was placed in a bottle (digester) then each digester was put at the same place that gets the most sunlight and all digesters will be observed for 14 days. Figure 4 shows the results of the biogas yield at five different amounts of biochar dosage. As depicted in the figure, the biogas yield increased from 0.594ml/g to 1.859ml/g when the dosage of biochar escalates from 1g to 3g. The yield of biogas keeps increasing from 5.652ml/g to 8.412ml/g as the dosage of biochar increases from 5g to 7g. The pores of biochar are becoming shelter places for microorganisms, which affects the abundance of microorganisms in the AD system [23]. However, the yield of biogas begins to decline from 8.412ml/g to 0.249ml/g when the dosage of biochar exceeds 7g. This was because moderate biochar addition could effectively alleviate VFA accumulation resulting in higher levels of methanogenic activity, while higher amount of biochar would lead to more propionic acid accumulated in the digester thereby reducing the AD process stability [22]. Thus, the effective amount of biochar dosage was noted as 7g.

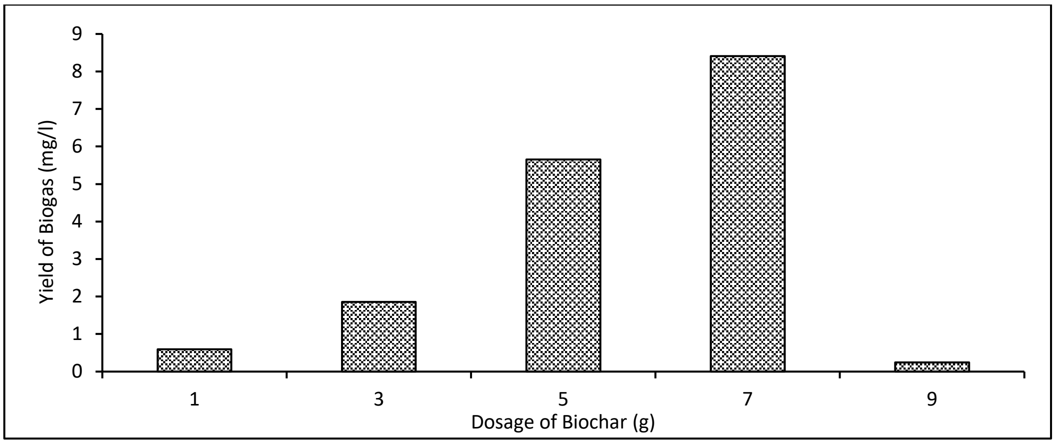

Fig. 4. Yield of biogas by using different amount of biochar dosage in AD

3.2.2 Effect of the amount of feedstock

To assess this parameter, the biogas yield was observed in five different values of feedstock, ranging from 100g, 200g, 300g, 400g and 500g. This operation was done under fixed condition of biochar dosage (7g) and pH value (5). Figure 5 shows the effect of the amount of feedstock on yield of biogas. As depicted in the figure, the yield of biogas increased from 0.479ml/g to 3.593ml/g when the amount of feedstock increased from 100g to 200g. Biochar in AD could accelerate the consumption of organic acids then resulted in higher biogas yield [24]. Then, the yield of biogas decreased to 2.555ml/g when the amount of feedstock increased to 300g. However, the amount of water displaced during the water displacement method for 300g of feedstock was higher, which was 800ml compared to 200g of feedstock which was 750ml. Nevertheless, the yield of biogas increased from 3.629ml/g to 6.131ml/g when the amount of feedstock used was 400g and 500g respectively. Hence, the higher the feedstock used, resulted in maximum biogas production [25].

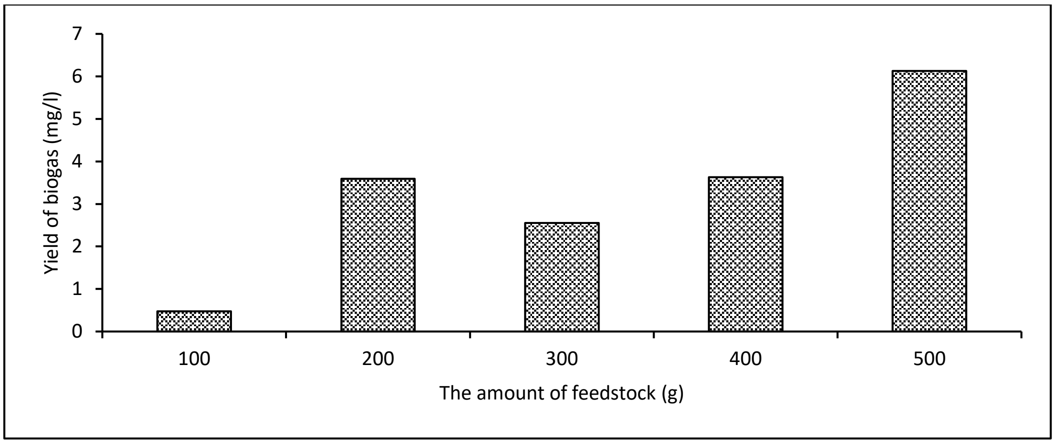

Fig. 5. Yield of biogas using five different amounts of feedstock

3.2.2 Effect of pH value

To assess this parameter, the biogas yield was observed in five different values of pH, ranging from 5, 6, 7, 8 and 9. This operation was done under fixed conditions of dosage of biochar (7g) and amount of feedstock (500g). Figure 6 shows the effect of the pH value on the yield of biogas. As depicted in Figure 6, the yield of biogas increased from 0.077ml/g to 0.364ml/g and further increased to 13.528ml/g when the pH values used were 5, 6 and 7 respectively. However, there a is significant decrement of biogas yield which was 0.240ml/g and 0.144ml/g when the pH value used were 8 and 9 respectively. Previous study has reported that the optimum pH range for normal digestion is 6.6 – 7.6 in an AD system [26]. Thus, the effective pH value for this study was noted as 7. This is because in the digesters with extremely low and high pH values, the methanogenic activity was seriously inhibited, and then keeping the biogas yield at a low level.

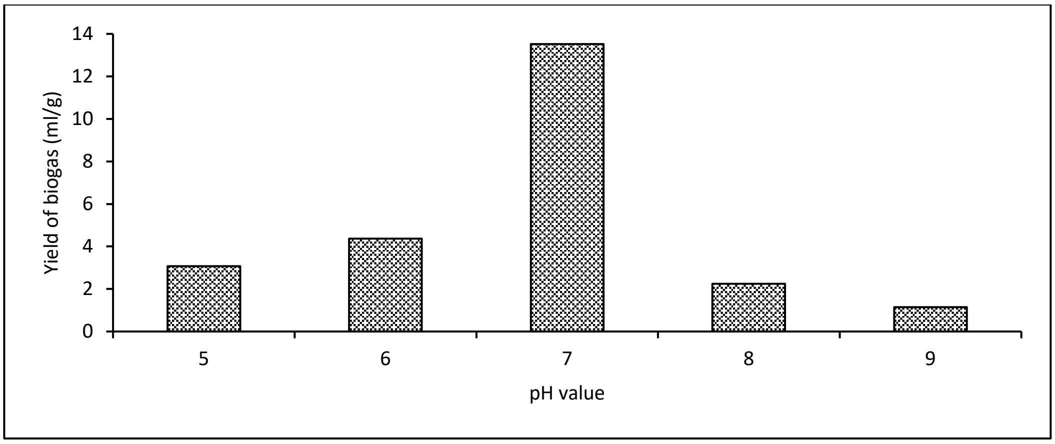

Fig. 6. Yield of biogas using five different values of pH in AD

4. Conclusions

The primary aim of this study is to enhance methane gas from AD of food waste by adding an additive which is SCG derived biochar. To achieve the aim of this study, two objectives were established which includes the study of characterization analysis of biochar as additive in AD of food waste from spent coffee ground and to analyze the performance of biochar as additive by studying the optimum operating conditions of AD. Each optimum operating condition was investigated by varying the dosage of biochar, the amount of feedstock used, and pH value. From this investigation, the highest biogas yield achieved was when the condition used 7g of biochar dosage with 500g of feedstock, and 7 pH value, resulting in 13.528ml/g of biogas yield. The results proven that SCG can be one of the options for further study as additive in AD especially for food waste.

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