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Characterization of Spent Coffee Grounds in the Community as Supporting Materials for Renewable Energy

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Abstract: Coffee grounds are a by-product of the coffee brewing process. Currently, coffee grounds in the community are still untapped waste. Whereas spent coffee grounds have the potential to be converted into various high value bio-products that are environmentally friendly. This study aims to characterize coffee grounds waste which is popular in the community as a supporting material for renewable energy. This study uses a comparative method of 3 samples of Arabica coffee grounds (SCG-A), Robusta (SCG-R), and the Arabica-Robusta blend (SCG-AR) from coffee brands that are popular in Indonesian. Quantitative analysis was carried out by comparing the percentage of residual yield of the three samples. Qualitative characterization of coffee grounds was carried out using the FTIR 8300/8700 Spectrophotometer. The results of the three samples showed different rendemen values, namely 70% SCG-A, 60% SCG-R, and 80% SCG-AR. The FTIR test results showed that the three spent coffee grounds had the same functional group characteristics in the frequency range of 650–3900 cm^{-1}. The detection of the hydroxyl functional group (-OH), the asymmetric strain of the CH bond of the methyl group ($-CH_3$), and the stretching vibration of CO in the COH bond found in coffee grounds waste shows its potential as a supporting material for renewable energy if a further process is carried out in the form of pyrolysis/calcination at room temperature 700˚C. Utilization of spent coffee grounds in the community can be done by establishing a Spent Coffee Grounds Bank (SCG Bank), educating the public so that they are willing to donate spent coffee grounds, and managing SCG as a supporting material for renewable energy.

Keywords: FTIR; Fuctional groups; Renewable energy; Spent coffee grounds.

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Introduction

Coffee is one of the most popular drinks in the world. Besides having great economic value, coffee also produces an environmental burden in the form of coffee grounds left over from brewing. The increasing rate of population growth can be correlated with two major problems. First, the increase in coffee grounds waste will further increase the burden on the environment. The results of a survey by the Central Statistics Agency (Statistics Indonesia) in 2020, the population of Indonesia reached 237 million people with a growth of 1.25% (Badan Pusat Statistik Indonesia, 2021). If 1% of the population consumes 1 cup of coffee per day with an average of 7 grams of coffee grounds waste, then there is 15.59 tons of coffee grounds waste per day. This means that there are 546 tons of coffee grounds waste burdening the environment every day, which is contributed by 1% of the 7.8 billion people of the earth. If the coffee grounds

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waste is not handled properly it will cause environmental degradation.

Second, the increase in population growth rate is also correlated with dwindling energy needs if only relying on non-renewable energy such as oil and natural gas. In addition, the use of non-renewable energy types of hydrocarbons emits carbon dioxide byproducts that are not environmentally friendly and contribute to global warming (Gielen et al., 2019). It is very important to develop alternative and renewable energy sources that are environmentally friendly. The Indonesian government has set an optimal energy mix target by 2025 with renewable energy contributing more than 15% of the total energy mix (Yansen et al., 2021). If coffee grounds waste in the community can be used as a supporting material for renewable energy, then these two problems can be overcome at once.

Currently, no research has been conducted on the potential utilization of coffee grounds waste in the community as a supporting material for renewable energy. Therefore, at the initial stage, it is necessary to characterize coffee grounds waste on a household scale from branded coffee products that are popular in the community. Generally, coffee product brands that are popular in Indonesian society are made from Arabica coffee, Robusta coffee, and a combination of the two.

Method

This study uses 3 brands of coffee that are popular in the community. The first brand represents packaged coffee made from Arabica coffee (A code) which produces Arabica coffee grounds waste (SCG-A code). The second brand represents packaged coffee made from Robusta coffee (R code) which produces Robusta coffee grounds waste (SCG-R code). The third brand represents packaged coffee made from a blend of Arabica and Robusta coffee (AR code) resulting in Arabica-Robusta coffee grounds waste (SCG-AR code). Coffee grounds waste is obtained by the method of brewing coffee which is often done by the people of Indonesia. Every 10% (w/v) coffee powder is brewed using water at 90˚C with stirring for 30 seconds. The coffee infusion is deposited for 10 minutes then filtered to separate the filtrate and residue (coffee grounds waste). The residue was then dried using an oven at 50˚C for 24 hours to remove the water content. The dried residue is then ground using a mortar and stamper into coffee grounds waste powder. Next, each sample was weighed to determine the percentage of residual yield. Spent coffee grounds were stored in airtight ampoules for Fourier transform infrared spectroscopy (FTIR) test.

The FTIR 8300/8700 spectrophotometer test in this study was used to characterize spent coffee grounds qualitatively. The analysis was carried out by observing the specific peaks indicating the vibration of the functional groups contained in the spent coffee grounds (SCG). FTIR spectra are generally useful for classifying entire regions into three to four broad regions. One way is to categorize some of the near IR regions (0.7-2.5 μ); fundamental area (2.5-5.0 μ); and far IR region (50-500 μ). Another way is to classify them as fingerprint regions (6.7-14 μ). From these two classifications it appears that in the second category all areas are fundamental, and this is the most widely used.

Results and Discussion

Spent coffee grounds yield

The results of the calculation of the percentage yield of the three types of coffee grounds are shown in table 1. The order of yield from the largest to the smallest is SCG-R, SCG-A, and SCG-AR, respectively. The three black coffee brands that are popular in Indonesia have good potential in producing coffee grounds residue yields between 60%-80%. This potential shows two meanings at once. First, the large residual yield of coffee grounds shows its potential as waste that pollutes the environment. This will happen if the coffee grounds residue is not used properly. However, the second potential shows the opposite. The high residue of coffee grounds shows its good potential to be used as an environmentally friendly renewable energy support material.

Table 1. Yield of spent coffee grounds powder

Code	Powder mass		yield
	coffee (g)	dregs (g)	(%)
SCG-A	10	7	70
SCG-R	10	6	60
SCG-AR	10	8	80

Research conducted by Hanif (2019) observed that variations in the mass of instant robusta coffee grounds were generally significant to the yield of coffee oil extract obtained (Hanif et al., 2019). The difference in residual yield in the three samples could be caused by various factors, one of which is the brewing process. Brewing is the process of dissolving coffee grounds using hot water, but the temperature used does not exceed 90-100˚C. The brewing temperature used by Indonesians varies, for example, people who work in offices usually use a dispenser to make coffee because it is more practical, while mobile coffee sellers use a thermos to keep the water hot. The temperature of the water dispenser and thermos water ranges from 70-80˚C. In contrast to people at home and in coffee shops, Tang uses boiling water at a temperature of 90-100˚C.

Increasing the brewing temperature will increase the solubility of the chemical components in coffee (Rao, 2014). In the brewing process, the technical conditions used will affect the composition of the coffee produced. These conditions include brewing ratio, temperature, particle size, brewing method and water pressure (Parras et al., 2007).

Spent Coffee Grounds of Arabica (SCG-A)

The results of the FTIR test for Arabica coffee grounds from a popular brand (SCG-A) are shown in Figure 1.

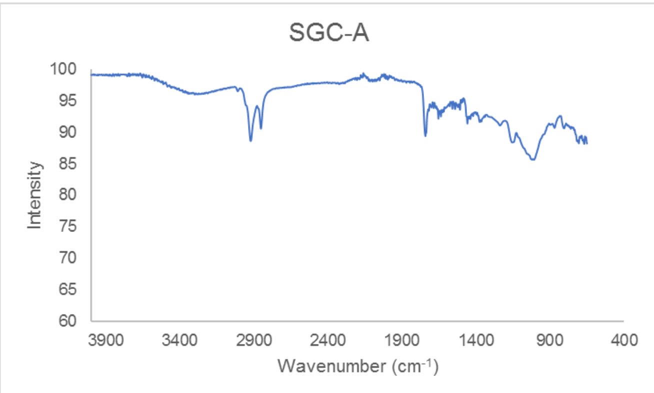

Figure 1. FTIR Test Result of Spent Coffee Grounds of Arabica

The SCG-A spectra show three distinctive peaks in the wavenumber range between 650-3900 cm^{-1}. Details of the peak characterization of the results of the SCG-A FTIR test are shown in Table 2. Based on the results of the FTIR test of Arabica coffee grounds (SCG-A) in Table 2, it is known that the three main functional groups are characterized, namely hydroxyl (-OH), asymmetric strain of the CH bond group of methyl ($-CH_3$), and C-O stretching vibrations in C-O-H bonds.

Table 2. Characterization of functional groups in SCG-A

Wave Number (cm^{-1})	Intensity	Functional groups
3,200-3,600	96	Hydroxyl (-OH)
2,800-3,000	96	Methyl ($-CH_3$)
952-1,135	85	Glycosidic (-COH)

Spent Coffee Grounds of Robusta (SCG-R)

The results of the FTIR test for Robusta spent coffee grounds from a popular packaged coffee brand (SCG-R) are shown in Figure 2.

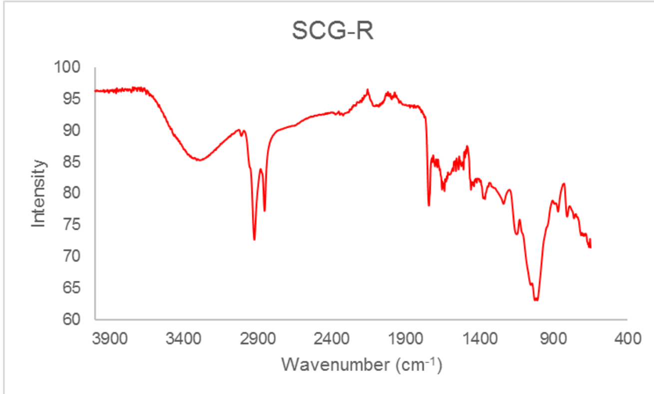

Figure 2. FTIR Test Result of Spent Coffee Grounds of Robusta

The FTIR SCG-R spectra in Figure 2 show three typical peaks in the wavenumber range between 650-3900 cm^{-1}. Details of peak characterization on the results of the SCG-R FTIR test are shown in Table 3.

Table 3. Characterization of functional groups on SCG-R

Wave Number (cm^{-1})	Intensity	Functional groups
3,200-3,600	85	Hydroxyl (-OH)
2,800-3,000	74	Methyl ($-CH_3$)
952-1,135	63	Glycosidic (-COH)

Based on the results of the FTIR test of robusta coffee grounds (SCG-R) in table 3, it is known the characterization of three main functional groups, namely hydroxyl (-OH), asymmetric strain of CH bond methyl group ($-CH_3$), and stretching vibration of C-O in C-O-H bond.

Spent Coffee Gounds of Arabica-Robusta (SCG-AR)

The results of the FTIR test for coffee grounds mixed between Robusta and Arabica from a popular brand in the community (SCG-AR) are shown in Figure 3.

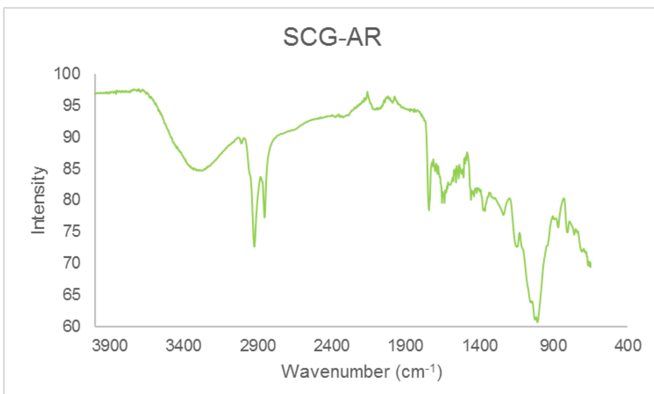

Figure 3. FTIR Test Result of Spent Coffee Grounds of Arabica-Robusta

The SCG-AR spectra show three distinctive peaks in the wavenumber range between 650-3900 cm^{-1}. Details of peak characterization on the results of the SCG-A FTIR test are shown in table 4.

Table 4. Characterization of functional groups in SCG-AR

Wave Number (cm^{-1})	Intensity	Functional groups
3,200-3,600	84	Hydroxyl (-OH)
2,800-3,000	73	Methyl ($-CH_3$)
952-1,135	60	Glycosidic (-COH)

Based on the results of the FTIR test of coffee grounds, a blend of arabica and robusta from a popular brand (SCG-AR) in Table 4, it is known that the characterization of three main functional groups, namely hydroxyl (-OH), asymmetric strain of CH bonds, methyl group ($-CH_3$) , and C-O stretching vibrations in the C-O-H bonds.

Comparison of the Spectra of Spent Coffee Grounds of Arabica (SCG-A), Robusta (SCG-R) and a blend of Arabica-Robusta (SCG-AR)

The comparison of the FTIR test results for the three samples of Arabica/Robusta/Arabika-Robusta coffee grounds from popular brands (SCG-A, SCG-R, SCG-AR) is shown in Figure 4. Based on the results of the FTIR test, Arabica coffee grounds (SCG-A) in table 5 is known to characterize three main functional groups, namely hydroxyl (-OH), asymmetric stretching of the C-H bond of the methyl group ($-CH_3$), and the stretching vibration of C-O in the C-O-H bond.

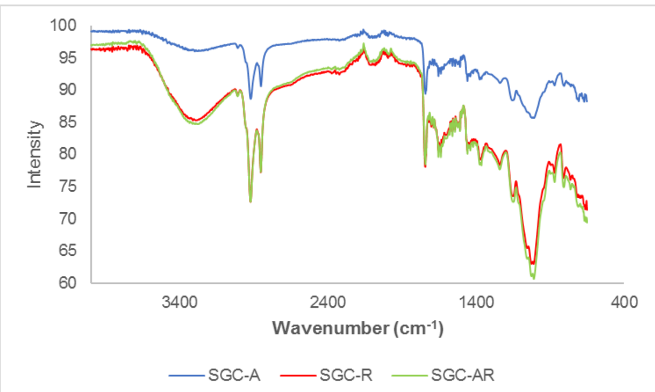

Figure 5. FTIR Test Results of Spent Coffee Grounds of Arabica, Robusta, and Arabica-Robusta

The three spectra of SCG-A, SCG R, and SCG-AR showed three distinctive peaks in the wavenumber range between 650-3900 cm^{-1}. Details of peak characterization on the results of the SCG-A FTIR test are shown in table 5.

Table 5. Characterization of functional groups in SCG-A/R/AR

Wave Number (cm-1)	SCG Intensity			Functional groups
	A	R	AR	
3,200-3,600	96	85	96	Hydroxyl (-OH)
2,800-3,000	96	74	96	Methyl ($-CH_3$)
952-1,135	85	63	85	Glycosidic (-COH)

FTIR analysis in Figure 4 and Table 5 reveals that SCG-A has an absorption band typical of lignocellulosic materials, although the magnitude of this band is different for each residue. The peak width between 3,600 and 3,200 cm^{-1} is related to the hydroxyl group of the O-H stretching vibration. The region between 3,000 and 2,800 cm^{-1} with two sharp bands at 2,923 and 2,852 cm^{-1} is associated with the C–H stretching vibration. These bands have previously been reported in the spectrum of roasted Arabica and Robusta coffee samples (Kemsley et al., 1995) and roasted coffee husks (Reis et al., 2013). Moreover, FTIR analysis studies of caffeinated beverages such as tea, coffee, and soft drinks have reported peaks at the same region (2,882 and 2,829 cm^{-1}), which is associated with the asymmetric strain of the C–H bond of the methyl group ($-CH_3$) in the caffeine molecule and can be successfully used to develop predictive models for quantitative analysis of caffeine (Paradkar & Irudayaraj, 2002).

Bands between 1,700 and 1,600 cm^{-1} are strongly associated with chlorogenic acid and caffeine (Ribeiro et al., 2010). Then, the peak at 1,654 cm^{-1} could be attributed to the absorption of these compounds, as the peaks are more intense as their concentration in the sample increases. The broad band between 1,135 and 952 cm^{-1} results from C-O stretching vibrations in C-O-H bonds such as glycosidic bonds and is associated with galactomannan polysaccharide sugars (Figueiró et al., 2004).

A review conducted by McNutt and He (2019) stated that coffee grounds waste has the potential to be used as bio-energy, bio-active components, and high-value new materials that are environmentally friendly (McNutt & He, 2019). Hydrocarbon fuels can also be produced from the conversion of triglycerides (coffee oil) obtained from coffee grounds, but produce a lot of waste that requires special handling (Döhlert et al., 2016). The defatted SCGs can be made into bio-char with a calorific value of 26.0 kJ/g and is smokeless, which meets the product standards of the Thai community (Per 238/2547) (Tongcumpou et al., 2019). The possibility of using SCG in the form of pellets as fuel has been proven to produce calories of 21.08 MJ.kg-1 which is higher than pellets from sawn wood with calories of 17.15 MJ.kg-1 (Nosek et al., 2020). This is reinforced by the results of Lee's research (2021) which shows that spent coffee ground of Arabica (SCG-A) in the form of bio-char has the potential to become a promising new energy generation. The SCG-biochar has high thermal efficiency with low activation energy (63.24 kJ.mol^{-1} –122.93 kJ.mol^{-1}) at an attractive cost of $7.22 per kg which can be used in the combustion process effectively (Lee et al., 2021). A number of studies have shown coffee grounds waste as an adsorbent to remove dyes in water that can be used directly or after special treatment (Blinová & Sirotiak, 2019). The bio-elastomeric foam of coffee grounds has also been confirmed to remove methyl violet and methylene blue which are water pollutants (Soriano et al., 2020). Spent coffee grounds can also be used as a supercapacitor (Andrade et al., 2020; Chiu & Lin, 2019; Deng et al., 2016), supporting material for PCM (phase change material) bio-composite production (Yoo et al., 2019), bone filling material (Triyono et al., 2020), renewable energy sources (Massaro Sousa & Ferreira, 2019), food and drug additives (Ballesteros et al., 2014), natural photosensitizer for dye-sensitized solar cells (DSSCs) (Bartolome et al., 2020).

Tsai (2019) proposes an easy process to synthesize nitrogen-doped carbon from agro-food using coffee grounds waste and made as anode material for Li/Na-ion batteries. Coffee grounds porous carbon (CGC) and nitrogen doped (N-CGC) materials have been compared with experimental measurements as well as theoretical calculations. Nitrogen doping from 2.23 to 6.17% was successfully modified into materials. N-CGC showed better reversible capacity and excellent rate capability than CGC anodes due to the different distribution function groups of N pyrolate and N pyridine. Tsai also used three different models to demonstrate differences in carrier transport properties. The difference in electrochemical properties of CGC and N-CGC may be due to the appearance of extra states near the Dirac cone when examining the partial density of states (PDOS) of N-CGC by Density functional theory (DFT) calculations. This investigation not only solved the problem of disposal of biomass waste, it also produced a valuable functional carbon-based material for energy storage applications (Tsai et al., 2019).

The potential of selected agricultural waste to produce nanoparticle-sized silicon solar panels is expected to replace the use of non-renewable fossil fuels that have a negative impact on people and the climate (Adebisi et al., 2017). Photovoltaic solar power was identified as an effective renewable energy source that has proven to be a promising candidate for clean and sustainable electricity supply. The synthesis of nanoparticle-sized silicon solar panels can use coffee starting material with biotransformation, calcination, and washing procedures at a maximum temperature of 700˚C to produce silica (Adebisi et al., 2017). Based on the literature, coffee grounds waste has great potential to be used as a supporting material for high-value and environmentally friendly renewable energy. This study focuses on the characterization of household-scale coffee grounds produced by the Indonesian people from popular branded coffee products. The follow-up results of this study can be used as study material in an effort to overcome the effects of the population explosion on the surge in energy demand and environmental degradation.

The results of the characterization of coffee grounds waste strongly support the idea of a circular bioeconomic plan proposed by Banu (2020). Circular bioeconomy is an innovative research-based economic scheme to improve the use and management of bio-resources in a sustainable bio-finance pathway (Rajesh Banu et al., 2020). Through this circular bioeconomic mechanism, coffee grounds waste in the community can be used as product precursors, product supporters, and higher value main products. For example, analysis of utilization related to biofuels (biofuels), spent coffee grounds (SCG) shows the efficiency of raw material costs, transportation, labor requirements, oil extraction operations, and biofuel production (Rajesh Banu et al., 2020). According to Passadis (2020) the process units that have been included in the biorefinery proposal include (1) oil extraction from SCG, (2) transesterification of oil extracts into biodiesel, (3) alkaline pretreatment to reduce SCG residues, (4) saccharification of delignified SCG with enzymatically by hydrolysis, and (5) fermentation from hydrolysate to bioethanol (Passadis et al., 2020). Technically, the utilization of coffee grounds waste in the community can be done by establishing a Spent Coffee Grounds Bank (SCG Bank), educating the community so that they are willing to donate coffee grounds waste, and managing coffee grounds waste as a supporting material for renewable energy. The Coffee Bin concept introduced by Vakalis (2019) can be an inspiration for SCG Bank. The Coffee Bin as a centralized waste collection scheme, where a special bin will be placed in a designated area for the collection of used pure coffee grounds. The collected coffee grounds are then dried and followed by a torrefaction and pyrolysis process to produce carbon-rich material (Vakalis et al., 2019). The coffee bin used for the development of a used coffee grounds collection scheme in the large municipality of Athens (Greece) could inspire similar applications in other countries, including Indonesia.

Conclusion

The results of the characterization of coffee grounds that are popular in the community show that SCG A/R/AR has the potential to be used as a supporting material for renewable energy. The calculation of residual yield shows the results of SCG-A of 70%, SCG-R of 60%, and SCG-AR of 80% showing their potential which is positively correlated with the content of chemical substances supporting renewable energy. The FTIR test results showed that the three coffee grounds had the same functional group characteristics in the frequency range of 650–3900 cm^{-1}. The detection of the hydroxyl functional group (-OH), the asymmetric strain of the C-H bond of the methyl group ($-CH_3$), and the stretching vibration of C-O in the C-O-H bond found in coffee grounds waste shows its potential as a supporting material for renewable energy with a follow-up process in the form of pyrolysis/calcination at a temperature of 700˚C. This study supports circular bioefineries.

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