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Morphological structure and functional group of Toraja robusta and arabica spent coffee grounds for electronic device applications

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Abstract
Spent coffee grounds (SCG) are waste byproducts of the coffee brewing process and are frequently disposed of in landfills, which raises environmental issues. A thorough overview of the properties of coffee grounds has yet to accompany the utilization of coffee grounds in many applications. This study attempts to categorize different coffee grounds based on their morphological structure and composition/element characteristics using scanning electron microscopy (SEM) for microstructural analysis and Fourier transform infrared spectroscopy (FTIR) to figure out the functional groups in coffee grounds. Morphological structure analysis showed that Robusta and Arabica SCG were dominated by around 70% of carbon, oxygen, and nitrogen. FTIR analysis revealed seven different peaks in Robusta and Arabica coffee grounds. Finally, the high concentration of carbon in Robusta and Arabica coffee grounds led to promising electrochemical energy storage for electronics applications.

Keywords: spent coffee grounds, Robusta, Arabica, electronics device

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I. Introduction

Coffee has been drunk all around the world for many years. Coffee is now a well-known beverage in many countries. The antioxidant content in coffee provides many health advantages, including preventing cell damage, protecting against certain cancers and chronic illnesses, and lowering the risk of cardiovascular and neurological death [1]. Following petroleum, coffee is the second-most traded commodity. [2]. As reported by the International Coffee Organization in January 2023, this massive market and demand have resulted in a high coffee production rate of 170,3 thousand packages (60 kg/package) in 2021/2022 [3]. As a result, the coffee business greatly impacts waste production.

Consumed coffee will leave a residue. Coffee pulp, husks, silverskin, and SCG are crucial byproducts of coffee manufacturing. According to research, at least 90% of the coffee produced—or 100 kg of coffee grounds—end up as so-called Spent Coffee Grounds [4]. A byproduct of the food business, spent coffee grounds (SCG) are primarily stored or burned [2]. Methane and carbon dioxide, two greenhouse gases that contribute to global warming and have negative environmental effects, are produced by SCG [5], [6]. An industry characterized by the careless disposal of coffee grounds without processing has not fully understood the implications of coffee waste. Currently, coffee waste has begun to be utilized as energy storage [7], [8],

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thermal energy storage [9], lithium-ion battery anodes [10], biosolid production [11], biofuel production [8], biodiesel production [12], and bio-batteries [13], [14].

So far, the use of coffee grounds in various applications has not fully been accompanied by an explanation of the characteristics of coffee grounds that allow them to be used in multiple applications. This research aims to classify various coffee grounds based on morphological structure and composition/element characteristics. The coffee grounds obtained will be prepared and then characterized using scanning electron microscopy (SEM) for microstructural analysis and Fourier transform infrared spectroscopy (FTIR) to figure out the functional groups in coffee grounds.

II. Methods

After brewing in Buntao' and Buntu Pepasan villages, the Toraja Arabica and Robusta spent coffee grounds were obtained. Arabica coffee from Buntao' and Robusta coffee from Buntu Pepasan is the kind of Toraja famous coffee with unique tastes. The brewing of coffee produces spent Coffee grounds. Typically, coffee powder is brewed with boiling water and then stirred as a common practice among Indonesians. The residue was then immediately dried for four hours directly under the sun. The dried residue is then crushed into spent coffee grounds powder with a mortar. Finally, Arabica and Robusta coffee grounds powder weighed 10 grams and were placed in a container. In addition, scanning electron microscopy was utilized to examine the morphological structure of the coffee grounds samples. At the same time, energy dispersive X-ray was used to detect the composition of the coffee grounds samples where scanning electron microscopy is coupled with energy dispersive X-ray or SEM-EDX (Phenom Desktop ProXL). The functional group of coffee grounds powder samples was detected using Fourier transform infrared or FTIR spectroscopy (Nicolet Avatar 360 IR) ranging from 4500 and 400 cm^{-1}. The complete characterization process is conducted at the Laboratorium Terpadu Universitas Islam Indonesia, Yogyakarta. A schematic of the preparation for characterization is shown in Figure 1.

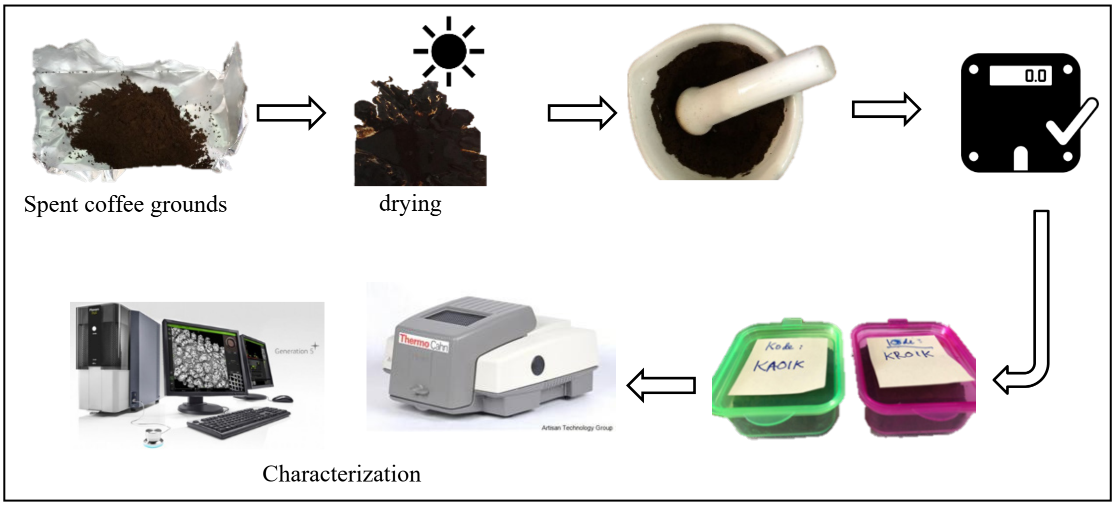

Figure 1. A schematic of the preparation for characterization

III. Results and discussion

Morphological structure

Toraja Robusta coffee grounds powder's morphological structure is characterized using Scanning Electron Microscopy, as shown in Figure 2, and Figure 3 shows the morphological structure of Arabica coffee grounds.

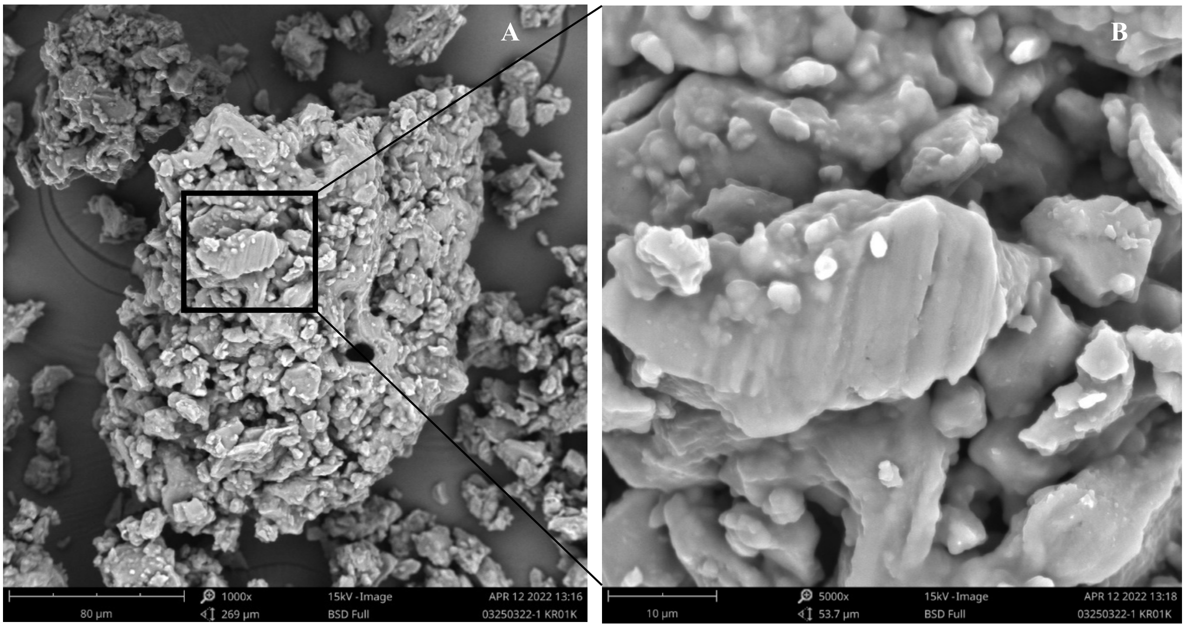

Figure 2. SEM images of the Robusta coffee grounds powder with the magnification of a) 1000X and b)5000X

Robusta coffee grounds powder's elemental composition is detected using an energy Dispersive x-ray (EDX) coupled with SEM. The elemental composition of Robusta and Arabica coffee grounds is shown in Table 1.

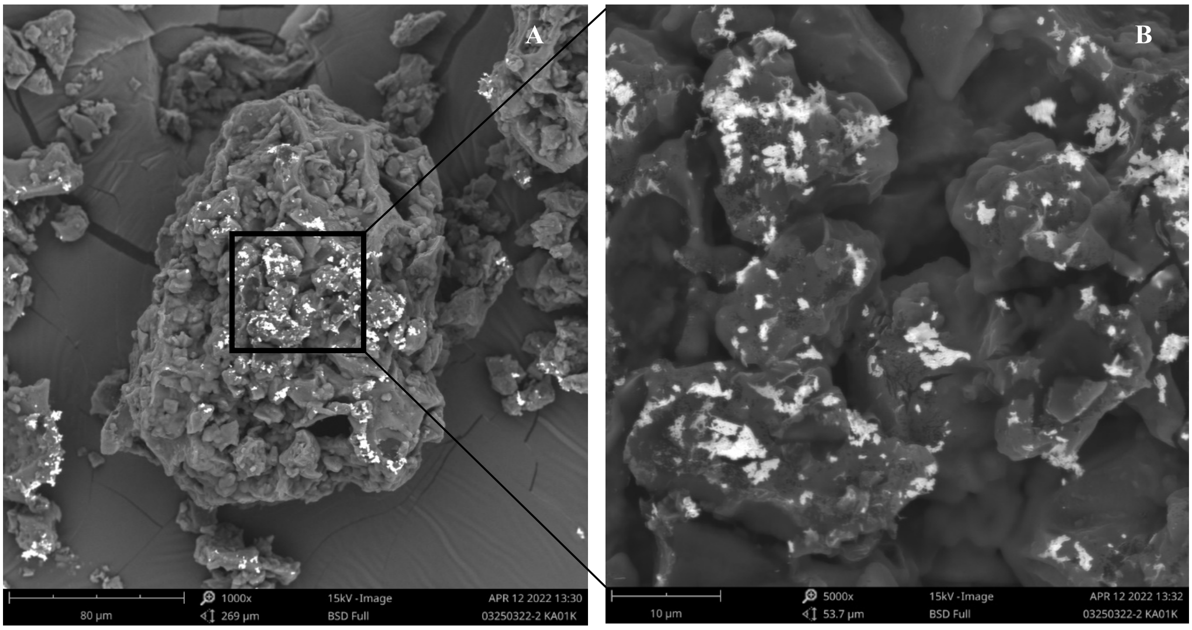

Figure 3. SEM images of the Arabica coffee grounds powder with the magnification of a) 1000X and b)5000X

Table 1. Elemental Composition of Robusta and Arabica coffee grounds powder

Element Name	Robusta		Arabica	
	% Atomic conc.	Weight conc.	Atomic conc.	Weight conc.
Carbon	70.49	65.11	70.92	65.71
Oxygen	20.27	24.94	13.65	16.85
Nitrogen	9.23	9.95	14.70	15.88
Silicon	-	-	0.61	1.31
Aluminium	-	-	0.12	0.25

Table 1 shows that the elemental or composition of Robusta coffee grounds is dominantly by carbon of 70.49 and 65.11 for atomic and weight concentrations, respectively. In comparison, Arabica coffee grounds consist of 70.92 and 65.71 for atomic and weight concentrations of carbon. Oxygen and Nitrogen in Robusta coffee grounds are detected at 20.27 and 24.94 for their atomic and weight concentrations. Arabica coffee grounds have oxygen at 13.65 atomic concentrations and nitrogen at 14.70 atomic concentrations. Silicon and Aluminum are the other minor components of Arabica coffee grounds in small atomic and weight concentrations, while these elements are not detected in Robusta coffee grounds. Carbon's high concentration presence in Robusta and Arabica coffee grounds resulted in promising electrochemical energy storage performance [15]. Carbon materials are commonly utilized as electrodes in supercapacitors [16].

Recent studies have reported that spent coffee grounds (SCG) have a high content of C, N, O, P, Mg, Ca, and S. The percentage of C ranges between 64 and 71%, while the percentage of O ranges from 24 to 31% [17]. However, the exact elemental composition of SCG can vary depending on the source and method of coffee preparation. According to Bekirogullari, spent coffee grounds contain the following components: 54.14% of C, 44.79% of O, 0.22% of P, 0.56% of K, and 0.29% of S [18]. According to Chwastowski, the main components of spent coffee grounds samples were C and O [19].

From these studies, it can be seen that there are some variations in the elemental composition of SCG depending on the source and method of preparation. Still, generally, SCG mainly comprises carbon, oxygen, and nitrogen.

Functional groups

Spectroscopic techniques such as Fourier Transform Infrared Spectroscopy (FTIR) are used to figure out the functional groups present in spent coffee grounds. FTIR works by measuring the absorption of infrared radiation at specific wavelengths, which can be used to identify the functional groups present in a sample. The functional groups of Robusta and Arabica spent coffee grounds are shown in Figure 4.

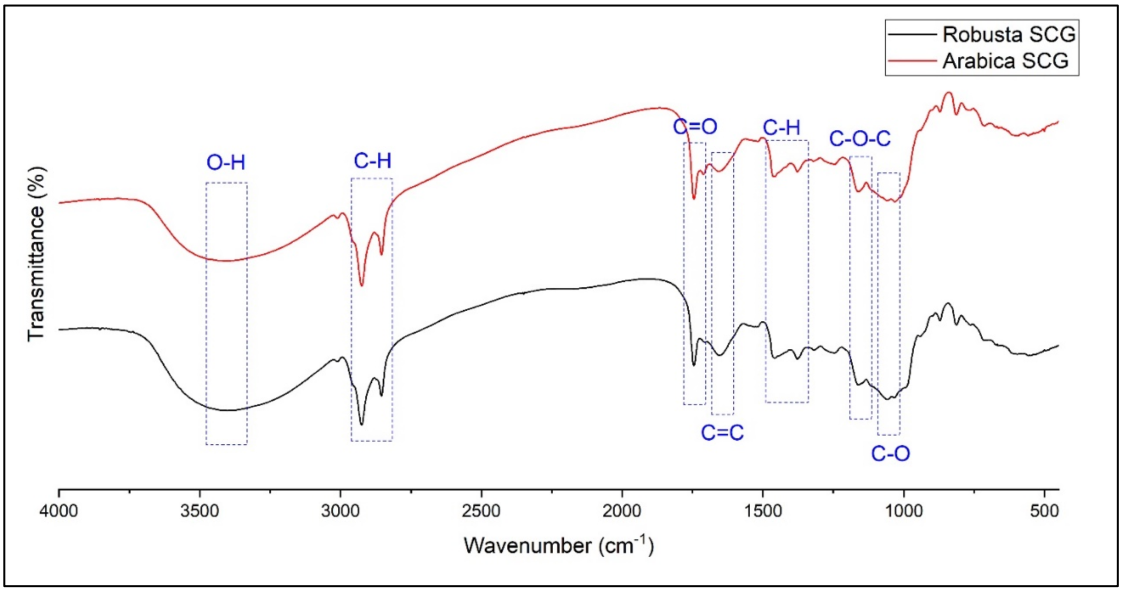

Figure 4. The FTIR spectra of Robusta and Arabica spent coffee grounds.

The FTIR spectra of robusta and arabica coffee spent coffee grounds are shown in Figure 3. Several well-defined peaks have been classified and assigned to various functional vibration modes. Peaks between 2854-2925 cm^{-1} represent C-H bonds [9], [17], [20]–[22]. Other chemical bonds include O-H at 3401 cm^{-1} and 3042 cm^{-1} [9], [21], [22], C=O bonds at 1745 cm^{-1} [17], [20], [22], C = C bonds at 1653 cm^{-1} [21], [22], C-H bonds at 1378 cm^{-1} and 1653 cm^{-1} [21], C-O-C bonds at 1162 cm^{-1} [22], and C-O bonds at 1032 and 1058 cm^{-1} [21]. The vibration mode revealed no significant difference in the FTIR spectra of Robusta and Arabica spent coffee grounds in terms of wavenumber in each vibration mode. Table 2 summarizes the FTIR vibration modes of Robusta, and Arabica spent coffee grounds.

Table 2. FTIR vibration modes of Robusta and Arabica spent coffee grounds

FTIR vibration modes	Wavenumber (cm^{-1})		Reference
	Robusta SCG	Arabica SCG	
O-H	3402	3401	[9], [21], [22]
C-H	2925	2924	[9], [17], [20]–[22]
	2854	2854	[17], [20], [21]
C=O	1745	1745	[17], [20], [22]
C=C	1653	1653	[21], [22]
C-H	1457	1457	[21]
	1378	1378	[21]
C-O-C	1162	1162	[22]
C-O	1058	1032	[21]

IV. Conclusions

In summary, we investigated Toraja Robusta and Arabica coffee grounds based on their morphological structure, composition/element characteristics, and the possibility of using coffee in electronic applications. The EDX analysis revealed that the analyzed spent coffee grounds primarily contain 70% of Carbon, O, and N, as well as minor elements of Silicon and Aluminum. Some peaks are detected and corresponding to the C-H bonds (2854-2925 cm^{-1}), O-H bonds (3401 cm^{-1} and 3042 cm-1), C=O bonds (1745 cm^{-1}), C = C bonds at (1653 cm^{-1}), C-H bonds (1378 cm^{-1} and 1653 cm^{-1}), C-O-C bonds (1162 cm^{-1}) and C-O bonds (1032-1058 cm^{-1}). The vibration mode revealed no significant difference between Robusta and Arabica SCG.

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