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Physical and Chemical Properties of Gayo Coffee Brewed by Boiling Method with Variation of Particle Coffee Ground

Evi Yufita[1], Teuku Muhammad Shadiq Maula[1], Gunawati Gunawati[1], Peter Lloyd Woodfield[2], Elin Yusibani[1]

[1]Department of Physics, FMIPA Universitas Syiah Kuala, Darussalam, Aceh, Indonesia 23111
[2]Griffith School of Engineering and Built Environment, Gold Coast Campus Griffith University, Parklands Dr Southport, Qld 4215, Australia

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Corresponding Author:

Elin Yusibani,
Email: e_yusibani@usk.ac.id

ABSTRACT

The effect of coffee ground particle size by the boiling method on the values of physical and chemical parameters is studied. The coffee used is Arabica (Luwak, wine, honey) and Robusta from the Gayo Highlands, Aceh Province, Indonesia. Extraction of the coffee brew uses the boiling method with different particle sizes of coffee grounds (fine and coarse). The caffeine content in the coffee brew is identified using the FieldSpec4 Hi-Res Spectrometer. The particle size of coffee grounds affected the coffee brew's physical properties and caffeine content. The physical properties in the form of the pH value of Arabica coffee brew are lower than Robusta in a range from 4.87 to 4.97 and 5.13 to 5.28, respectively. The pH of coffee brew with fine particle sizes is slightly higher than for coarse ones for Robusta coffee brew. The density of the brew is in the vicinity range of 0.99 g/cm^3. Arabica and Robusta brews differ in viscosity and caffeine release, influenced by coffee particle size. Coarse particles yield more caffeine in Arabica, while fine particles release more in Robusta, demonstrating the impact of grind size on caffeine extraction in coffee.

1. INTRODUCTION

Coffee is one of the world's commodities, cultivated in over 50 countries. The type of coffee that dominates the world coffee market is Arabica coffee (Coffea Arabica) by 70-80% because it has superior sensory properties compared to other types of coffee (Belitz et al., 2009). According to the International Coffee Organization (ICO), Arabica exports in 2021 reached 92.3 million bags and Robusta reached 75.7 million bags, while in 2022, Arabica coffee exports reached 94 million bags and Robusta reached 74.2 million bags (1 bag = 60 kg). Based on this data, global coffee consumers are increasingly making coffee the world's favorite drink (Pereira et al., 2019; Dong et al., 2017). The compounds in coffee include alkaloids (e.g., caffeine), chlorogenic acid, minerals, bases, aliphatic acids, lipids, carbohydrates (e.g., arabinose and sucrose), amino acids (tryptophan), and flavonoids (Garattini, 1993). The bitter taste of coffee is one of the effects of caffeine in coffee grounds and the stimulant effect of coffee. Consumption of excessive coffee (the maximum limit according to SNI 01-7152-2006 is 150 mg/day or 50 mg/serving) can have negative effects on consumers, such as anxiety, insomnia, and hypertension (Kerrigan, 2005). One of the contributing factors is the presence of caffeine in coffee. Nowadays, coffee-loving people prefer low-caffeine coffee. According to the US Food Drug Administration (FDA), the safe limit of caffeine consumption for adults is 400 mg/day, which is equivalent to four or five cups of coffee. Differences in standard maximum limits for caffeine consumption are adjusted to the conditions of society in each country. The maximum caffeine limit from the United States (FDA) standards is indeed higher than the standards set in several countries, including Indonesia. This is because, in the US, caffeine consumption through coffee, tea, and energy drinks is very common and has become part of the daily lifestyle. Therefore, the limits set may be higher to suit the consumption habits of the United States population. Meanwhile, in Indonesia, lower consumption patterns are more considered when setting safety limits, especially when considering different tolerance levels and health risks in the general public. The processing of coffee beans largely determines the caffeine content of coffee. Important factors in determining coffee quality are the processing method, geographical location, and climate where the coffee is produced. However, the final quality of coffee is still poorly understood based on these factors (Pereira et al., 2019). The processing of green coffee beans before marketing involves roasting, grinding, and brewing. The roasting stage is one of the most important processing stages because it involves heating, therefore affects the color, taste, aroma, chemical composition, and physical properties of coffee (Otsogile et al., 2022; Clarke, 1987), as well as the chemical composition of coffee. In addition to the roasting process, the grinding process is another important factor in the coffee brewing process because it produces different particle sizes, which affect the chemical composition of coffee (Herawati et al., 2019; Herna´ndez et al., 2008; Fujioka & Shibamoto, 2008; Doğan et al., 2019).

Coffee is usually marketed in powder (particle) form. The coffee particle size is an important physical property of powdered food products (Sharma, 2013). The coffee grinding process aims to reduce the particle size of coffee beans and change their physical properties. In the grinding process, the inner part of the coffee bean is opened or disassembled to optimize the extraction process. Commonly used particle sizes are coarse (841 – 2000 µm), medium (500 – 800 µm), and fine (100 - 400 µm). Many studies have been conducted on the effects of grinding size on coffee quality. Grinding size plays a key role in producing well-extracted coffee. The extraction is a process in which coffee grounds interact with hot water. The size of coffee particles affects the extraction rate of several chemical compounds. Fine extraction surface area increases the surface contact area between particles and the water, and increases the diffusion of chemical compounds into the solution (Severini et al., 2017; Cordoba et al., 2020). The results of this extraction affect the taste, aroma, and acidity of the coffee. Optimum extraction will produce delicious coffee drinks. The size of the coffee grounds is one factor that determines the extraction results because it influences the extraction time. Extraction that is too fast or too slow can produce an unbalanced coffee taste, such as bitter or sour (Angeloni et al., 2023). The preparation of high-quality brewed coffee drinks is also greatly influenced by the type of roast and extraction method, particle distribution, and surface area of particles in contact with the solvent (Doğan et al., 2019; Severini et al., 2017; Cameron et al., 2023; Cordoba et al., 2020). The choice of roasted coffee beans is based on the coffee brewing method that will be used (Cordoba et al., 2020) because it plays an important role in the physicochemical characteristics (pH, density, water content, and volatile compounds of the coffee beans) and the sensory characteristics of the coffee produced (Farah, 2012; Severini et al., 2017).

A recent review classified coffee extraction into the stew method (boiled), Turkish, percolator, and vacuum coffee (Cordoba et al., 2020). The most widely studied methods of brewing coffee are the espresso method (pressure), the filter method (infusion), and the boiling method. In the boiling method, most of the coffee extraction process is performed with hot water. However, the coffee-making trend still focuses on cold extraction. Based on the literature, the use of this boiling method is also influenced by the particle size of the coffee grounds, which affects the taste and caffeine content. For example, very coarse particle sizes are suitable for cold brew coffee and cowboy coffee-type boiling methods, while medium coarse particle sizes are suitable for chemical coffee-maker-type boiling methods, and fine particle sizes are suitable for the espresso method and mocha pot. The difference in the particle size determines the taste of coffee resulting from these methods. This study aimed to evaluate the effect of coffee powder particle size on the physical properties and caffeine content of coffee brewing by the boiling method. The coffee beans used were roasted at medium to dark levels (MTD) at temperatures of around 200 ^{o}C. The parameters studied were the coffee brew's viscosity, density, pH, and caffeine content. This is considered important because the coffee powder's size greatly affects the compounds' content, the surface's flow property, the taste of coffee after hot water brewing, and the health of coffee users.

2. METHOD

This research was conducted using samples of Arabica coffee (Luwak (mongoose), wine, honey), and Robusta that were roasted with medium to dark (MTD) levels at temperatures around 200°C. The coffee used comes from Central Aceh Regency, Gayo Highland, Indonesia. The density, viscosity, and pH (acidity degree) were measured. The caffeine content was identified using a FieldSpec4 Hi-Res Spectrometer. The physical and chemical properties were measured after being left for 1 day after the coffee brew preparation.

2.1 Coffee brew preparation

The coffee bean was ground using a blender between 30 to 60 s, followed by sieving with a sieve (CONTROLS) of 10 meshes restrained by 20 meshes (coarse: 841-2000 μm, with an average of 1420 μm) and pass of 30 meshes (fine: >595 μm). Next was brewing coffee grounds up to 92 °C. This temperature was chosen because, according to the Specialty Coffee Association of America (SCAA), it is the optimal temperature for boiling coffee, which provides ideal extraction for various chemical compounds that give good coffee taste and aroma. This process was carried out using a magnetic stirrer equipped with a temperature-measuring device. Where 1:18 was the ratio used for water and coffee grounds (18 grams of water for every one gram of coffee), according to SCAA, The next process was filtering using V60 paper. Figure 1 shows the process of making coffee brew using this study's boiling method.

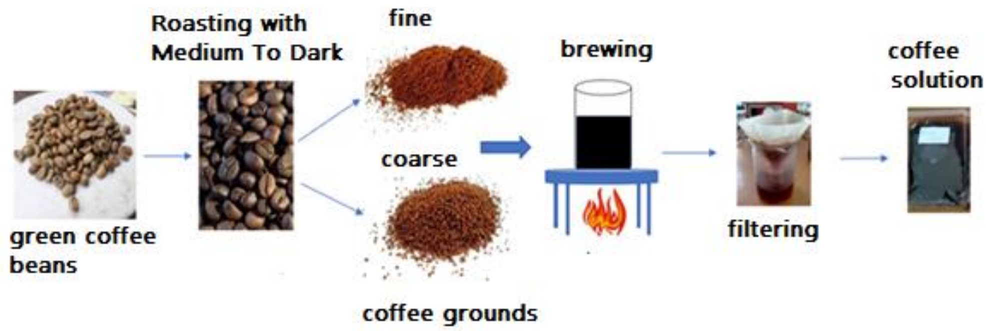

Figure 1 Coffee brew preparation using the boiling method was used in this study.

2.2 pH, Density, and Viscosity Characterization

The pH of coffee drinks was measured using a pH meter calibrated with a buffer for pH 7. The coffee brew density was measured using a pycnometer. 100 mL of coffee brew was introduced into the pycnometer and then weighed. The density of particles can be determined as the total mass of the solution divided by the total volume (g/cm^3) (Yüksela et al., 2020; NakilcioğluTaş & Ötleş, 2019; Ozguven & Vursavus, 2005; Herna´ndez et al., 2012). The viscosity measurement used a rotational viscometer (Thermo Scientific™ HAAKE™ Viscotester™ C). The viscometer uses the Searle principle, where the spindle rotates, and a stationary container contains the sample. The coffee brew was placed in a measuring cup suitable for samples up to 50 mL. Then, the spindle connected to the tool was inserted into the coffee brew. The tool was optimized by adjusting the spindle size and rotational speed of the spindle. Spindles have several sizes (levels 1, 2, 3, and 4). The size of the spindle is matched by how viscous the fluid is (where a thicker fluid requires a spindle with a higher level). The viscosity measurement data appears immediately on the display with cP units. All viscosity measurements of the four types of coffee brew with different grinding sizes were carried out using the same steps.

2.3 Chemical Compound

The spectrometer identified the caffeine content of coffee brew used to measure the infrared reflectance spectrum of coffee solution samples the FielsSpec4 Hi-Res spectrometer (Analytical Spectral Devices (ASD) Inc., CO, USA). These spectrometers can measure the reflection and transmission of electromagnetic waves interacting with materials. This tool is specifically designed to measure the spectrum of electromagnetic waves in the visible light interval, Near Infrared (NIR), and Short-Wave Infrared (SWIR), with wavelengths of 350-2500 nm. FielsSpec4 Hi-Res spectrometers can acquire spectra very quickly at 0.2 seconds per spectrum. The spectrometer is equipped with a high light source intensity used for VNIR reflectance spectra measurements (350–1000 nm) and two thermoelectrically cooled indium gallium arsenide (InGaAs) detectors to obtain SWIR reflectance spectra (1000–2500 nm). The reflectance spectrum of the sample (coffee brew) was measured using a 2 cm diameter ASD contact probe by inserting it into a 5 cm diameter sample container. A graph of spectral characteristics appears on the RS3 software, which is then stored according to the predetermined index number. The data from this measurement was used to detect the caffeine content in the coffee solution using ENVI 5.3 software.

3. RESULTS AND DISCUSSION

In addition to affecting the brewing method of coffee drinks, the content of steeping compounds of coffee solution also affects the physical properties of coffee brewing solutions. The physical characterization of the coffee brew in this study is shown in Table 1. The physical condition of coffee with medium to dark levels from Gayo has a darker color with little oil appearing on the surface of the beans. Table 1 shows that coffee ground particle size affects each physical parameter of the coffee.

Table 1 Physical Parameters of Gayo Arabica and Robusta Coffee solution in this study.

	Types of coffee							
	Arabica luwak,		Arabica wine		Arabica honey		Robusta	
	Coarse	fine	coarse	fine	coarse	fine	coarse	fine
pH	4.97	4.88	4.86	4.75	4.87	4.94	5.13	5.28
Density (g/mL)	0.990	0.991	0.990	0.991	0.987	0.991	0.990	0.992
Viscosity (cP)	1.8	1.5	1.8	1.6	2	1	2.3	1.7

3.1 pH of coffee solution

The pH of Arabica and Robusta green beans ranges from 5.26 to 6.11 and 5.27 to 6.13, respectively whereas if the effect of roasting rate is considered, the pH of Arabica and Robusta can vary between 5.45 to 5.12 and 5.49 to 5.32, respectively (Bicho et al., 2011; Bicho et al., 2012). This is consistent with research by Yüksela *et al* (2020), that roasting temperature is one factor that can lower pH. The decrease in pH in coffee beans can be influenced by changes in the content of compounds that occur during the roasting process. Based on Table 1, the pH measurement for Arabica and Robusta coffee brews is in the acidic region. The pH value of the Arabica coffee brew is lower than that of the Robusta coffee brew, ranging from 4.87 to 4.97. Figure 2 shows the pH measurement of other researchers. Abubakar et al. (2020) measured a mixture of Robusta with Arabica up to 30%. The present data is consistent that Arabica tends to be more acidic than Robusta.

Judging from the particle size of coffee grounds, the pH for Arabica coffee brew at coarse and fine sizes is different by about 0.1. For Robusta, the pH of the fine ground size is slightly higher than the coarse one. The difference in pH value is influenced by the particle size of coffee grounds and the organic acid content of coffee, such as carboxylic acid, acetic acid, malate, formate, lactic, chlorogenic, and quinic acid (Farah, 2012; Angeloni et al., 2023). If the particle size is fine, it has a larger surface area in contact with water during the boiling process than a rough surface area. This condition allows the water to easily extract chemical compounds from the coffee particles. Smaller coffee particles tend to be extracted more quickly because water can easily dissolve the compounds contained in coffee (Cardoba, et al., 2020). In addition, the method of brewing coffee also affects the solubility of chemical compounds contained in coffee grounds. Boiling temperature often significantly affects the solubility of compounds in coffee water. In this study, coffee brews were prepared using the boiling method at a temperature of 92 ^oC. At this temperature, the kinetic energy of water molecules is higher than at low temperatures, resulting in an increase in the rate of release of coffee layer compounds, dissolving and extracting organic compounds from the layers of coffee, such as chlorogenic acid and citric acid, as well as caffeine extracts organic compounds from the layers of coffee such as chlorogenic acid and citric acid, as well as caffeine which causes variations in coffee bitterness. According to previous research, an increase in the temperature gradient (88–93°C) results in an increase in caffeine, as well as for small, irregular particles to release their soluble content faster and produce a more concentrated coffee (Blittersdorff & Klatt, 2017), thereby affecting the acidity of the coffee brew. However, studies conducted by Andueza et al. (2003) reported no correlation between pH and perceived acidity in coffee.

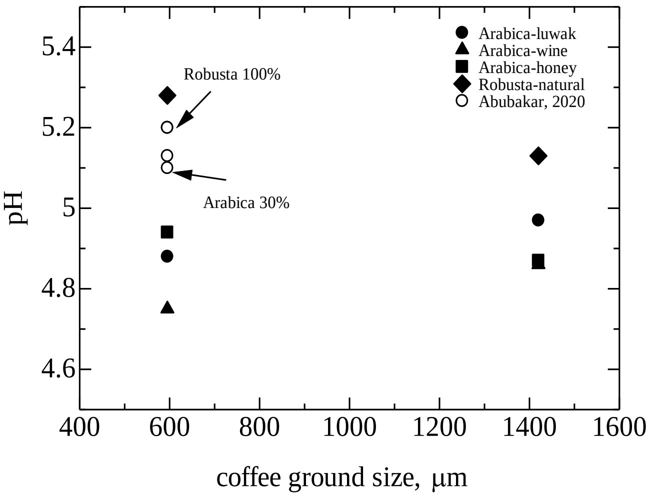

Figure 2 pH measurement of various Arabica and Robusta coffees brew.

3.2 Density

Density measurements were performed to determine the effect of particle size in the coffee solution. Based on the measurement results, the density value of the coffee brew (coarse and fine) was not significantly different for both coarse and fine particle sizes. Yusibani et al., (2023) measured the same sample as in the present study for green and roasted beans. The apparent density increases by about 0.1 g/ml from bean to coffee brew, as shown in the Figure. 3.

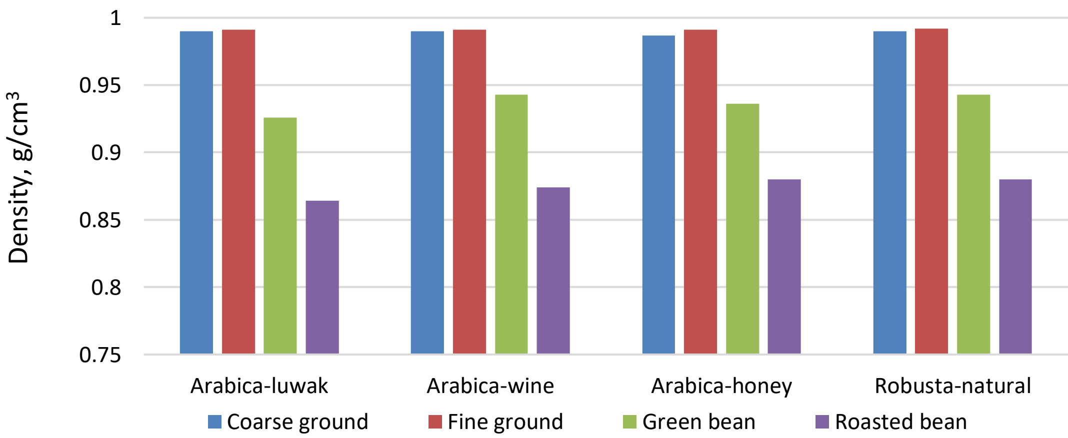

Figure 3 Density measurement of various Arabica and Robusta coffees brew.

3.3 Viscosity

Higher viscosity is believed to arise due to the presence of solid material suspended in the brewed coffee. This is in the form of fine particles of ground coffee that pass through a brewing filter. The viscosity value is expected to be directly proportional to density, so the lower the density, the lower the viscosity. However, in this study, the viscosity value was found to decrease with increasing density. This condition can be seen in Table 1, where there is a difference between viscosity values for coffee solutions derived from coarse and fine particle sizes, both for Arabica coffee and Robusta coffee. The highest viscosity is in Arabica and Robusta coffee brews, which come from coarse sizes and have relatively low densities. This shows that the influence of particle size on coffee grounds does not always make the coffee brew thicker, so the viscosity measurement value is not directly proportional to the value obtained when measuring density. Other research indicated that there was no dependence of treatment or particle size on the viscosity of coffee samples (Doğan et al., 2019; Sobolík et al., 2002). The viscosity is influenced by the protein content in coffee (Esteban-Diez, 2002).

3.4 Chemical analysis

The chemical composition of coffee brew is not only influenced by the roasting process (Doğan et al., 2019; Herna´ndez et al., 2008; Fujioka & Shinayono, 2008) but it is also influenced by the extraction method of the coffee brew (Cordoba et al., 2020). One of the compounds that indicate the quality of a coffee is caffeine content. Caffeine contained in coffee, in addition to having pharmacological effects that are clinically beneficial, such as stimulating effects, also has side effects for consumers. Therefore, several studies have considered the caffeine content in coffee beans both based on the roasting level and particle size of coffee grounds (Angeloni et al., 2023). Several steps must be carried out to identify the characteristics of the reflectance spectra of a sample. Some of them are associated with continuum removal. Continuum removal is a procedure used to normalize reflectance spectra to compare individual absorption features with a common baseline. The process separates or clarifies absorption features so that the spectral analysis process can be carried out easily and accurately (Clark & Roush, 1984). The continuum is the background absorption feature that acts as the basis for comparing the target features (Clark, 1999).

Figure 4 shows measurements from the present research. Runs 1 to 3 indicate reproducibility of the measurements over three samples. The spectrum of Robusta and Arabica includes peaks and valleys indicating the presence of chemical content in materials at certain wavelengths. The more interactions NIRS waves have with the chemical content of the material, the more these waves are absorbed by the material molecules so that more peaks and valleys are formed. This interaction indicates the number of NIRS waves hitting the molecules in the material. Typically, the fine spectrum is higher than the coarse one. The differences in the particle size of coffee grounds affect the release of bioactive and volatile compounds in coffee drinks (Angeloni et al., 2023). The Figure shows difficulties in observing the absorption spectra in the wavelength region of 1200 - 1294 nm, indicating the presence of caffeine compounds in the coffee (Ribeiro et al., 2011).

The caffeine compound in this study is observed at wavelengths of 1294 nm, 1287 nm, 1285 nm, and 1276 nm for Arabica (luwak, wine, honey) and Robusta, respectively (Figure 5). The caffeine content is at a wavelength of 1000-2495 nm (Barbin et al., 2014). The differences in peaks that appear at different wavelengths for various types of coffee are caused by differences in the composition of caffeine and the combination of other chemical compounds in each type of coffee. Furthermore, the Figure shows that the spectral form of Arabica coffee brew for fine and coarse particle sizes has the same typical peak with differences in the depth of absorption value. However, in contrast to Robusta brew, the results show that the depth of absorption for fine size is deeper than for coarse size. It is thought that its caffeine content is higher for fine size. A consistent finding from other studies is that caffeine content increases significantly with a decrease in particle size (Lingle, 1996; Spiro, 1993; Andueza et al., 2003; Bell et al., 1996; Angeloni et al., 2023; Doğan et al., 2019). The smaller the particle size, the more active the sample extraction process will be during the extraction process. Several factors can affect caffeine levels in coffee, including the roasting method and water temperature. Temperature greatly influences the level of caffeine in coffee because the higher the temperature, the more easily the caffeine dissolves so that more caffeine is extracted from the coffee grounds.

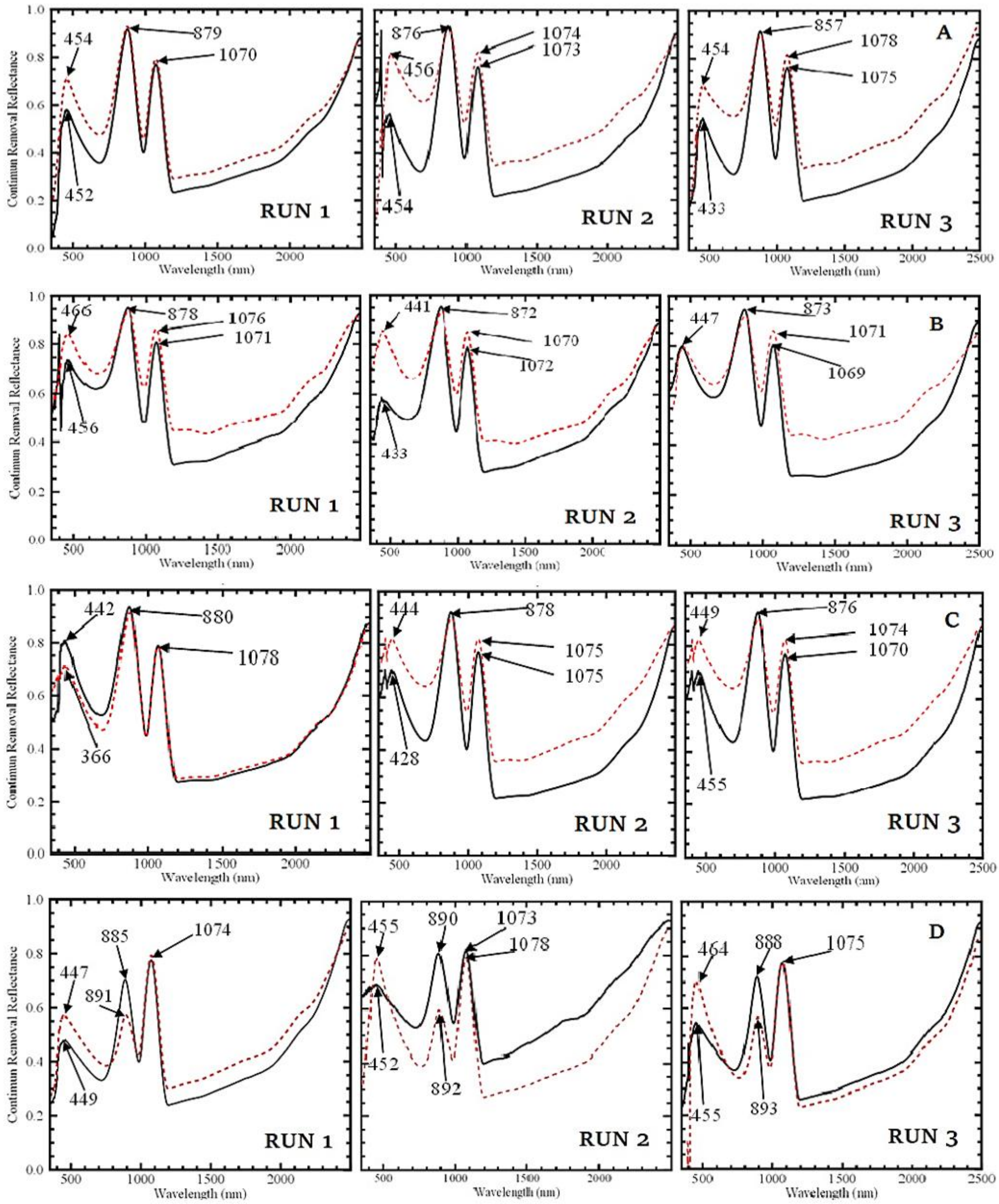

Figure. 4 Spectrum measurement for Arabica-Luwak (first row), Arabica-wine (second row), Arabica-honey (third row), and Robusta-natural (forth row). Red line is for fine and black line is coarse ground size.

Additionally, higher temperatures can increase extraction efficiency by speeding up chemical reactions that occur during the boiling process. In this study, coffee brew uses a temperature of 92 °C. This temperature is included in the high category, and therefore, the hot water dissolves and extracts many organic compounds from the roasted coffee powder. The ability to release caffeine content will also be different for different sizes of coffee grounds (Bell et al., 1996; Andueza et al., 2003).

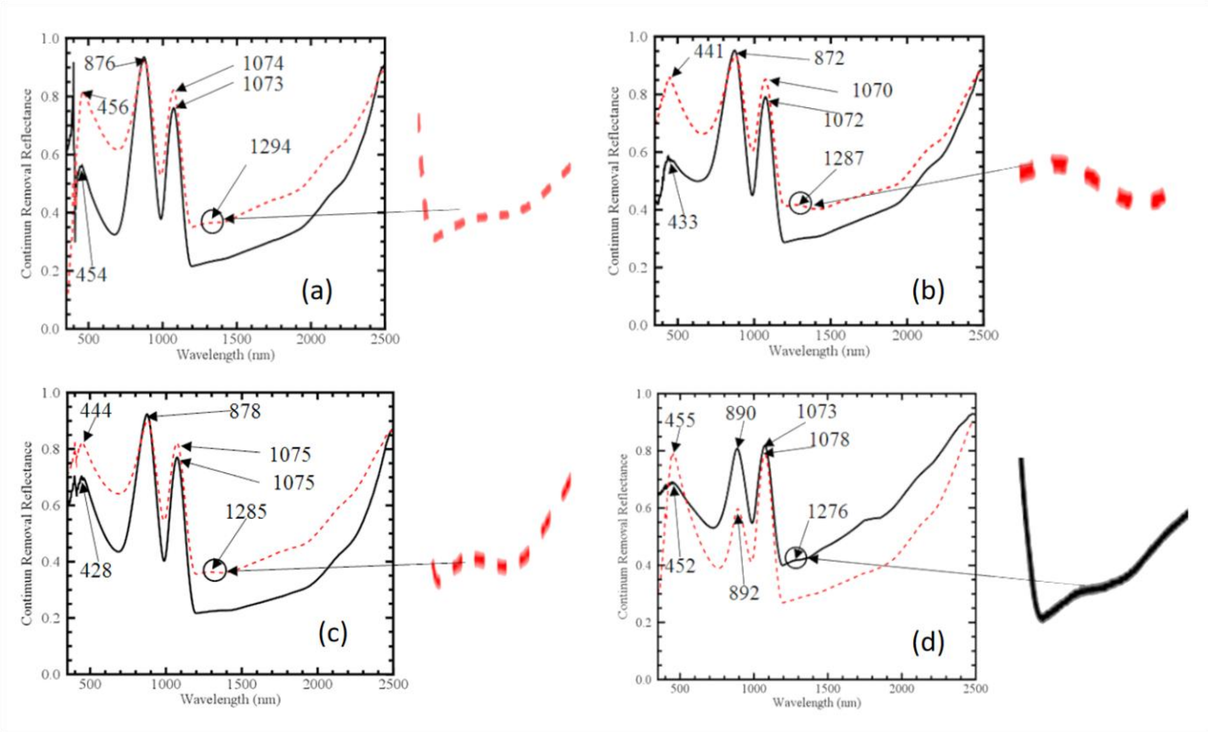

Figure. 5 Caffeine identification for (a) Arabica-Luwak, (b) Arabica-wine, (c) Arabica-honey, and (d) Robusta-natural, red line is for a fine and black line is coarse ground size.

4. CONCLUSION

The physical and chemical properties of gayo coffee (Arabica and Robusta) brewed by boiling with variations of particle coffee grounds have been studied. The brew composition of a 1:18 ratio of coffee to water is used, according to SCAA. The measurement shows the effect of fine and coarse coffee grinding on the physical in the form of pH value, density and viscosity, and chemical properties of Gayo coffee. The pH values for the Arabica coffee brew were lower than those of Gayo Robusta. The pH of Arabica coffee brew ranges from 4.87 to 4.97, and the pH of Robusta from 5.13 to 5.28. The density of coffee brew (coarse and fine) is not significantly different for both coarse and fine particle sizes; in all cases, it is in the range of 0.99 g/cm^3. Meanwhile, the viscosity coefficients are found to decrease with increasing density. In addition, the results showed that the caffeine content is released differently in the coffee brew, depending on the size of the particle. For Arabica coffee (Luwak, wine, honey), the spectrum of fine particles is higher than the coarse one, contrary to the Robusta coffee brew.

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