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Research Paper

Physical and Chemical Properties of Indonesian Coffee Beans for Different Postharvest Processing Methods

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Abstract

The purpose of this study was to identify the physical and chemical properties of Indonesian coffee beans for different postharvesting methods after being roasted. Several types of Indonesian export coffee, i.e., Gayo Luwak coffee, Wamena coffee, Toraja coffee, Gayo coffee, Flores coffee and Kintamani coffee, were used in the present study. Each coffee has its own aroma and taste according to the location, soil type, and land elevation. The roasting process started with preheating the roasting machine, after which the samples were roasted for about 15 minutes at 215°C to obtain the medium-to-dark (MTD) roasting level. The physical properties measured included density, mass loss, porosity, water content, and morphology using a scanning electron microscope. The transmittance spectrum was observed by Fourier transform infrared spectroscopy (FTIR). The physical properties of the coffee were successfully measured. The bulk density varied from 0.6 to 0.7 g/cm^3, and particle density was about 0.9 g/cm^3 for green beans. The roasting process reduced the bulk and particle density to 0.3 g/cm^3 on average and 0.8 g/cm^3, respectively. The fully-washed condition gave an overlapping spectrum for green and roasted beans, which shows that the roasting process did not affect the spectrum. The results can be used to study the coffee quality resulting from different postharvest processing methods.

Keywords: *coffee; Flores; roasted; Gayo Luwak; Gayo; Kintamani; Toraja; Wamena.*

Introduction

One of the leading export commodities from Indonesia are coffee beans, especially varieties that are considered specialty coffees, such as Gayo Luwak coffee, Wamena coffee, Toraja coffee, Gayo coffee, Flores coffee and Kintamani coffee. Each coffee has its own aroma and taste according to soil type, location, and land elevation. Luwak coffee is made from coffee beans that have been partially digested by civets. Wamena coffee comes from Papua, a province located in the central part of Papua Island, which is the easternmost part of the Indonesian territory of Papua. Toraja coffee is coffee that comes from the land of Toraja, South Sulawesi. Gayo coffee comes from the Gayo Highlands, Central Aceh, Indonesia. Kintamani Bali coffee is coffee produced from coffee plants grown in the Kintamani highlands at an altitude greater than 900 m above sea level [1].

The terminology for coffee samples distinguishes coffee cherries (ripe fruit), green beans (coffee after postharvest processing), and roasted beans (coffee after the roasting process). Based on the number of bean segments, there are two types of coffee beans. The first can be described as polyembryonic (dicotyledonous), which is the most common type. It has a convex surface on one side and is flat on the other. The other type is called peaberry (monocotyledonous), which is a type of coffee bean with a single bean segment, but it does not belong to a particular variety of coffee plant [2,3]. Clifford et al. [4] found that the processing method used affects the quality of the coffee beans. Based on their classification for processing techniques, postharvest coffee cherries can be categorized as follows:

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1. Natural/dry method: This is a simple, inexpensive, ancient, and traditional method most often used by farmers.
2. Washed/wet method: Three processing stages distinguishes this from dry processing: peeling the skin from the cherry fruit (pulping), fermentation, and washing for about 12 to 48 h to remove mucus [4]. Fermentation as part of the wet processing method aims to reduce the mucilage layer of the coffee fruit. It is carried out over shorter periods (<36 h) and is able to improve quality without damaging the coffee bean layer [5].
3. Honey (pulped natural): The process of producing honey type coffee is a combination of the natural and washed methods. This method is called 'honey' because in the process it produces coffee beans that are sticky like honey.
4. Wine (fermented): This type of coffee has a unique taste and a wine aroma due to the fermentation process. According to the experience of farmers, coffee that is processed as coffee wine must be grown over 1500 m above sea level, because the higher it is grown, the more sap the coffee cherry has.

Based on the rating level of the cupping test rubric referring to the Specialty Coffee Association of America (SCAA), the following two types of coffee beans are distinguished: (a) specialty – primary defects 0%, secondary defects maximum 5%, moisture content 10-12% and cupping test value above 80; (b) premium – cupping test value 70-80.

Many researchers have investigated the physical properties of coffee beans with different roasting degrees. These properties include the pore structure [6], the effect of moisture and water activity [7], coffee bean processing [8], engineering properties [9], density changes during storage [10], volatile compound profiles [11], quantification and evaluation of selected coffee bean shape and size [12], and temperature to achieve different roasting degrees [13,14]. Most researchers agree that the physical properties of coffee beans will change after roasting [15-17].

The objective of the present study was to evaluate the physical and chemical properties of coffee beans with variation of variety and postharvesting method. This fundamental data is important for food science and process control, since there are various postharvesting methods that can be conducted to obtain a cup of coffee. The physical properties evaluated in the present study were: weight loss, porosity, mass density, morphology, and water content for different Arabica coffee sample locations in Indonesia. Fourier transform infrared (FTIR) spectroscopy was used to characterize the bean compounds for the different postharvesting methods.

Methodology

The independent variables in the present research were: (a) Arabica coffee bean sample (Gayo Luwak coffee, Wamena coffee, Toraja coffee, Gayo coffee, Flores coffee and Kintamani coffee); (b) postharvest processing method of Gayo coffee (fully-washed, semi-washed, specialty, premium, honey, wine, peaberry, and natural); and (c) roasting method (medium-to-dark (MTD)). The dependent variables of the present research were: density, porosity, weight loss, water content, morphology, and transmittance spectrum. The results of the measurements are presented as the mean of three measurements ± standard deviation (SD).

Sample and Roasting Process

The coffee samples used for the experiment were obtained from various provinces in Indonesia, i.e., Gayo and Gayo Luwak coffee (obtained directly from Bener Meriah, Aceh), Wamena coffee, Toraja coffee, Gayo coffee, Flores coffee and Kintamani coffee (supplied from Worcas Coffee, Jakarta). The coffee cherry samples were prepared with different postharvest processing methods: fully-washed, semi-washed, specialty semi-washed, premium semi-washed, honey, wine, peaberry semi-washed, and natural. The roasting process started with preheating the roasting machine (NOR A3000i) and then setting the temperature to 215 °C. About one kilogram of green coffee beans were inserted into the roasting machine for about 15 minutes to obtain a medium-to-dark (MTD) roasting level.

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Density Measurement

Density measurements were carried out in two ways, namely bulk (ρ_{bulk}) and particle density ($\rho_{particle}$). Measurement of particle density was done by inserting 50 g of coffee beans into a pycnometer of 100 ml and then filling it with toluene. Bulk density measurement was done by weighing the mass of coffee beans in a measuring cup of 10 mL. These methods together with Eq. (1) have been used to calculate the density of coffee and other food products [13,18-20].

$$\rho = m/v \tag{1}$$

Weight Loss

Weight loss (W) was measured by weighing 50 g of coffee beans before (w_i) and after roasting (w_f). The roasting temperature to evaluate a weight loss was set at 242 C for 13 minutes while the sample was placed in the roasting machine (Gene Café). The calculation used Eq. (2) [21].

$$W = \frac{(\mathrm{Wi} - \mathrm{Wf})}{Wi} \times 100\% \tag{2}$$

Water Content

Water content was measured by measuring the change in mass of 5 g of coffee beans after being heated in an oven for 16 h at a temperature of 105 C (SNI 01-2907-2008). The water content was calculated using Eq. (3) [22]. In this equation, m_o is the weight of the cup and lid, and m_1 and m_2 are the combined weight of the cup, the lid, and the coffee sample before and after drying, respectively.

$$\%\text{water content} = \frac{(m_1 - m_2)}{(m_1 - m_0)} \times 100\% \tag{3}$$

Porosity

The porosity of the beans was calculated from the bulk and particle densities. Thus, the porosity could be calculated using Eq. (4) [13,23].

$$\%porosity = \frac{\rho_{particle} - \rho_{bulk}}{\rho_{particle}} \times 100\% \tag{4}$$

The morphology of the samples was obtained using a scanning electron microscope (SEM – JEOL 6510 LA). The raw and roasted coffee beans' transmittance spectra were analyzed using Fourier transform infrared spectroscopy (FTIR) (IRPrestige-21, Shimadzu).

Results and Discussion

The samples were processed to a medium-to-dark (MTD) roast level. MTD roast has a darker color and less visible oil on the surface of the seeds. MTD roast has many differences compared to light or medium roast. The MTD roast process is the initial phase of the second crack or the middle of the second crack. The MTD roast process applied to the present samples used a temperature of 215 C (Figure 1).

Table 1 shows the bulk and true density measurement results. Table 2 shows the porosity, water content, and weight loss measurement values. After the roasting process, the density of each coffee bean decreased by 6 to 8%. The weight loss was 11 to 23%. The porosity of the samples before and after roasting increased from 33 to 45 %. The water content of the samples (green beans) was less than 12% (Standard Nasional Indonesia, SNI) and less than 13% based on ASEAN STANDARD (ASEAN STAN 31:2013) [24] requirements. The water content variation ranged from 5 to 11%. The maximum water content for green beans was 11% for the Wamena, Kintamani, and Toraja coffee beans. Thus, the roasting process caused a decrease in the weight of the coffee samples related to the initial water content.

Figure 1 Medium-to-dark (MTD) roasted samples from this study (left to right: Flores, Wamena, Toraja, Kintamani and Gayo Arabica).

Table 1 Bulk and true density measurements.

Type	Green Bean Density (g/cm^3)		Roasted Bean (g/cm^3)	
	Bulk	True	Bulk	True
Arabica Wamena semi-washed	0.707±0.002	0.926±0.001	0.324±0.001	0.857±0.001
Arabica Kintamani semi-washed	0.665±0.001	0.923±0.001	0.335±0.001	0.854±0.001
Arabica Flores fully-washed	0.707±0.001	0.926±0.001	0.326±0.001	0.862±0.002
Arabica Toraja semi-washed	0.730±0.001	0.926±0.001	0.285±0.001	0.853±0.002
Arabika Gayo Luwak	0.711±0.001	0.926±0.001	0.299±0.001	0.864±0.001
Arabica Gayo Premium, semi-washed	0.686±0.001	0.927±0.001	0.315±0.002	0.856±0.003
Arabica Gayo Specialty, semi-washed	0.704±0.001	0.930±0.004	0.332±0.000	0.861±0.003
Arabica Gayo natural	0.695±0.001	0.925±0.027	0.332±0.001	0.864±0.001
Arabica Gayo Peaberry semi-washed	0.686±0.002	0.928±0.004	0.295±0.000	0.858±0.001
Arabica Gayo fully-washed	0.685±0.001	0.928±0.006	0.313±0.001	0.858±0.004
Arabica Gayo Wine	0.720±1.156	0.943±0.001	0.324±0.001	0.874±0.001
Arabica Gayo Honey	0.697±0.001	0.936±0.001	0.294±0.001	0.880±0.001
Gayo Robusta	0.707±0.0	0.943±0.001	0.281±0.001	0.880±0.001

Table 2 Water content, weight loss and porosity measurements.

Type	Water content (%)	Weight loss (%)	Porosity (%)	
			Green bean	Roasted Bean
Arabica Wamena semi-washed	11	15.07	24	62
Arabica Kintamani semi-washed	11	23.12	28	61
Arabica Flores fully-washed	10	17.16	24	62
Arabica Toraja semi-washed	11	18.31	21	67
Arabika Gayo Luwak	8	19.30	23	65
Arabica Gayo Premium, semi-washed	10	16.10	26	63
Arabica Gayo Specialty, semi-washed	8	14.35	24	61
Arabica Gayo natural	8	18.88	25	62
Arabica Gayo Peaberry semi-washed	8	13.98	26	66
Arabica Gayo fully-washed	7	18.86	26	63
Arabica Gayo Wine	6	11.84	24	63
Arabica Gayo Honey	5	18.86	26	67
Gayo Robusta	8	14.01	25	68

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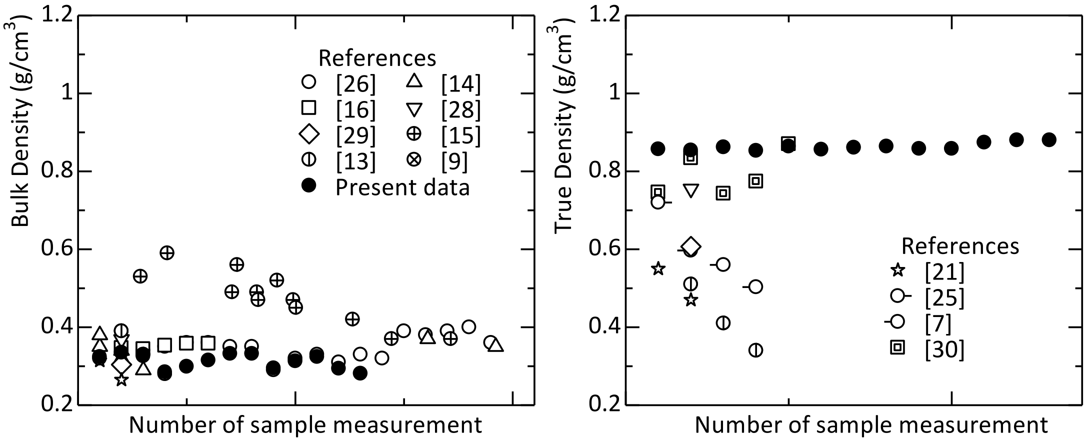


Figure 2 Density measurement: bulk and true density after roasting.

Bulk density shows the volume ratio between the coffee beans' weight and volume, including pores. Thus, the bulk density shows the packing density of the coffee beans. True density and bulk density are related, since the denser a coffee bean, the higher the value of bulk density (if porosity is constant). The bulk densities from the present data are in good agreement with the findings of other researchers [7,9,13-16,21,25-29], with the highest discrepancy around 20%, as shown in Figure 2. The data presented in Figure 2 was measured with variation of time and temperature roasted. For example, the data from Ref. [15] was measured with roasting times of 7 to 40 min and a roasting temperature of 170 °C (light roast degree). This data was slightly higher in the beginning (roasting time 7 min) and then went down to 0.37 g/cm^3 (roasting time 40 min). Table 1 shows that the bulk density of the beans had decreased after roasting. Particle density is the density of a material excluding its pores, and therefore is a function of liquid content and type of solid. This means that material moisture content significantly affects particle density. The amount can be as much as 50 to 61%.

Figure 3 shows the weight loss percentage after roasting. The porosity and water content contribute to the weight loss. The roasting process also causes some of the coffee bean constituents to be converted into volatile compounds and gases are released [27]. The present data give a higher value of weight loss due to high-temperature roasting in a short time. Kintamani coffee had the highest weight loss for the same roasting condition, whereas Arabica Gayo wine had the lowest weight loss.

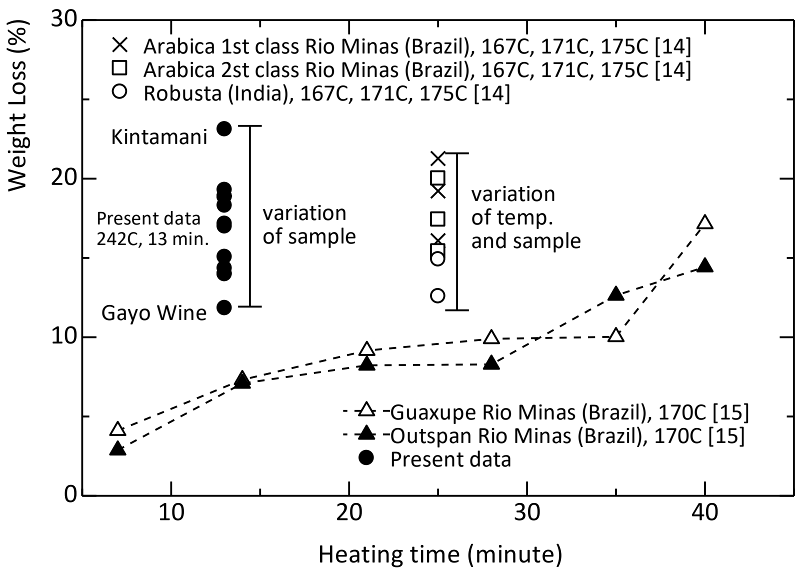


Figure 3 Weight loss measurements after roasting compared to other researchers.

Porosity measures the cavities in a material and is calculated by the fraction of the cavity volume to the total volume. In the present study, we used particle and bulk density to measure the porosity [30]. Our data shows that the porosity after roasting was relatively higher than found by other researchers, as shown in Figure 4. This behavior is related to the degree of roasting. For example, green beans with a light degree (low temperature roasting) gives a lower value than the MTD degree that is consistent with the present data. Table 1 shows that the porosity increased after the roasting process. The value was more than three times compared to that of the green beans, which is consistent with Ref. [31].

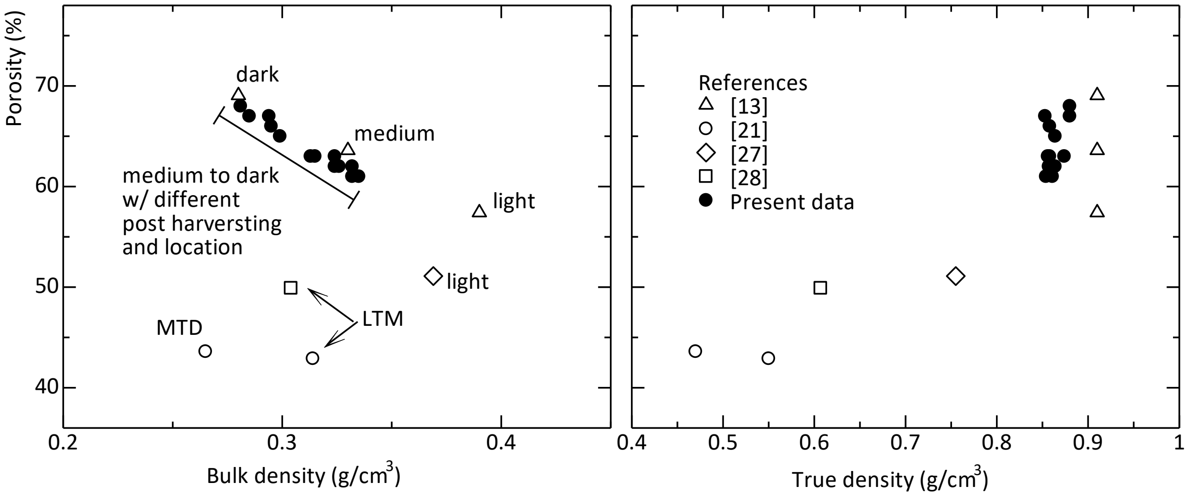


Figure 4 Sample porosity.

Table 3 shows the morphology measurements by SEM. Overall we can see that the bean pore size after roasting increased. This is consistent with the porosity, which can increase after roasting by about 33 to 45% [6]. After the roasting process, the surface of the beans looks smoother than that of the green beans. This happens because coffee beans contain lipid embedded in the cytoplasm of the coffee bean cells in an oil film along the cell walls. The roasting process damages the coffee cell walls and releases the oil onto the surface. The oil release results from the gas pressure coming out of the coffee beans due to the roasting process. In the case of Kintamani coffee, it can be seen clearly in Table 3 that there was oil migration to the surface due to the roasting process [32].

Table 3 Morphology measurements by SEM.

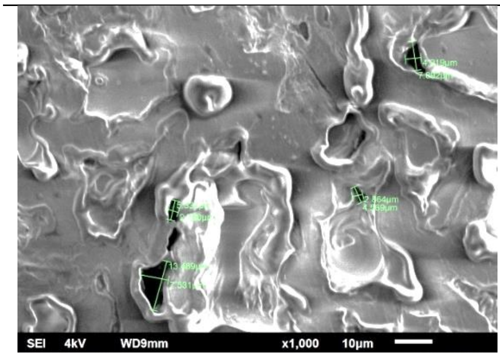
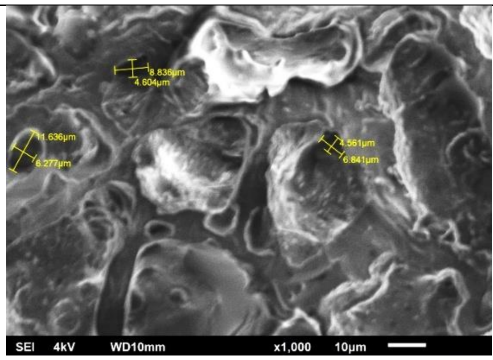
Green bean	**Roasted bean**
Toraja	
	

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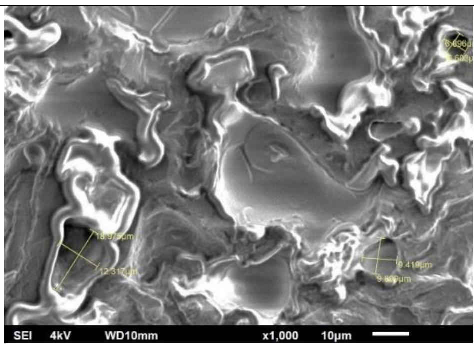
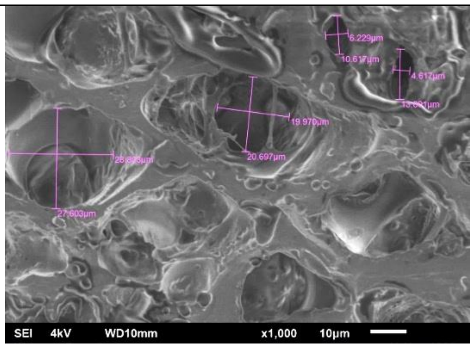
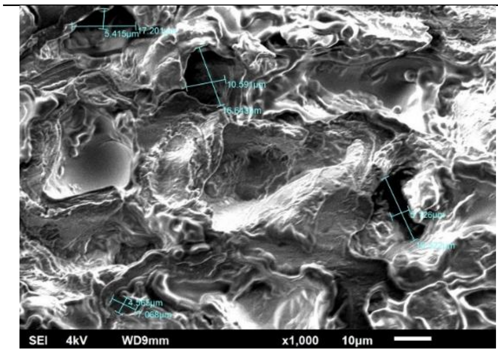
Table 3 Continued. Morphology measurement by SEM.

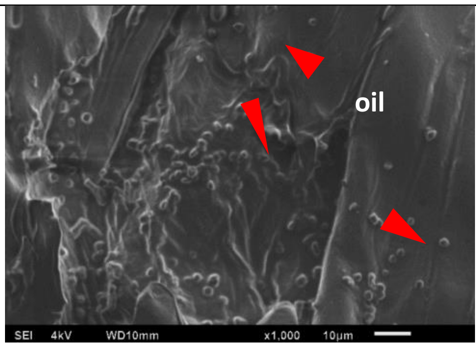
Wamena



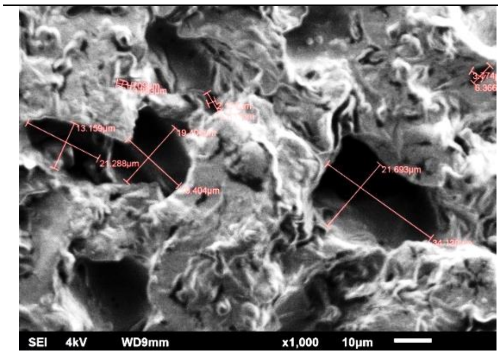


Kintamani





Flores



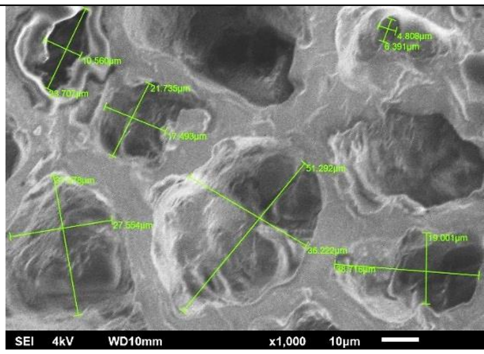


Figure 5 shows the transmittance spectra for Gayo coffee with different postharvesting conditions before and after roasting. In general, the data shows that the transmittance spectrum of the roasted beans was lower than that of the green beans. Gayo with natural processing gave a lower transmittance spectrum and premium processing resulted in a higher spectrum after the roasting process. Fully-washed gave an overlapping spectrum for the green beans and the roasted beans, which means that the roasting process did not affect the spectrum. This result is consistent with solid-state NMR data of green and roasted coffee beans from Indonesia [33].

The region of 1800-1680 cm^{-1} (Figure 6) is the carbonyl (C═O) region in the Gayo coffee sample. This region indicates the difference in the types and concentrations of aromatic acid (1700-1680 cm^{-1}), vinyl ester and lactone (1780-1762 cm^{-1}), aldehyde (1739-1724 cm^{-1}), aliphatic ester (1755-1740 cm^{-1}), aliphatic acid (1714-1705 cm^{-1}), and ketone (1725-1705 cm^{-1}) compounds in the sample [34]. The down band at around 1742 and 1743 cm^{-1} was also observed in the FTIR studies of the present samples as a region of aliphatic esters [35,36,37]. Kemsley *et al.* reported that the band at 1744 cm^{-1} was larger in Arabica in comparison to Robusta samples [35]. Caffeine content was estimated as standard and the samples corresponded to an absorbance band of around 1700-1600 cm^{-1} [36,38,39]. From the graph, it can be seen that the transmittance spectrum at around 1655 cm^{-}

[1] (caffeine band) was lower for the natural process, and relatively similar for peaberry semi-washed, full-washed, specialty semi-washed, and Gayo luwak, and relatively high for the premium semi-washed process. It is suggested that the concentration of caffeine was relatively lower for the premium semi washed coffee roasted beans, however this must be confirmed with additional data.

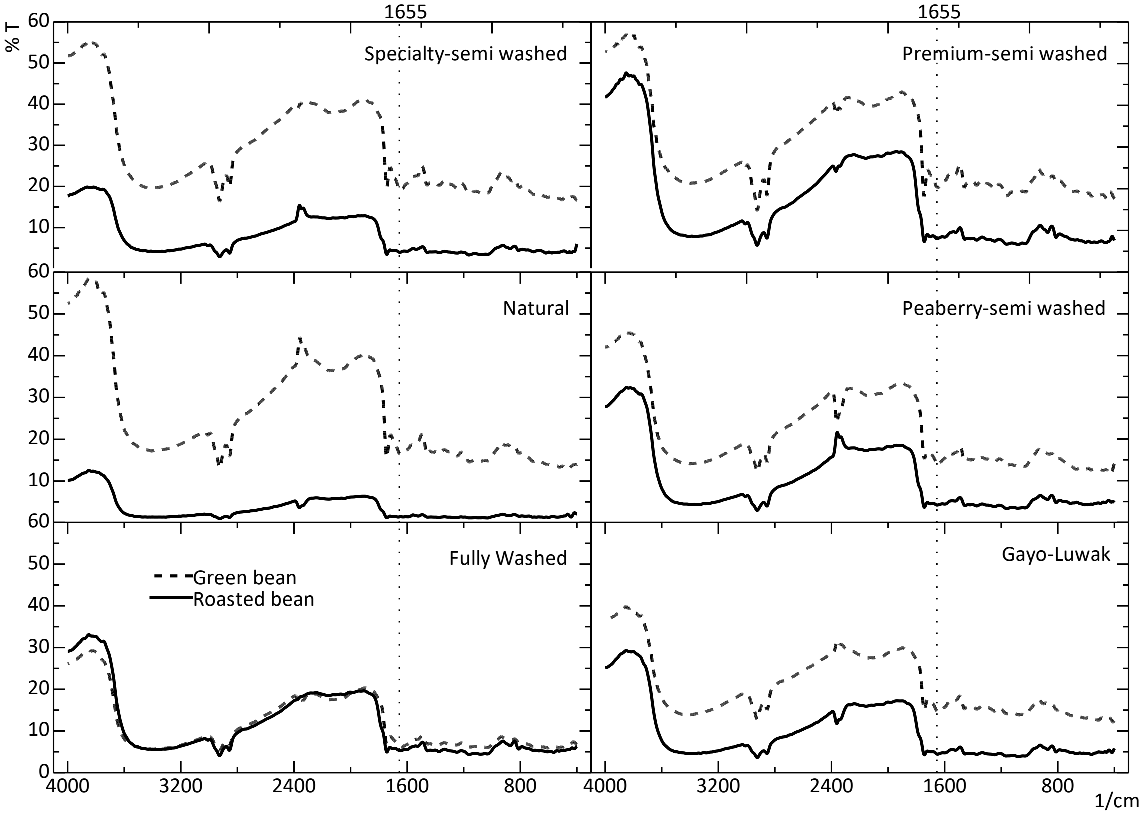


Figure 5 Transmittance spectra of Gayo coffee before (dashed line) and after roasting (solid line) for different postharvesting conditions.

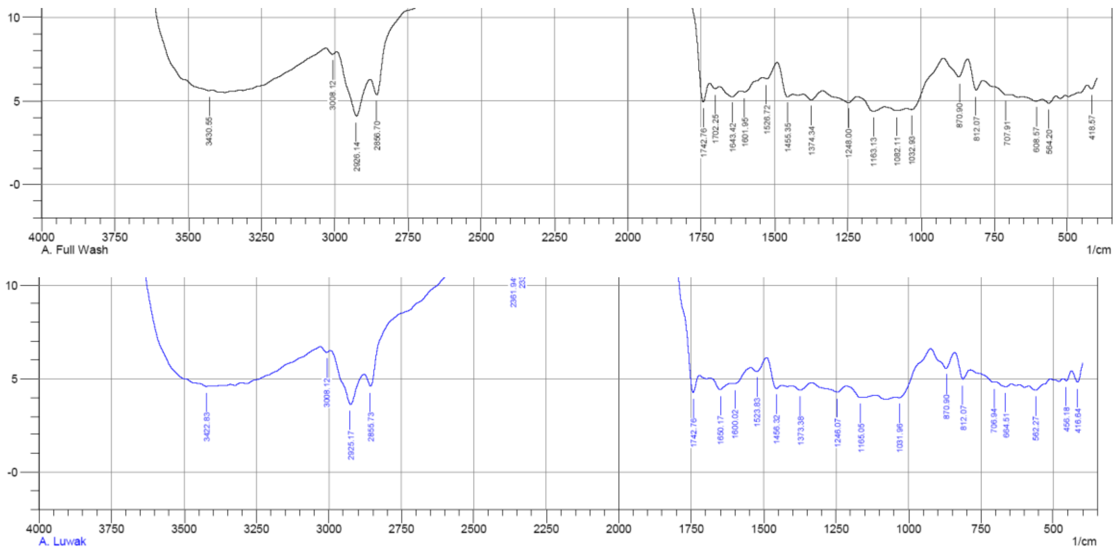


Figure 6 The spectrum of 2000-1500 cm^{-1} fingerprints region of the Gayo coffee sample.

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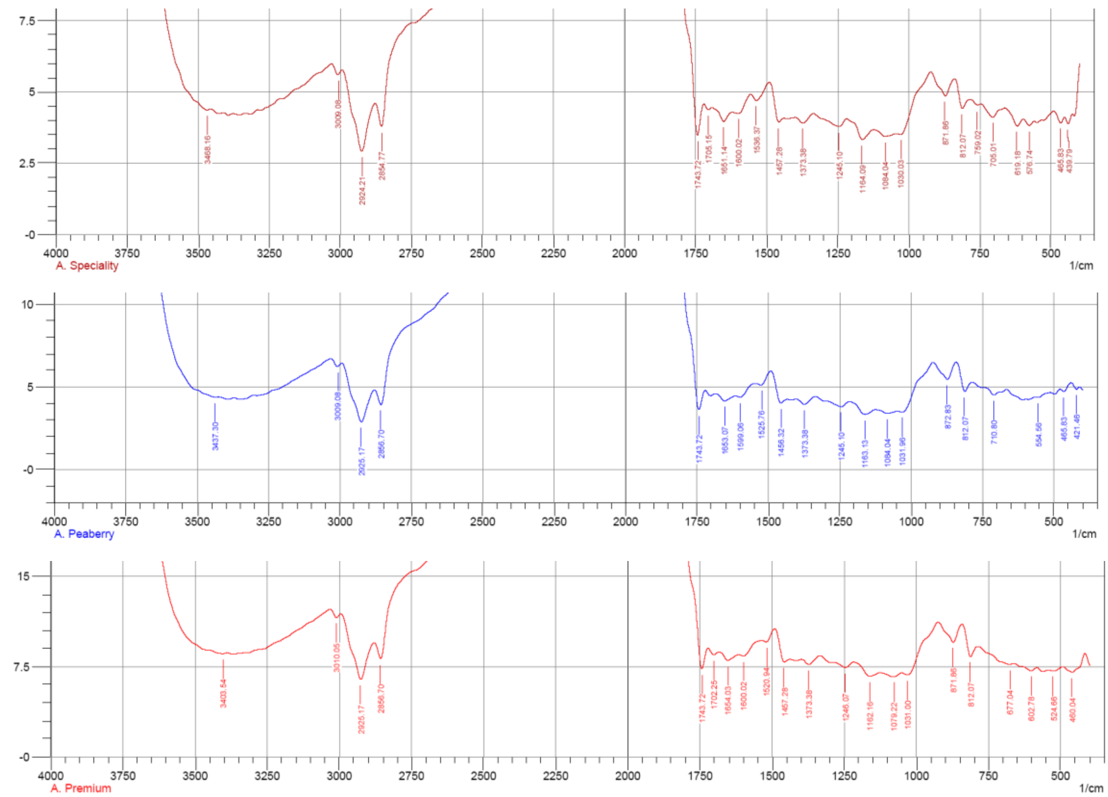

Figure 6 Continued. The spectrum of 2000-1500 cm^{-1} fingerprints region of the Gayo coffee sample.

Conclusion

The physical and chemical properties of Indonesian coffee beans with different postharvesting treatments were successfully measured. The bulk density varied from 0.6 to 0.7 g/cm^3, and particle density was about 0.9 g/cm^3 for the green beans. The roasting process influenced the bulk and particle density, resulting in 0.3 g/cm^3 on average and 0.8 g/cm^3, respectively, for the roasted coffee beans. The density of the coffee mass is inversely proportional to its porosity – the greater the density value of the coffee beans, the lower the porosity of the coffee. The morphology of the sample follows the porosity. The various postharvesting methods not only influenced the coffee beans' physical properties but also their chemical property characteristics. However, the fully-washed treatment gave an overlapping spectrum for green and roasted beans, which means the roasting process did not affect the spectra.

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