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THE EFFECT OF TEMPERATURE AND ROASTING TIME ON THE PHYSICAL PROPERTIES OF ARABICA AND ROBUSTA GAYO COFFEE BEAN

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Abstract*. The effect of variations in temperature and roasting time on the physical properties of coffee beans originating from the Gayo highlands with Arabica and Robusta types have been studied in this paper. Physical properties measured include weight loss, true density, porosity, and water content. The measurement procedure follows Standard Nasional Indonesia (SNI) 01-2907-2008. Three roasting levels were used in this study, i.e., Light Roast (159 -164 °C), Medium Roast (211 - 215 °C), and Dark Roast (above 232 °C) by an oven. The result showed that the weight loss for Arabica and Robusta coffee beans is from 11 - 19% and 14 - 29%, respectively. The true density for Arabica and Robusta coffee beans ranged from 0.905 - 1.085 g/cm^3 and 0.950 - 1.156 g/cm^3, respectively. The difference in porosity changes before and after roasting was 23 - 73% for Arabica and 33 - 68% for Robusta coffee beans. Meanwhile, the water content of Arabica and Robusta coffee beans after roasting is 0.7 - 5% and 0.6 - 6%, respectively. The value of the weight loss, true density, and water content of Arabica is lower than that of the Robusta coffee bean, while the porosity value of Arabica is higher than that of the Robusta coffee bean.*
Keywords: arabica; coffee; density; porosity; robusta; roasting

1. Introduction

Based on data from the International Coffee Organization (ICO) in 2020, Indonesia became one of the largest coffee producers, with total production reaching 11,950 in a thousand bags (60 kg per bag), which is the second largest after Vietnam in Asia and Oceania (International Coffee Organization, 2020). Aceh is one of the largest coffee-producing provinces in Indonesia. One of the coffee originating from Aceh is Gayo coffee which grows in the tropical climate region of Central Aceh. Gayo coffee is well known among Aceh residents themselves, Indonesians, and managed to pocket several international certificates. Coffee plants that are widely consumed by this community, come from the family Rubiaceae, genus Coffea (Najiyati & Danarti, 2004). More than 80 species of coffee have been identified worldwide (Clarke, 2013), however, there are only two famous, i.e. Coffea Arabica (70% of the global coffee market) and the rest Coffea Canephora or Robusta coffee. The quality and the flavors of these two coffees are continuously improved through the selection of plant breeding and varieties as well as better agricultural practices (Hidayat *et al*., 2020; Yusdiali, 2008; Fadri *et al*., 2020). Additionally, the distinctive aroma of coffee can be an attraction for coffee connoisseurs. This aroma is usually developed during the roasting process, which is divided into three stages: drying, roasting, and cooling (Santoso *et al*.,

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2018). During this stage, the coffee beans will undergo a series of reactions that lead to changes in chemical and physical properties (Chu, 2012; Agustini, 2020; Lyman *et al*., 2003; Wang *et al*., 2011; Fadri *et al*., 2019; Ifmalinda *et al*., 2019; Bicho *et al*., 2013). Therefore, the roasting stage becomes the most important stage and it must be controlled properly to avoid excessive roasting that can change the quality of the coffee taste. Research on the physical properties of coffee beans has been conducted by many researchers (Schenker & Rothgeb, 2017; Severa *et al*., 2012; Sunarharum *et al*., 2018; Yuwana *et al*., 2015). Pre and postharvest processing practices are among the factors that can affect the physical quality of green and roasted coffee beans (Ameyu & Mechara, 2016; Yusibani *et al*., 2023). The aroma formation and physical properties in coffee are considerable differences at a high temperature with a short time and at a low temperature with time conditions (Baggenstoss *et al*., 2008). The physical properties of the coffee show have dependencies on its type and class and roasting conditions (Baggenstoss *et al*., 2008a). Elevated roasting temperature causes water activity to decrease (Odžaković *et al*., 2019). In evaluating the level of coffee roasting, most coffee roasting companies still rely on highly experienced roasting masters, but only look at sensory aspects such as color and aroma. While in the coffee roasting process there is also a complex heat transfer event, coffee beans experience a decrease in water content, increased volume, and decreased density that needs to be considered. Research revealed that humidity and changes in density can affect the mechanical properties of coffee beans during roasting, which affects the taste and aroma of coffee (Jokanović *et al*., 2012). Additionally, Edzuan *et al.* (2015) attempted to identify the decreased mass density, surface temperature, and spectral characteristics of Arabica coffee beans to determine the optimal roasting period.

Based on the description above, it is important to identify the physical properties of Gayo Arabica and Robusta coffee beans after the roasting process as one of the important products originally from Aceh, Indonesia. Identification includes elevated time and temperature to the physical properties. The properties to be studied include water content, true density, weight loss, and porosity. The study is focused on the effect of variations in roasting temperature on the physical properties of Arabica and Robusta Gayo coffee beans and the behavior of the properties with variations in roasting time.

2. Methods

The samples were obtained by a direct visit to the coffee plantation area located in Timang Gajah District, Bener Meriah Regency of Aceh Province. This direct visit was performed in addition to getting a good sample and seeking information from local farmers about the process of planting or processing Gayo coffee. The sample used in this study was the coffee cherry that is late ripe, characterized by the skin color of the fruit already red. Two processing methods were

performed as a post-harvesting of the coffee cherry sample in producing coffee beans in small or large quantities, i.e. dry processing and wet processing. In this study, a semi-wash processing method was applied. The coffee cherry harvested was spread on a clean dryer floor, giving a base for drying. The time required in the drying process ranged from 21-28 days. It is highly dependent on weather, fruit size, maturity level, and moisture content in a coffee cherry. Drying is the processing stage that most affect the taste, this misconduct process will damage the physical quality and taste of the final steeping. The drying method depends largely on the type of coffee (Arabica or Robusta) and the condition of the coffee beans before they are dried. The purpose of drying is to decrease the water content of coffee beans from 60 - 65% to 12 - 13% so that the quality and taste of coffee beans are not damaged during storage. The homogeneity and selection of the coffee bean sample follow SNI 01-2907-2008.

The green beans were roasted using an oven with a direct heater. The three roasting levels used in this study, i.e., Light Roast (159 -164 °C), Medium Roast (211 - 215 °C), and Dark Roast (above 232 °C) by an oven (Nabertherm). The roasting time ranged from 5 to 45 minutes. The physical properties analyze in this study are density (ρ, g/cm^3), weight loss (W_T, g), water content, and porosity. Equations (1) to (4) are used in this study. The pore size distribution was measured by Scanning Electron Microscope-Energy Dispersive Spectroscopy (SEM-EDS, Thermofisher).

$$\rho = \frac{m}{v} \quad (1)$$

$$W_T = \frac{(W_i - W_f)}{W_i} \times 100\% \quad (2)$$

$$\%\text{Water content} = \frac{(m_1 - m_2)}{(m_1 - m_o)} \times 100\% \quad (3)$$

$$\%\text{Porosity} = \frac{Mb - Mk}{vb} x \frac{1}{\rho} x 100\%$$
$$\%\Delta P = \%P_{ar} - \%P_{br} \quad (4)$$

where m (g) and v (cm^3) indicate the coffee bean's mass and the water volume, respectively. W_i (g) and W_f (g) indicate the initial coffee bean mass before and after the roasting process (Rodrigues *et al*., 2002). To measure water content, we measured the cup and lid weight (m_o, g), the cup, the lid, and the coffee sample weight before drying (m_1, g), and after drying (m_2, g). To measure a porosity, we must measure the coffee bean wet-mass (M_b, g), the coffee bean dry-mass (M_k, g), and the coffee bean volume (v_b, cm^3). P_{ar} and P_{br} indicate the porosity after and before roasting, respectively, and it used to measure the porosity difference (ΔP, %).

3. Results and Discussion

Figure 1 shows the pore size distribution of Arabica and Robusta green coffee beans by SEM-EDS. The figure shows that the Arabica green bean has a bigger pore compared (max to 29.3 µm) to Robusta (max to 25.1 µm). This pore size distribution affects the density of the sample. The figure shows that the Gayo Robusta density will have relatively higher compared to Gayo Arabica according to the pore size distribution. According to previous researchers (Odžaković *et al*., 2019; Schenker *et al*., 2000), the volume of a green bean will increase after the roasting process.

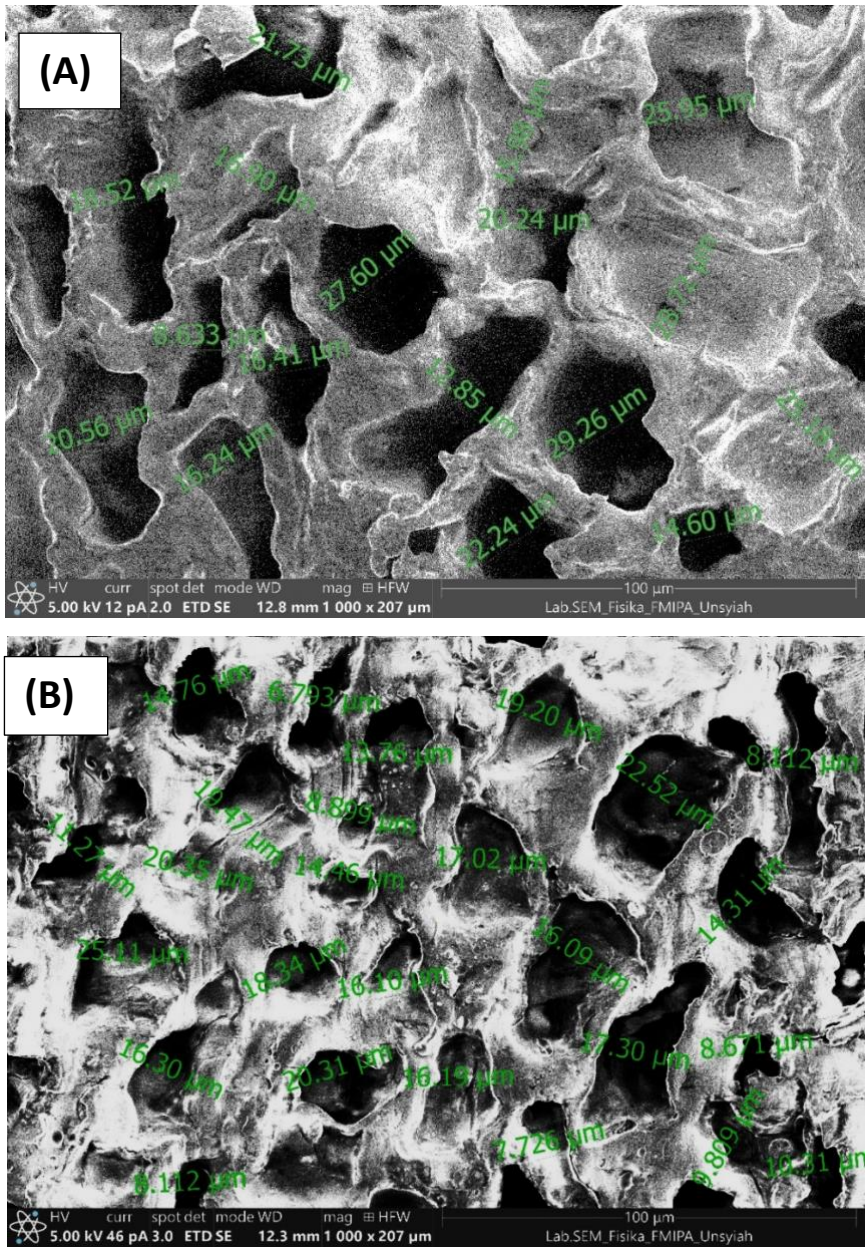

Figure 1. Pore size distribution of the sample before roasting for (a) Arabica and (b) Robusta green bean.

The chemical properties by Fourier transform infrared spectroscopy (FTIR) of various samples of Gayo Coffee bean have been measured by the present Author (Yusibani *et al*., 2023).

The spectra measurement in the region of carbonyl (C=O) at 1800-1680 cm^{-1}, indicates the difference in the type and concentration of aromatic acid, vinyl ester and lactone, aldehyde, aliphatic ester, aliphatic acid, and ketone. Kemsley *et al*. (1995) notices that the band at 1744 cm^{-1} in Arabica was larger in comparison with Robusta samples. This study confirmed by SEM-EDS result shows that the percent weight of Carbon (C) for Arabica is higher than Robusta, it reaches 72.7% (Table 1). The measurement data of true density, weight loss, water content, and porosity are tabulated in Table 2.

Table 1. SEM-EDS results before *roasting*

	Arabica			Robusta		
Element	**Weight, %**	**Atomic, %**	**Sigma**	**Weight, %**	**Atomic, %**	**Sigma**
C	72.7	78.0	0.7	61.5	68.1	0.8
O	27.3	22.0	0.7	38.5	31.9	0.8

Table 2. Physical properties result from elevated temperature and time.

	Temp, C	**Time, min.**	**Weight loss, %**	**Density, g/cm^3**	**Water content, %**	**ΔP, %**
Arabica	163 ± 1	15	11.9	1.029 ± 0.001	3.2	63.24
	159 ± 1	30	14.2	1.077 ± 0.001	0.9	73.76
	164 ± 1	45	13.5	1.085 ± 0.001	0.9	68.54
	215 ± 1	10	11.1	0.991 ± 0.001	1.7	45.34
	211 ± 1	20	12.8	0.974 ± 0.001	2.1	36.14
	212 ± 1	30	18.5	0.912 ± 0.001	0.7	30.39
	232 ± 1	5	17.3	0.923 ± 0.001	5.0	23.25
	237 ± 1	10	15.4	0.905 ± 0.001	1.9	23.72
	236 ± 1	15	15.6	0.942 ± 0.001	1.2	28.91
Robusta	164 ± 1	15	28.8	1.083 ± 0.001	3.2	57.75
	160 ± 1	30	14.7	1.125 ± 0.001	1.6	68.12
	163 ± 1	45	14.7	1.156 ± 0.001	1.6	66.12
	215 ± 1	10	14.4	1.076 ± 0.001	2.2	38.89
	211 ± 1	20	15.6	1.114 ± 0.001	2.0	52.89
	213 ± 1	30	18.5	0.950 ± 0.001	0.6	33.16
	235 ± 1	5	18.6	1.021 ± 0.001	5.7	37.16
	237 ± 1	10	17.6	1.009 ± 0.001	4.0	43.27
	236 ± 1	15	17.2	0.967 ± 0.001	3.8	37.15

Figure 2 shows water content measurement after roasting with elapsed time. The water content tends to decrease with time for all temperatures. The water content decreased from 2 to 4% for Robusta and Arabica coffee beans, respectively, at high temperatures. The result is consistent with the pore distribution measurement that Robusta has a relatively small pore rather than the Arabica green bean. Overall, with high temperatures, the water content tends to reduce.

Figure 3 shows the measurement of true density with elevated temperature and time. The tendency of the density decreases with time. The comparison was made with Outspan dan Guaxupe

coffee from Rio Minas at 170 ºC (Jokanovića *et al*., 2012). However, their measurement is bulk density, while ours was true density. Generally, the bulk density value is lower than the true density (Yusibani *et al.*, 2023). Our measurement data show that the Robusta roast bean has a relatively higher value of true density compared to Arabica coffee. This is consistent with the measurement of Jokanovića *et al*. (2012). Based on Figure 4, there is a difference in the percentage of weight loss between the Arabica and Robusta coffee beans in each sample with variations in temperature and time. The data show that when the temperature is high, then the weight loss increases. The present study shows that at high temperatures (~235 ºC) the density and the weight loss in short-time roasting remain constant.

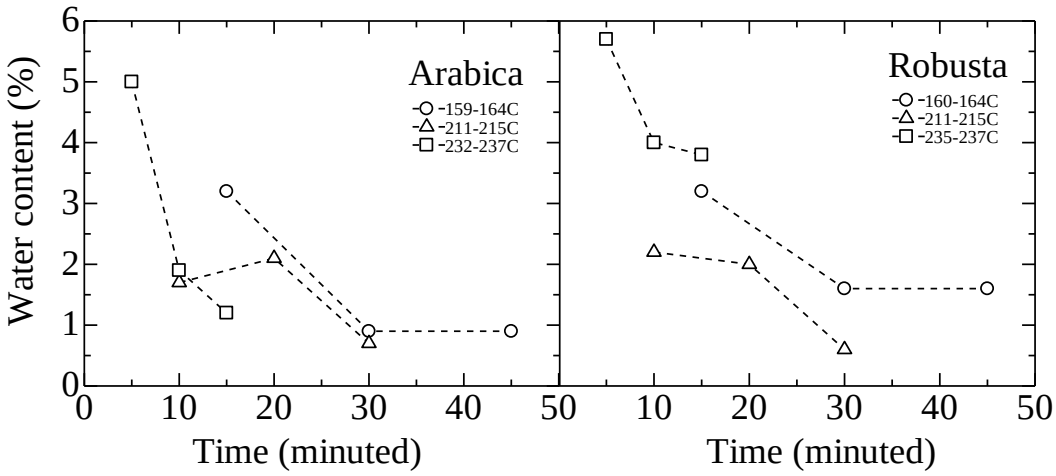

Figure 2. Water content measurement after roasting

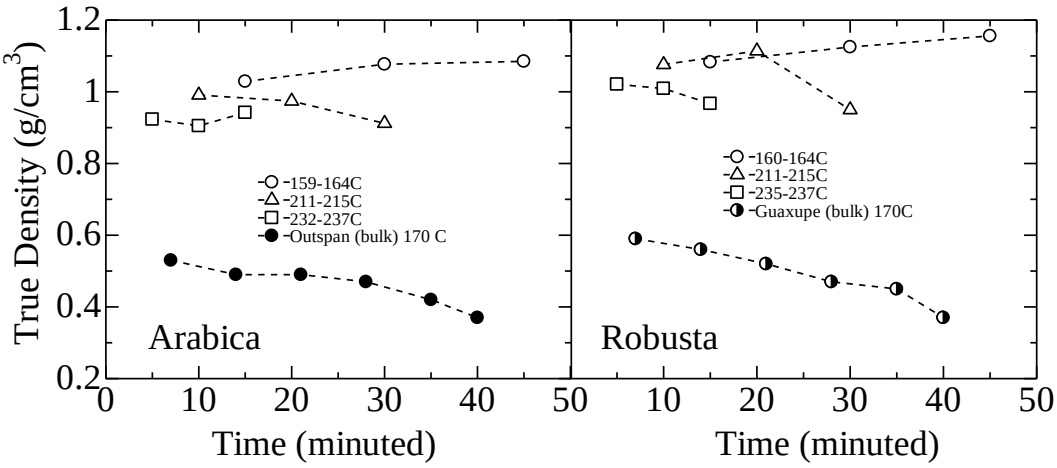

Figure 3. True density measurement after roasting

The different porosity measurements before and after the roasting process are shown in Figure 5. The tendency is similar to the density. When the density of the sample is decreased, then the porosity is also decreased. The difference in porosity measurements in this study was higher than those measured by other researchers. Some other researchers have measured the difference in porosity before and after the roasting process in a positive value. The negative means that the porosity expanded while the positive mean reduces (Yusibani *et al*., 2022).

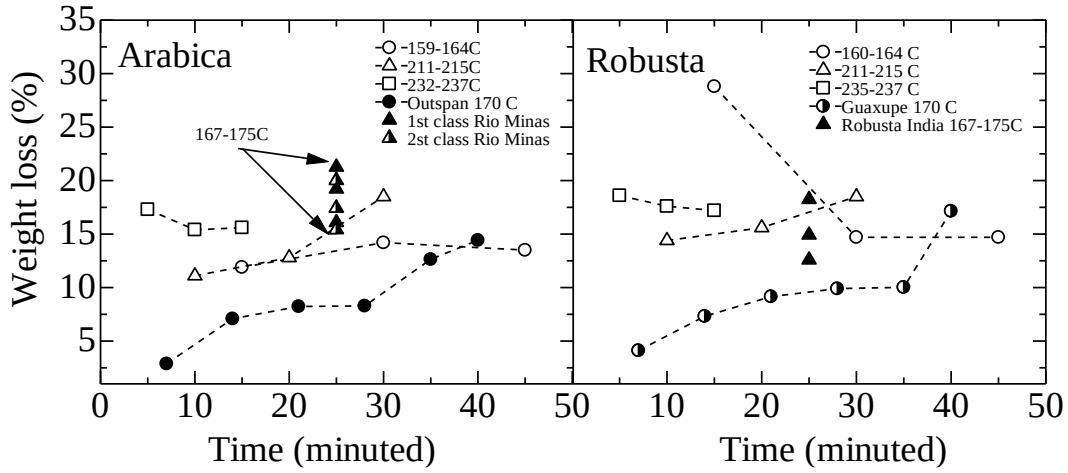

Figure 4. Weight loss measurement compared to the other researcher (Jokanovića *et al*., 2012; Odžaković *et al*., 2019).

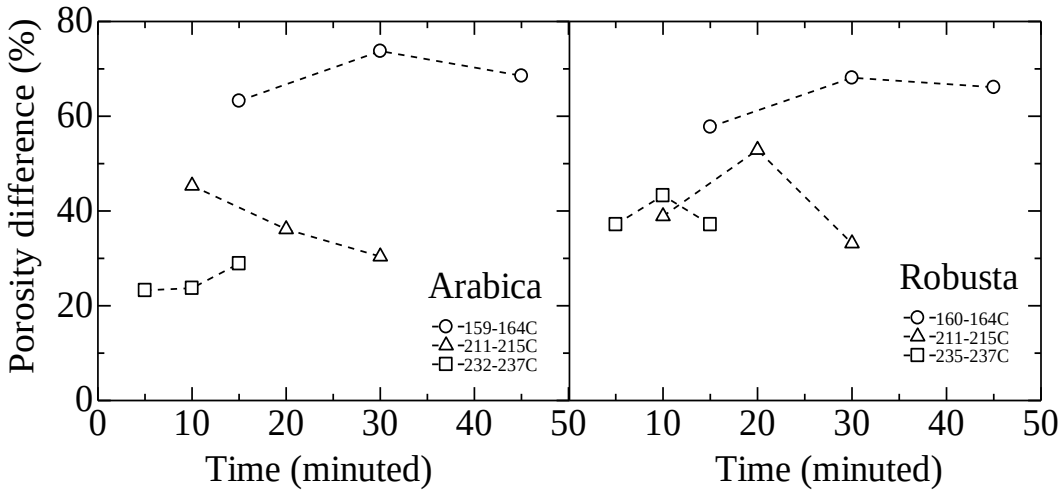

Figure 5. Different porosity measurements.

4. Conclusions

The Arabica and Robusta Gayo coffee bean's physical properties have been investigated in this study. The type of roasting level was light, medium, and dark roast with a temperature between 160 to 237 ºC and a roasting time is 5 to 45 minutes. The results obtained from this study showed that the Arabica and Robusta Gayo coffee bean's weight loss is 11 - 19% and 14 - 29%, respectively. The true density for Arabica ranged from 0.905 - 1.085 g/cm^3 and 0.950 - 1.156 g/cm^3 for the Robusta coffee bean. The difference in porosity changes before and after roasting was 23 - 73% for Arabica and 33 - 68% for Robusta coffee beans. Meanwhile, the water content of Arabica after roasting is 0.7 - 5% and 0.6 - 6% for Robusta coffee beans. Overall, the results of this study conclude that the value of the weight loss, true density, and water content of Arabica is lower than that of the Robusta coffee bean, while the porosity value of Arabica is higher than that of the Robusta coffee bean.

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