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Chemical and Sensory Characteristics of Arabica Coffee Due to Variations in Processing Methods and Fermentation Time

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ABSTRACT

The natural, full-wash, and honey processing methods, along with fermentation duration, significantly influence the chemical components and flavour profile of the resulting coffee. Therefore, it is essential to conduct research to determine the chemical and flavour characteristics produced by each processing method to maintain quality and ensure flavour consistency. The research design employed is a complete two-factor block design. The first factor is the variation in processing methods: natural, full-wash, and honey. The second factor is fermentation duration: 18 h, 24 h, and 30 h. The analyses performed include moisture content, ash content, pH, lipid content, protein content, total acid content, caffeine content, and sensory evaluation using the SCAA method. The results of this study indicate that variations in processing methods affect the values of moisture content, protein content, caffeine content, lipid content, and total acid content. Similarly, the fermentation duration of coffee cherries affects the moisture content, protein content, caffeine content, lipid content, and total acid content. The study also shows a relationship between the variations in processing methods and the fermentation duration of coffee cherries. The honey processing method and optimal ripeness levels were most preferred by the panelists. All the coffee produced in this study has met the SNI 01-3542-2004 standard.

1. INTRODUCTION

Coffee is one of leading export commodities from Indonesia which makes a significant contribution to the foreign exchange. Indonesia is the fourth largest coffee producer in the world. In 2021, coffee contributed USD 858.56 million with an export volume reaching 387.26 thousand tons. During the last decade (2013-2022), the type of coffee production in Indonesia is dominated by Robusta with average production of 508.33 thousand tons (73.0%), while Arabica coffee production 187.98 thousand tons or 27.0%. Recently, however, the composition of Indonesian coffee production shifts with Robusta coffee increase to around 83% and Arabica coffee decrease to 17% (BPS, 2024).

In the midst of increasing global coffee consumption, Arabica coffee from Indonesia is one of the most popular coffee lovers throughout the world. The issue of coffee quality is a concern for exporters who demand consistent taste and good quality of coffee. A better understanding of coffee fermentation methods, especially Arabica, can be a solution to improve coffee quality according to international standards and minimize the factors that influence the decline in Indonesian coffee production and exports. The ultimate goal is for Indonesian coffee to compete with other coffee producing countries in the world.

Generally, farmers have limited knowledge about coffee processing and fermentation methods, resulting in low coffee quality. Several studies have found that coffee bean quality is influenced by various factors such as genetics, post-harvest processes, and brewing and serving methods (de Melo Pereira *et al*., 2019; Bastian *et al*., 2021; Hall *et*

al., 2022; Poltronieri & Rossi, 2016). In recent years, research has revealed that the microbial ecology in the wet fermentation of coffee beans comprises diverse groups of microorganisms, including lactic acid bacteria (LAB), acetic acid bacteria (AAB), *Bacillus*, *Enterobacteriaceae*, yeasts, and filamentous fungi. A recent review (de Melo Pereira *et al*., 2019) has examined the specific functions of each microbial group in coffee fermentation. LAB and yeasts are thought to play a key role in breaking down macromolecules like polysaccharides and are primarily responsible for eliminating the mucilage layer that encases the coffee beans during the fermentation process.

Coffee bean processing can be categorized into three main processing methods, namely the dry processing method (natural), the wet processing method (fullwash) and modified methods such as semi-dry (honey process/wet milling process) (de Melo Pereira *et al*., 2019). With the increasing demand for unique sensory properties, various new processing methods have been developed to optimize the taste and flavor potential of coffee, such as carbonic maceration (Azmi *et al*., 2024), anaerobic fermentation (da Silva Vale *et al*., 2023), and digestion (Raveendran & Murthy, 2021). Processing methods influence the composition (Hall *et al*., 2022), quality (Firdissa *et al*., 2022), and accessibility and availability of bioactive compounds in coffee (Bastian *et al*., 2021; Wu *et al*., 2022). During coffee fermentation, various factors affect microbiota diversity, metabolite formation, and final coffee quality. These factors encompass the following: coffee variety, fermentation method (submerged in water or stack fermentation, closed or open system, sporadic or continuous, agitated or static), epiphytic microorganisms, temperature, pH, and acidity. A key challenge in fermentation lies in effectively managing the process and accurately identifying its completion.

This research aims to explore the influence of processing methods and fermentation duration on the chemical composition and sensory quality of coffee beans, with the aim of improving the quality of the coffee produced. The benefits of this research are expected to provide deeper insight into how the processing and fermentation process affects the functional and sensory characteristics of coffee beans, which in turn can support the development of more optimal processing methods to produce coffee with superior quality.

2. MATERIALS AND METHODS

This research was conducted at the coffee processing shelter of Sensory Bean Wonolelo, Magelang, Central Java, and the Laboratory of the Faculty of Agricultural Technology, STIPER Agricultural Institute (Yogyakarta) with a research period of 3 months (May - July 2023). The *S. Sigararutang* variety line and typica Arabica coffee beans were taken from Wonolelo, Magelang, Central Java.

2.1. Experimental Design

The experiment was performed according to Complete Block Design with 2 factors. The first factor was coffee processing method (S), consisted of S1 = modified-natural, S2 = full-wash, and S3 = honey. The second factor was fermentation time (B), comprised of B1 = 18 h, B2 = 24 h, and B3 = 30 h. The experiment was repeated 2 times to obtain 18 experiment units. The data obtained was analyzed statistically for variance.

2.2. Preparation of Green Beans

The coffee beans were processed through different stages according to methods (modified-natural, full-wash, and honey methods) and the fermentation time (18, 24, and 30 h). For modified-natural processing method (Figure 1), fresh coffee beans were sorted based on color and then soaked to separate good and poor quality coffee beans. A total of 6 kg of fresh coffee beans were sealed in plastic bag with different fermentation times (B1 = 18 h, B2 = 24 h, B3 = 30 h). After that, the coffee beans were dried under the sunlight for ±50 days until the water content drops to 12%. The dried coffee beans were then hulled to separate the outer skin and husk (parchment). The obtained green beans were stored in zipped plastic sack for chemical analysis and organoleptic test.

For the full-wash processing method, fresh coffee beans were pulped to separate the outer skin from the coffee beans. Six kg of wet coffee was fermented in a bucket by adding 6 L of water so that the coffee beans were completely submerged in water. The fermentation time is according to the design, namely B1 = 18 h, B2 = 24 h, and B3 = 30 h. After fermentation was complete, the coffee beans were washed using running water until clean and then dried in the sun for ± 7 days to reach water content of 12%. The dried coffee was then hulled to obtain green beans.

Figure 1. Preparation of coffee beans processing stages for modified-natural method

For the honey processing method, 6 kg of fresh coffee beans were sealed in plastic bag for different fermentation time (B1 = 18 h, B2 = 24 h, B3 = 30 h). The coffee beans were then pulped to separate the fruit flesh from the coffee beans, then dried for 7 days until the water content is 12%, then hulled to obtain green beans.

2.3. Coffee Roasting

The green beans were then roasted using an Ailio Bullet R1 machine at a temperature of 210 ºC and a time of 11-12 min. The roasted coffee beans were rested for 7 days, and then ground using a Latina grinder size 4. The ground coffee was then brewed for organoleptic testing.

2.3. Observations and Analysis Methods

This research aimed to analyze chemical and sensory parameters that influence the quality of coffee beans, including water content, caffeine, pH, ash, total acid, and fat content. In addition, the quality of coffee was also assessed using organoleptic tests in accordance with the procedure from the SCAA (Specialty Coffee Association of America) which involve various sensory aspects of coffee, specifically aroma, taste, aftertaste, acidity, body, balance, and uniformity.

2.3.1. Water Content

The moisture content of coffee beans is measured using a Moisture Analyzer. A sample of coffee beans with initial weight (a) was inserted into the device and was heated to evaporate moisture. At the same time, the weight loss of the sample is recorded (b) continuously till no longer decreases. The moisture content (M) is calculated as follows:

$$M = \frac{a-b}{a} \times 100 \quad (1)$$

2.3.2. Caffeine Content (BSN, 2014)

Caffeine content was analyzed using the HPLC method. The coffee beans (sample) were ground and weighed 5 g and put into an Erlenmeyer flask. Distilled water of 200 ml was poured into the flask, and 5 g of MgO was added. The mixture was heated for 2 h and cooled, then diluted to 500 ml using a volumetric flask and filtered. As much as 300 ml of the sample solution was taken and 10 ml of H_2SO_4 (1: 9) was added, then boiled until the liquid volume decreased to 100 ml. The liquid is poured into a separating funnel. The flask was rinsed with sulphuric acid (1:99), and the solution was boiled several times by adding 10 ml, 15 ml, 20 ml and 25 ml of chloroform, respectively. The rinsing liquid is put into a separating funnel. Then 5 ml of 1% KOH solution was added, shaken and left until the separation occur. Two layers was formed, the bottom layer was caffeine solution, the upper layer was water and other ingredients.

$$\text{Caffeine Content} = \frac{Residue\ (g)}{Sample\ (g)} \quad (2)$$

2.3.3. Acidity Level (pH) (Sudarmadji *et al*., 1984)

The pH was measured using a pH meter. The pH meter was first calibrated with a buffer for pH 7. Sample of Arabica coffee (10 g) was diluted using 100 ml of hot aquades (100°C), then cooled and separated the precipitate into a beaker glass. The pH meter was turned on and dipped in the solution and rotated till homogeneous and the numbers appeared.

2.3.4. Ash content (Sudarmadji *et al*., 1984)

Coffee beans of 5-10 g was put in the crucible cup, heated in oven at around 120 °C for 2 h, then cool it in a desiccator and weigh it. The sample was burnt in a muffle furnace at 525 °C for 2 h and weighed after cooling.

$$\text{Ash content (\%)} = \frac{\text{Ash weight (g)}}{\text{Sample dry weight (g)}} x100\% \quad (3)$$

2.3.5. Total Acid

Total titrated acid analysis was carried out using the titration method (Fardiaz, 1988) by weighing 5 grams of the ground sample (60 mesh) and putting it into a beaker glass and diluting it using 50 ml of distilled water, and then filtered using filter paper. The filtrate was put into 100-ml measuring flask and diluted using distilled water. The diluted sample was taken as much as 5 ml and added with 2 drops of 1% phenolphthalein. Titration was carried out using 0.01N NaOH solution until the color changed to pink. The following formula was used to calculate total acid:

$$\text{Total acid (\%)} = \frac{V_1 \times N \times B}{V_2 \times 1000}\ 100\% \quad (2)$$

where B is molecular weight of lactic acid (90), N is normality of NaOH, V_1 is volume of NaOH used (ml), and V_2 is weight of titrated sample (g).

2.3.6. Fat Content

Fat analysis was performed using the Soxhlet extraction method (Sudarmadji *et al*., 1984). The fat content was calculated from the extracted fat (B) and sample mass (A) according to the following.

$$\text{Fat content (\%)} = \frac{\text{B}}{\text{A}}\ 100\% \quad (3)$$

2.3.7. Protein Content

Caffeine content was analyzed using HPLC method. Sample of coffee beans were ground and weighed 5 g and put into an Erlenmeyer, added with 5 g MgO and 200 ml distilled water. The mixture was heated by reverse cooling for 2 h, then diluted to 500 ml using a volumetric flask, then filtered. 300 ml of solution was taken and 10 ml of H_2SO_4 was added in a ratio of 1: 9, then boiled until the liquid volume remained 100 ml. The liquid was poured into a separating funnel. A boiling flask was rinsed with acesulphic acid (1:99), and the solution was boiled many times by adding 10 ml, 15 ml, 20 ml and 25 ml of chloroform respectively. The rinsing liquid is put into a separating funnel. Then 5ml of 1% KOH solution was added, shaken and left until the liquid separated. After that, 2 layers will form, the bottom layer is caffeine solution of in chloroform and the layer above is water and other ingredients and is stored in an Erlenmeyer.

2.5.8. Organoleptic Tests

Coffee quality assessment was based on standards set by the SCAA (Specialty Coffee Association of America). Various aspects of coffee were assessed, such as aroma, taste, aftertaste, acidity, body, balance and uniformity. The panelists in this study are coffee connoisseurs: Individuals who have an interest in coffee, even though they do not work as a barista or coffee expert. A total score >80 points was considered to have specialty grade quality.

2.6. Data Analysis

The data was analyzed using Analysis of Variance (ANOVA) to test significant differences between treatment factors. If ANOVA shows significant differences, DMRT (Duncan's Multiple Range Test) is carried out at $\alpha = 0.05$.

3. RESULTS AND DISCUSSION

3.1. Caffeine Levels

Caffeine is a group of xanthine-derived alkaloids that are found in almost all parts of coffee. Therefore, each coffee has a different amount of caffeine, such as 2.47% Robusta coffee and 1.99% Arabica (Saloko, 2020). Table 1 shows effect of treatments on the caffeine content of coffee beans. The processing method and fermentation time have a significant effect on the caffeine content with *p*-value of 0.001 and 0.000, respectively. From the DMRT results, green coffee beans with the lowest caffeine content (0.8837%) was resulted from honey processing method with a fermentation time of 18 h. This is because the caffeine compound is quite soluble in water and has hydrophobic properties (Ramalakshmi & Raghavan, 1999), so that the lowest caffeine levels are produced in the full-wash process which uses the most water as compared to the modified-natural or honey processing methods. Table 1 shows that the caffeine content of the Arabica coffee beans produced tends to decrease with longer fermentation time. The decrease in the caffeine content may be caused by the decomposition of caffeine into xanthin and uric acid during fermentation by bacteria. The results of this research are inline with (Farida *et al.*, 2013) and (Mubarok *et al.*, 2014) showing that the longer the fermentation time, the lower the caffeine content in Arabica coffee beans. Balyaya & Clifford (1995) reported small caffeine losses (3%) during the soaking phase in the wet process compared to the dry process. According to (Gokulakrishnan *et al*., 2005) the caffeine decomposition into uric acid starts at 12-36 h of fermentation.

The caffeine levels in this study were in accordance with SNI 01-3542-2004, namely a maximum of 0.4 - 2%. The full-wash process can cause a decrease in caffeine levels even though it only involves water, because during soaking, some of the caffeine can dissolve into the water, although it is not as effective at high temperatures. Arabica coffee, which has naturally lower caffeine levels, also contributes to these results. In addition, other factors such as fermentation time, water temperature, and processing conditions may influence the caffeine content produced. Therefore, the decrease in caffeine levels found in this study is likely caused by a combination of these factors.

Table 1. Effect of treatment on the caffeine content (%) in green coffee beans

Fermentation Time (h)	Processing Method			Average
	S1 (Modified-Natural)	S2 (Full-wash)	S3 (Honey)	
B1 (18 h)	0.9139	1.0897	0.8837	0.9624 A
B2 (24 h)	1.1706	1.2709	1.1678	1.2031 B
B3 (30 h)	1.3171	1.5092	1.2899	1.3721 C
Average	1.1339 a	1.2899 b	1.1138 a	

Note: Mean values followed by different letters are significantly different based on DMRT at α = 5%. Capital letters are for column (Fermentation Time), and lowercases are for Processing Method.

Table 2. Effect of treatment on the total acid content (%) in green coffee beans

Fermentation Time (h)	Fermentation Method			Average
	S1 (Modified-Natural)	S2 (Full-wash)	S3 (Honey)	
B1 (18 h)	0.0084	0.1426	0.0619	0.0710 A
B2 (24 h)	0.0052	0.1657	0.0609	0.0773 AB
B3 (30 h)	0.0087	0.1933	0.0755	0.0925 B
Average	0.0074 a	0.1672 c	0.0661 b	

Note: Mean values followed by different letters are significantly different based on DMRT at α = 5%. Capital letters are for column (Fermentation Time), and lowercases are for Processing Method.

3.1.2. Total Acid

Table 2 shows total acid content increases with the fermentation time. Total acid is the amount of organic acid found in coffee beans, organic acids in the form of formic acid, oxalic acid, lactic acid, acetic acid and citric acid. The coffee processing methods have a significant effect on the total acidity of the coffee beans, with a *p*-value of 0.000. The fermentation time also has a significant effect on the total acidity of coffee beans, with a *p*-value of 0.035. There is no significant interaction both factors on the total acid levels of coffee beans. The formation of aliphatic acids causes high

acidity in coffee during the fermentation process. This is in accordance with Sulistyowati & Sumartono (2002), that acid is released during fermentation and causes changes in acidity levels.

Controlled moisture levels during the honey process allow optimal conditions for microorganisms to produce acid compounds. This differs from the wet method, where immersion in water tends to wash away some of acid compounds. In the honey process, some of the mucilage (a slimy layer) remains attached to the coffee beans during drying. This mucilage contains sugars and pectin which become substrates for microorganisms, thereby causing controlled fermentation and contributing to the development of sour taste (Wamuyu *et al*., 2017). During fermentation, microorganisms can influence pectin sugars and a number of other reducing or non-reducing sugars present in coffee mucilage, which contribute to the production of lactic, butyric, acetic and other high carboxylic acids and tend to lower the pH of the final result of coffee brewing (Haile & Kang, 2019). The total acid value correlates with the pH value. The higher the total acid, the lower the pH (Kasim *et al*., 2020).

3.1.3. Lipid Content

Lipids are greatly important group of compounds in coffee, essential for the texture and the taste sensation in the mouth. Lipid content is within 7–17% of the dry bean weight (Silva *et al*., 2020). Table 3 shows the effect of treatments on the lipid content of coffee beans. Test results show that the processing method has no significant effect on the lipid content of coffee beans, with a *p*-value of 0.468. Meanwhile, fermentation time affects significantly the lipid content of coffee beans, with a *p*-value of 0.001. The lowest lipid content was produced from the honey processing method with a fermentation time of 18 hours, namely S3B1. Post-harvest processes have a major impact on the chemical composition of coffee beans and the quality of the coffee drink in terms of body, aroma, sweetness, sourness, taste, etc. (Joët *et al*., 2010; Haile & Kang, 2019) showed a decrease in lipid content after fermentation. Chemical components in coffee beans may be reduced or lost due to processing. Variations in the level of chemical composition due to the influence of metabolic activity in coffee beans have also been reported by other authors such as (Selmar *et al*., 2006; Patui *et al*., 2014). Lipid activity in coffee beans can catalyze the hydrolysis of ester bonds in monoacylglycerol, diacyglycerol and triacylglycerol to become free fatty acids and glycerol (Toci *et al*., 2013; Patui *et al*., 2014). It is reported that most of the lipids are found in the oil fraction of the coffee bean endosperm and a small part is found in the form of a wax layer located on the surface layer of the coffee bean. Therefore, it is suspected that the lipids in the outer layer can be lost due to processing or metabolic activities.

Table 3. Effect of treatment on the lipid content (%) in green coffee beans

Fermentation Time (h)	Processing Method			Average
	S1 (Modified-Natural)	S2 (Full-wash)	S3 (Honey)	
B1 (18 h)	12.6804	13.1330	11.7654	12.5263 A
B2 (24 h)	14.4412	14.1720	13.7868	14.1333 C
B3 (30 h)	13.3457	12.6094	13.7656	13.2402 B
Average	13.4891 a	13.3048 a	13.1059 a	

Note: Average values followed by different letters in columns or rows are significantly different based on DMRT at α = 5%. Capital letters are for column (Fermentation Time), and lowercases are for Processing Method.

3.1.4. Protein Content

Protein is an organic component that plays a vital role in providing coffee flavor because it is needed during the Maillard reaction. This group of proteins is considered as a precursor for the formation of volatile compounds that appear in coffee beans, such as furans, pyrazines, pyrroles, aldehydes and melanoidins (Farah, 2012). Table 4 indicates that all factors and their interaction are significant on the protein content of coffee beans with a *p*-value 0.022 for interaction, and of 0.000 for both processing methods and fermentation time. The lowest protein content in coffee beans is produced from the honey processing method with a fermentation time of 18 h. Coffee beans contain around 9 to 16% protein based on dry weight (Farah, 2012). The fullwash processing method allows the mucus to be degraded more due to washing with water. (Nigam & Singh, 2014) reported that free amino acids are released in coffee beans which are the result of protein degradation during the fermentation process. It can be expected that the fullwash fermentation processing method causes more coffee degradation compared to natural processing methods. This is what

causes low protein levels to be produced in the full-wash process and a fermentation time of 30 h. The loss of components such as protein in coffee beans can be minimized in natural processing processes. Protein and free amino acids determine the taste of coffee, especially as flavor precursors in the Maillard reaction (Joët *et al*., 2010) during the coffee roasting process to produce aroma compounds such as furans, pyrroles, pyrazines (Nigam & Singh, 2014).

Table 4. Effect of treatment on the protein content (%) in green coffee beans

Fermentation Time (h)	Fermentation Method			Average B
	S1 (Modified-Natural)	S2 (Full-wash)	S3 (Honey)	
B1 (18 h)	12.5194 [a]	13.0906 [b]	12.3409 [a]	12.6503 A
B2 (24 h)	14.4822 [d]	15.4316 [f]	13.8953 [c]	14.6030 B
B3 (30 h)	15.0653 [e]	16.0947 [g]	14.9322 [e]	15.3641 C
Mean S	14.0223 b	14.8723 c	13.7228 a	

Note: Average values followed by different letters are significantly different based on DMRT at α = 5%. Capital letters are for column (Fermentation Time), and lowercases are for Processing Method.

Table 5. Effect of treatment on the pH values of coffee bean

Fermentation Time (h)	Fermentation Method			Average
	S1 (Modified-Natural)	S2 (Full-wash)	S3 (Semiwash)	
B1 (18 h)	4.0500 [b]	3.0000 [a]	3.0100 [a]	3.3533 A
B2 (24 h)	3.0250 [a]	3.0000 [a]	4.0050 [b]	3.3433 A
B3 (30 h)	3.0100 [a]	3.0050 [a]	4.0050 [b]	3.3400 A
Mean	3.3617 b	3.0017 a	3.6733 c	

Note: Average values followed by different letters are significantly different based on DMRT at α = 5%. Capital letters are for column (Fermentation Time), and lowercases are for Processing Method.

3.1.5. pH Value

The test results show that the interaction of processing method and length of fermentation time have a significant effect (p = 0.000) on the pH value of the coffee beans produced during the fermentation process (Table 5). The p-value for processing methods is 0.000, which is smaller than 0.05, thus indicating that different processing methods have a real influence on changes in the pH value of coffee beans. The length of fermentation time is not significant on the pH value, with a p-value of 0.693, which is greater than 0.05. This shows that the duration of fermentation affects the acidity level of the coffee beans produced. This is because the lower the pH value, the more acidic the green coffee beans produced will be. The fullwash fermentation method gets a low average pH value, while the semiwash fermentation method gets a still high pH value. The initial pH of fermentation is around 5.4 which gradually decreases to 3.0. According to (Kustiyah, 1986) acidity or pH greatly influences the taste and aroma of coffee. The fermentation time factor of 18, 24, and 30 hours has a very significant effect on the pH value produced from green coffee beans. This is because the longer the fermentation process takes, the higher the resulting pH value.

The end point of fermentation can be determined based on empirical observations or measurements. Measurement of the pH value is determined as a parameter to determine the end of fermentation. The decrease in pH value is caused by microbial metabolism (Silva *et al*., 2008). The bacteria and yeast present in coffee produce large amounts of acid, especially citric acid. The end point of fermentation can be determined based on empirical observations or measurements. Measurement of the pH value is determined as a parameter to determine the end of fermentation. The decrease in pH value is caused by microbial metabolism (Silva *et al*., 2008). The bacteria and yeast in coffee produce large amounts of acid, especially citric acid, one of the causes of the decrease in pH.

3.1.6. Ash Content

From Table 6, the ANOVA test results show that the processing method and length of fermentation time do not have a significant effect on the ash content produced during the fermentation process. This is proven by the respective p-values of 0.642 for processing method, 0.157 for fermentation time, and 0.300 for the interaction which all are greater than the 0.05 significance level. Therefore, it can be concluded that variations in processing methods or fermentation

duration do not significantly influence the ash content of coffee beans during the fermentation process. It can be seen that the highest ash content was found in treatment B1 of 18 h fermentation at 4.605%, while the lowest was in treatment B2 with 4.1747%. All treatments showed insignificant differences from each other. The high ash content produced is due to the water content of the coffee beans produced from this research tending to be low at less than 12% so that the mineral content or ash content increases. In addition, coffee beans contain many minerals such as monovalent metals (sodium and potassium), as well as large amounts of phosphorus and sulfur (Clarke & Macrae., 1987), which causes the ash content of coffee beans to increase. The processing method does not affect the ash content produced in coffee beans but still meets the SNI 01-3542-2004 standard for ash content of less than 5%.

Table 6. Effect of treatment on the average coffee bean ash content (%)

Fermentation Time (h)	Fermentation Method			Average
	S1 (Modified-Natural)	S2 (Full-wash)	S3 (Honey)	
B1 (18 h)	4.6718	4.8276	4.1820	4.5605 A
B2 (24 h)	3.9582	4.4764	4.0895	4.1747 A
B3 (30 h)	4.2524	4.0920	4.7422	4.3622 A
Mean	4.2941 a	4.4653 a	4.3379 a	

Note: Average values followed by different letters are significantly different based on DMRT at α = 5%. Capital letters are for column (Fermentation Time), and lowercases are for Processing Method.

Table 7. Effect of treatment on the average water content of coffee beans (%)

Fermentation Time (h)	Fermentation Method			Average B
	S1 (Modified-Natural)	S2 (Full-wash)	S3 (Honey)	
B1 (18 h)	11.1754	11.1861	11.2146	11.1920 A
B2 (24 h)	11.8333	11.4571	11.1984	11.4963 A
B3 (30 h)	11.3333	11.2237	11.1636	11.2402 A
Average	11.4473 a	11.2890 a	11.1922 a	

Note: Average values followed by different letters are significantly different based on DMRT at α = 5%. Capital letters are for column (Fermentation Time), and lowercases are for Processing Method.

3.1.7. Water Content

The reduction in water content is carried out by drying in the sun, which can be seen in Table 7. The ANOVA test results show that the processing method and length of fermentation time do not have a significant impact on the water content of coffee beans produced during the fermentation process. This is proven from the respective *p*-values of 0.574 for processing method, 0.422 for fermentation time, and 0.834 for interaction, of which are all greater than the 0.05 significance level. Thus, it can be concluded that changes in processing methods or fermentation duration do not significantly affect the water content of coffee beans during the fermentation process. The natural, full-wash, honey processing methods have no effect on the water content produced in green coffee beans. This is because in all three processing methods there is a fermentation process where the water content of the coffee beans decreases as the fermentation process lasts. Water content correlates with temperature, which influences microbial and enzyme activity. This activity produces heat which will cause the mucus in the seeds to disintegrate and open the pores of the seeds, so that the water in them evaporates (Sivetz, 1963). The water content of the coffee produced in this research still complies with SNI of maximum 12.5% (BSN, 2008). The water content in green coffee beans was highest during the fermentation period of 24 h.

High water content in coffee beans can cause problems such as microbial growth, mycotoxin formation, changes in final taste and unstable production. In general, a moisture content of between 8.0% and 12.5% is considered sufficient to avoid this problem, in accordance with the requirements set out by Agriculture Ministry (Menteri Pertanian, 2012) and SNI 01-2907-2008 (BSN, 2008). Drying speed is influenced by internal and external factors. According to (Mulato, 2018) these internal factors are the type of coffee, mass of fruit per bean, initial water content, and size of the fruit (beans), while external factors include temperature, relative humidity, pressure and air speed in the drying machine. There are three methods used to dry coffee beans, namely natural drying, mechanical drying and a combination of the two.

3.1.8. Organoleptic Preference

Organoleptic testing is carried out to measure the quality of coffee from sensory attributes and is one of the most important factors determining coffee prices. (Hall *et al*., 2022) reported that Arabica coffee is considered to be of higher quality than Robusta due to its richer sensory profiles. The sensory quality of bean coffee is determined using steeping roasted beans. Drinks from Arabica beans are mainly characterized by a sour taste and the fruit of Robusta beans is basically bitter and thick-bodied (Sunarharum *et al*., 2014). In terms of taste, high-quality coffee drinks are defined as complex, balanced, and "pleasant". Low quality coffee drinks are basically defined as coffee that is flat and unbalanced with defects and exhibit an "unpleasant" sensation. Analysis characterizes coffee brewing based on several taste parameters including aroma, taste, acidity, body (SCA, 2022). High quality Arabica has a cupping score of >80.

The ANOVA test results as shown in Tables 8–11 indicate that the processing method and fermentation time have varying effects on the organoleptic characteristics of coffee, specifically aroma, body, acidity, and flavor. For aroma, the processing method does not significantly affect the result (p = 0.105), while the length of fermentation time shows a significant effect (p = 0.002). In addition, the interaction between the two factors also has a significant impact (p = 0.039), as the p-values for fermentation time and interaction are both less than the 0.05 significance level. In the body parameter, both the processing method (p = 0.020) and fermentation time (p = 0.000) significantly influence the outcome. However, the interaction between them does not show a significant effect (p = 0.108), since the p-value is above the 0.05 threshold. As for acidity, the fermentation time (p = 0.000) and the interaction between processing method and fermentation time (p = 0.006) significantly affect the acidity of the coffee, while the processing method alone does not show a significant effect (p = 0.945). Regarding flavor, both the processing method (p = 0.005) and the fermentation time (p = 0.000) have a significant impact, whereas the interaction between the two factors does not (p = 0.411), as its p-value exceeds the 0.05 significance level.

Based on the organoleptic test, treatment S1 (Natural) and B1 (Fermentation 18 h) is the most preferred by panelists with average score of 74.9667 and 72.8125, respectively (Table 12). The natural process produces the most

Table 8. Effects of treatments on the organoleptic test for aroma

Fermentation Time (h)	Fermentation Method		
	S1 (Modified-Natural)	S2 (Full-wash)	S3 (Semiwash)
B1 (18 h)	76.1500 c	76.1000 c	75.6000 bc
B2 (24 h)	73.3500 b	74.7500 bc	70.3000 a
B3 (30 h)	75.1500 bc	73.6500 bc	74.9000 bc

Note: Average values followed by different letters are significantly different based on DMRT at α = 5%. Capital letters are for column (Fermentation Time), and lowercases are for Processing Method.

Table 9. Effects of treatments on the organoleptic test for body

Fermentation Time (h)	Fermentation Method			Average
	S1 (Modified-Natural)	S2 (Full-wash)	S3 (Honey)	
B1 (18 h)	76.8000	72.5500	73.9000	74.4167 B
B2 (24 h)	71.2500	70.3500	69.6000	70.4000 A
B3 (30 h)	71.2000	71.3500	70.0500	70.8667 A
Mean	73.0833 b	71.4167 a	71.1833 a	

Note: Average values followed by different letters are significantly different based on DMRT at α = 5%. Capital letters are for column (Fermentation Time), and lowercases are for Processing Method.

Table 10. Effects of treatments on the organoleptic test for acidity

Fermentation Time (h)	Fermentation Method		
	S1 (Modified-Natural)	S2 (Full-wash)	S3 (Honey)
B1 (18 h)	76.0500 e	73.8000 d	71.7000 cd
B2 (24 h)	69.3000 ab	70.9500 abc	71.4500 bc
B3 (30 h)	68.9500 a	69.7500 abc	70.8000 abc

Note: Average values followed by different letters are significantly different based on DMRT at α = 5%. Capital letters are for column (Fermentation Time), and lowercases are for Processing Method.

Table 11. Effects of treatments on the organoleptic test for flavors

Fermentation Time (h)	Fermentation Method			Average
	S1 (Modified-Natural)	S2 (Full-wash)	S3 (Honey)	
B1 (18 h)	74.8000	75.1500	77.0000	75.6500 C
B2 (24 h)	71.4500	74.1000	74.1000	73.2167 B
B3 (30 h)	69.3000	70.9500	71.1500	70.4667 A
Mean	71.8500 a	73.4000 b	74.0833 b	

Note: Average values followed by different letters are significantly different based on DMRT at α = 5%. Capital letters are for column (Fermentation Time), and lowercases are for Processing Method.

Table 12. Average value of results from all organoleptic tests of ground coffee

Treatment	Aroma	Body	Acidity	Flavors	Average
Fermentation Time					
B1 (18 h)	75.9500	74.4167	73.8500	75.6500	74.9667
B2 (24 h)	72.8000	70.4000	70.5667	73.2167	71.7459
B3 (30 h)	74.5667	70.8667	69.8333	70.4667	71.4334
Processing Method					
S1 Natural	74.8833	73.0833	71.4333	71.8500	72.8125
S2 Fullwash	74.8333	71.4167	71.5000	73.4000	72.7875
S3 Honey	73.6000	71.1833	71.3167	74.0833	72.5458

complex coffee flavor and is most preferred by the panelists, this is because in the natural process the substrate acid compounds produced during the fermentation process penetrate more fully into the coffee beans because the drying process is slower than the full-wash and honey processes, resulting flavor attributes more complex in natural process coffee brews (Mulato & Suharyanto, 2012). The diversity of microbes in coffee berries in a natural process produces a more complex coffee taste, with a stronger sweet and fruity taste intensity due to the diverse population of microorganisms, bacteria, yeast and filamentous fungi found during the drying of the coffee berries (Silva *et al*., 2000). The activity of these microorganisms influences the physical and chemical changes of the coffee cherries, which are caused by the metabolism of the coffee beans (endosperm) and the gradual loss of water in the coffee beans. Changes in physicochemical such as pH, sugar content, and the decomposition of pectin compounds in mucilage (fruit flesh) occur by the activity of pectinase enzyme. Depolymerization of pectin becomes a carbon source for micro-organisms. This process takes place during the fruit drying for >20 days in a natural process (Firdissa *et al*., 2022).

4. CONCLUSION

From the results of research and statistical tests on the influence of processing methods and fermentation time, it can be concluded that fermentation time and drying time influence the values of water content, protein content, caffeine content, lipid content, and total acid content. Meanwhile, in the second case, the fermentation time of the coffee fruit affects the water content, protein content, caffeine content, lipid content, and total acid content. Research also shows that there is a relationship between variations in processing methods and the length of coffee fruit fermentation. All coffee produced from this research meets SNI 01-3542-2004.

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