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Impact of Aerobic and Anaerobic Fermenters on the Sensory Profile of Coffee in Villa Rica, Peru

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Abstract

Controlled coffee fermentation is an innovative technique that significantly improves cup quality and contributes to the production of specialty coffees, increasing their value in the market. This study aimed to evaluate the impact of fermentation in aerobic and anaerobic bioreactors on the sensory profile of coffee from Villa Rica, using Coffea arabica fruits, caturra variety, from the 2022-2023 harvest of the CUNAVIR Association in Villa Rica, Oxapampa, Pasco. The beans were sorted, disinfected and fermented in anaerobic and aerobic bioreactors, and their attributes were compared with a natural fermentation control. Subsequently, the beans were pulped, washed and dried in the sun, and then roasted and sensory evaluated by 7 certified SCAA Grade Q tasters. The results indicated that coffee fermented under anaerobic wet conditions obtained the highest score (86.77 points), followed by natural fermentation (84.40 points) and aerobic wet fermentation (83.63 points) ($p<0.05$). These findings suggest that anaerobic wet fermentation is the most effective method of improving the sensory quality of coffee. In conclusion, controlled fermentation in anaerobic bioreactors is an innovative process that optimizes the sensory profiles of coffee and increases its value in the market.

Keywords: Anaerobic fermentation, aerobic fermentation, sensory profile, coffee.

1. Introduction

Coffee is one of the most consumed beverages worldwide, and its quality depends on the planting altitude, variety of the bean, fermentation methods, and post-harvest processing, directly influencing its sensory scores and final aroma and flavor characteristics (Oliveiras et al., 2021) (Barbosa et al., 2019). Fermentation is an essential process in the development of the sensory profile of coffee, significantly influencing the aroma, flavor and acidity of the final product (Cândido et al., 2019). Traditionally, coffee fermentation has been carried out by natural methods on open platforms, concrete tanks or polypropylene bioreactors with small quantities (20-80 L) in which homogenization, control and hygiene are difficult (Martinez et al., 2021). In addition, the duration of fermentation has proven to be a critical factor in the composition of green coffee beans and the quality of the resulting cup (Zhang et al., 2019). On the other hand, the choice of appropriate microorganisms is essential to have a positive impact on the taste and aroma of coffee during fermentation, highlighting the need to control this process to achieve positive results (Haile & Kang, 2019).

Recent research has shown that anaerobic fermentation applied to coffee processing can markedly improve the quality of the taste and aroma of the final beverage (Mulyara et al., 2021). Likewise, studies have shown that fermentation techniques can substantially improve the quality of coffee, affecting acid and alcohol profiles, which directly influences the sensory characteristics of the resulting beverage (Silva, 2024). In addition, the growth of microorganisms during coffee fermentation has been explored, providing valuable insights into microbial activity and its impact on the process (Sulaiman & Hasni, 2022). Coffee fermentation not only affects the chemical and sensory properties, but can also influence the functional and antioxidant properties of the final product (Halagarda, 2023). Arenas et al. (2022) mention that different fermentation methods can alter the sensory profile of coffee, underscoring the importance of understanding this process in detail to ensure product quality. The implementation of automated stainless steel bioreactors improves process control and hygiene, allowing the continuous production of specialty coffees. A recent study showed unique sensory profiles with non-automated stainless steel vessels (Bressani et al., 2020).

Villa Rica, Peru, is a region known for the production of high-quality coffee. The diversity of microclimates and the coffee tradition of the area contribute to the uniqueness of its beans (Montilla et al., 2020). However, variability in post-harvest processing methods, especially in fermentation, has generated inconsistencies in the sensory profile of coffee produced in this region (Gaitán et al., 2018). In this context, the implementation of controlled aerobic and anaerobic bioreactors is presented as a promising alternative to optimize the organoleptic characteristics of Villa Rica coffee. The lack of control in the coffee fermentation process can cause significant challenges for the coffee industry. Puerta and Echeverry (2015) point out that the lack of control in fermentation results in variable flavor and aroma profiles, complicating the production of uniform and distinctive batches. In addition, uncontrolled fermentation can result in undesirable flavors, such as astringent or fermented notes, negatively impacting the consumer experience.

Given the importance of proper control during fermentation, this study focuses on the validation of both anaerobic and aerobic bioreactors, equipped with automated systems for the regulation of critical parameters such as temperature and oxygen. These bioreactors are designed to improve the sensory profile of coffee through specific protocols that ensure superior and consistent quality (Martínez et al., 2021). A bioreactor is a vessel where an optimal environment is provided to meet the needs of any biological system and achieve its high performance (Wang & Zhong, 2007). The implementation of bioreactors with automated control allows precise and constant regulation of temperature, pH and oxygen concentration, which helps to minimize variability and ensure repeatability in production. As a result, consistent sensory profiles will be obtained in each batch of coffee. The objective of this study is to evaluate the impact of fermentation in aerobic and anaerobic bioreactors on the sensory profile of coffee from Villa Rica. In which the sensory characteristics obtained from both types of fermentation will be compared to determine which method produces a coffee with better attributes of flavor, aroma and acidity. The results of this research will provide valuable insights for coffee producers in Villa Rica and offer information applicable to other coffee-growing regions with similar conditions. In addition, this study will contribute to the field of food science and technology by providing empirical evidence on the benefits of controlled fermentation in the production of high-quality coffee.

2. MATERIALS AND METHODS

2.1 Materials

Raw material: The fruits of Coffea arabica, caturra variety, 2022-2023 harvest, between the months of April and July were harvested by hand by the coffee growers of the farms located in the sectors of El Oconal, Ñagazú, Santa Herminia, Palomar, Eneñas, Entre Ríos, Entaz and Cedropampa, belonging to the CUNAVIR Association. This association is located in the district of Villa Rica, province of Oxapampa, Pasco region, at an altitude of 1,814 meters above sea level (masl), with a latitude of 10°45'12.48"S and a longitude of 75°15'57.18"W, and an average annual temperature of 17.7°C.

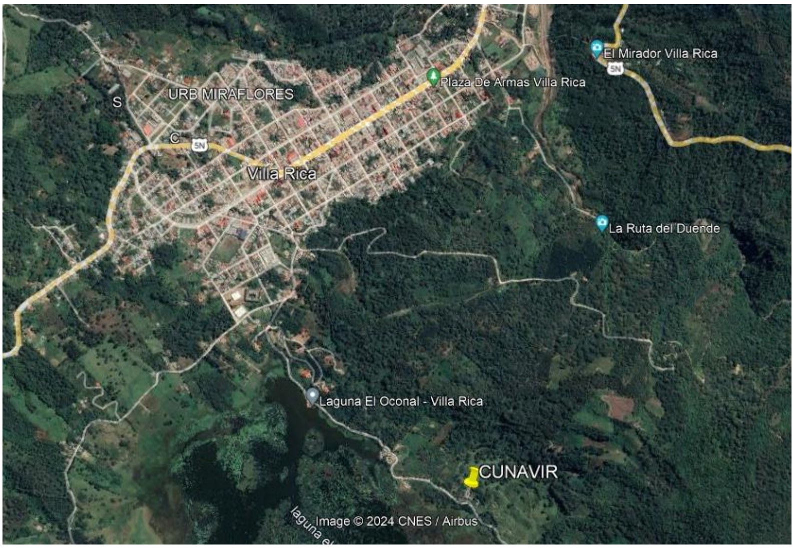

Figure 1. Location of the wet processing plant of the CUNAVIR Association - District of Villa Rica - Province of Oxapampa

Note: Taken from IGN 2024.

2.2 Methods

a) Preparation of the Coffee Beans:

The coffee beans were received at the wet processing plant of the CUNAVIR Association, where data such as the date and time of receipt, as well as the origin of the beans, were recorded. Subsequently, the grains were mechanically classified, removing damaged grains, leaves, branches and impurities by washing with drinking water and manually ensuring uniformity of ripeness. Once sorted, the beans were disinfected with a sodium hypochlorite solution at 50 ppm for 10 minutes to remove potential contaminants. After disinfection, the beans were washed with drinking water to remove the residues of the disinfectant solution and any other impurities. Finally, the soluble solids content and pH of the washed grains were measured using a digital refractometer and a pH-meter, respectively, to ensure that the beans were in optimal condition before fermentation. The beans were then placed in bioreactors, dividing the batches into aerobic and anaerobic fermentation.

b) Prototypes of anaerobic and aerobic bioreactors

Anaerobic Bioreactor Prototype: The finished anaerobic bioreactor prototype is for a capacity of 100 to 120 kg of coffee pulp which was designed for field testing. Figure 2a shows the anaerobic bioreactor, which has the following components: a jacketed fermentation cabin, a chiller for temperature control by cold water circulation, a vertical axis with paddles to homogenize the product to be fermented, a control panel with a single-phase motor of 0.75 Hp, and outlet valves in the lower part for the discharge of waste from the fermentation process. In addition, the bioreactor includes a pair of temperature sensors that are monitored through the control panel. The lid has an AIRLOCK 30-210 L attachment, which allows fermentation gases to pass through and does not allow air to enter the system.

Aerobic bioreactor prototype: The design followed the same steps as the anaerobic bioreactor, considering that in this prototype the lid and water cooling chiller system were omitted. Figure 2b shows the parts of the aerobic bioreactor. This includes a control board and a fermentation chamber containing paddles with a horizontal axis. The lid is not airtight, allowing the aeration necessary for the process, which is called open fermentation.

c) Fermentation

Anaerobic wet fermentation: In this operation, 50 kilos of cherry coffee were entered into the hopper of the closed fermenter. This process was controlled by measuring the pH, which should generally start around 7 and not fall below 3.5, and the working temperature was between 20-25°C. Fermentation lasted approximately 72 hours. After 15 minutes of adding the cherry trees to the hopper, the first measurement of soluble solids was taken, which was between 17 and 20°Brix. Fermentation culminated when values close to 4 °Brix were obtained (Figure 2a).

Aerobic wet fermentation: Likewise, 50 kilos of coffee cherry were entered into the hopper of the open fermenter. This process was controlled by measuring the pH, which should generally start around 7 and not fall below 3.5, and the working temperature was between 20-25°C. Fermentation lasted approximately 72 hours. After 15 minutes of adding the cherry trees to the hopper, the first measurement of soluble solids was taken, which was between 17 and 20°Brix. Fermentation culminates when values of 4.5°Brix are obtained (Figure 2b).

To compare the physical, physicochemical, chemical and sensory attributes, natural fermentation was taken as a control treatment, for this the dry fermentation of 50 kilos of coffee cherry was followed.

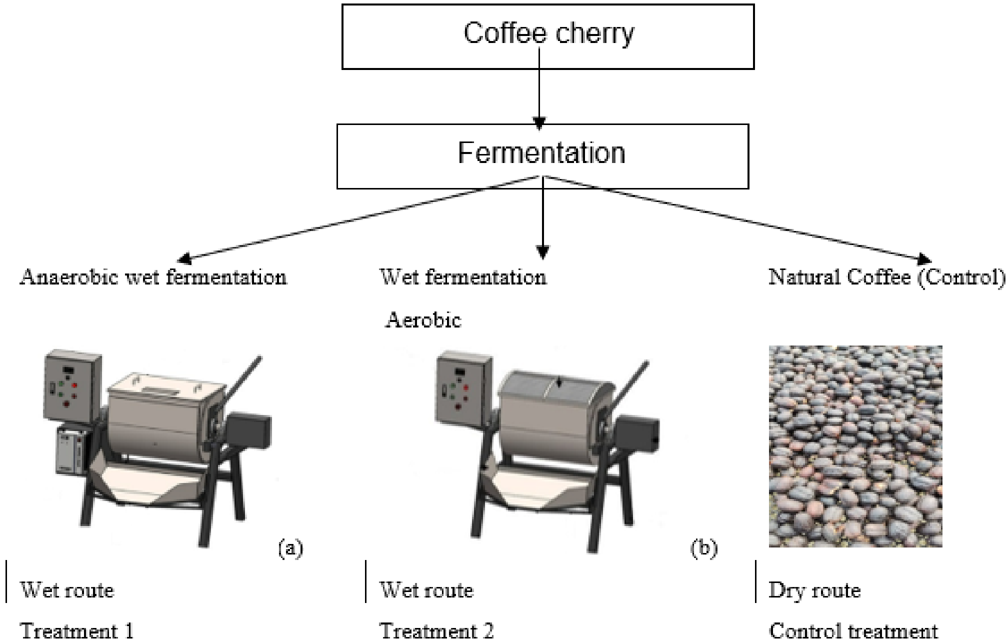

Figure 2. Experimental scheme of the coffee fermentation process under aerobic and anaerobic conditions of coffee (Coffea arabica L.)

Note: The anaerobic and aerobic bioreactors are made of stainless steel material with a capacity of 100 to 120 kg per batch of AISI grade 316L stainless steel material.

After fermentation, the beans were pulped and washed against the current with plenty of water to completely remove the degraded mucilage. Then, they were dried in the sun for approximately 28 days until they reached 12% average humidity. The dried beans were taken to a 500 g HGH brand laboratory roaster per bacth of Peruvian origin, where 150 grams of green coffee were roasted without defects at 190°C at the beginning of roasting, with a roasting time that varied from 8 to 12 minutes, obtaining an average roasting color of 63° Agtron. The roasted beans were left to sit for about 8 hours before cupping.

The coffee was milled on a Mahlkönig GH2 equipment with a capacity of 3Lb of Chinese origin, where the size of the particles was reduced by controlling times and sizes to standardize the samples and facilitate the infusion of coffee. This process was carried out 30 minutes before cupping. The ground coffee was packaged in grain pro bags in 250 g presentations, labeled to identify and track the traceability of the batches produced in the research. The product was stored in open environments at average temperatures of 15-25°C, with a relative humidity of 50-70%, in a cool and dry warehouse.

d) Evaluation of physical, physicochemical, chemical and functional parameters

- Gold weight (g): The quartering method was used where a sample of 50 gold (dry) coffee beans was chosen and weighed individually on an analytical balance (JOANLAB). Then, the weight of the coffee beans is averaged to obtain an average value that represents the gold weight of the sample. This process is repeated for each type of fermented coffee, allowing an accurate estimate of the gold weight of the coffee beans in each sample method recommended by Hanjing et al., (2023)

- Yield: For each experiment, 300 g of dried cherry coffee (weight 1) was taken, the threshed coffee (weight 2) was reweighed, obtaining the Weight 1 / Weight 2 ratio, establishing it as a percentage of yield of green coffee as indicated (Mendoza et al., 2023).

- Density: The bulk density was recorded by determining the volume in milliliters of 100 grams of green coffee, expressed (Kg/L) as indicated by Márquez-Romero et al., (2020).

- Color: For the evaluation of the color of ground green coffee , the parameters of the L* a* b* (CIELAB) system were taken in the L* measures the luminosity of a color and ranges from black (0) to white (100); a* indicates the contribution of red or green (when their value is positive or negative, respectively); and b* indicates the contribution of blue or yellow (when their value is negative or positive, respectively). The overall color difference, ΔE, was determined using the equation $\Delta E=[(\Delta L)^2+(\Delta a)^2+(\Delta b)^2]^{1/2}$ as established by Bicho et al., (2014) and Chervin et al., (1996).

- Total acidity: 10 ml of sample prepared for the determination of soluble solids was taken, NaOH at 0.1N is added in the solution until a pH of 8.2 is obtained, the expenditure was taken to the calculation of the % acidity according to (Vega et al., 2021) with some modifications.

- pH: The pH was measured by placing the potentiometer electrode directly (Brand: Ohaus, Model: Starter 3100), on the coffee sample at a temperature of 20°C according to the AOAC 970.21 method (AOAC, 2010).

- Soluble solids: It was obtained from 2 grams of sample diluted in 50mL of distilled water, being stirred in a mechanical agitator for 1 hour at 150 rpm. The extract was taken to a refractometer as recommended by AOAC 932.14C (AOAC, 2010) with some modifications.

- Humidity: Coffee samples (2 g) were dried on a hot air stove, (FAITHFUL) at 105°C for 24 hours. They were then cooled in a desiccator and weighed to calculate the percentage of moisture per weight difference (International Organization for Standardization ISO:6673, 2003).

- Ash: Coffee samples (2 g) were dried, weighed, and placed in crucibles. They were calcined in a digital muffle furnace (Daihan) at 550°C for 6 hours until white or light gray ashes were obtained. They were then cooled in a desiccator and weighed to calculate the percentage of ash per weight difference recommended by Ramalakshmi and Kubra (2007).

- Total phenolic compounds (TPCs): The determination of total phenols was carried out using the Folin-Ciocalteu method as described by Singleton and Rossi (1965) mentioned by Quispe et al. (2021). The assay was performed using a Genesis 10s UV-Vis spectrophotometer (Thermo Fisher Scientific, UK). The procedure involved adding 500 μL of the Folin-Ciocalteu reagent and 40 μL of each extract to a 10 mL volumetric flask, which was then covered with aluminum foil. After a 10-minute resting period, 500 μL of 10% Na_2CO_3 was added, and the volume was topped up to 10 mL with Milli-Q ultrapure water. Absorbance was measured at a wavelength of 755 nm against a target prepared with 40 μL of ultrapure water. For quantification, a calibration curve was prepared with six points (0.1, 0.2, 0.4, 0.5, 0.6, and 0.9 mg/mL) of gallic acid in water. Total phenol content (TPC) was expressed in mg gallic acid equivalents (GAE) per gram of dry sample. All samples were analyzed in triplicate.

- Antioxidant activity: Determination of antioxidant activity was carried out using the DPPH assay as described by Brand-Williams et al. (1995). The procedure involved and was carried out on a Genesis 10s UV-Vis (Thermo Fisher Scientific, UK) at 515 nm. The DPPH solution was prepared with a mixture of 80% ethanol and 20% Milli-Q ultrapure water. This solution was standardized. The absorbance of the samples was recorded at 540 nm in a spectrophotometer. Quantification was performed using a calibration curve with six points (0.1, 0.2, 0.3, 0.5, 0.6, 0.7 and 0.8 mM) of Trolox in ethanol. Results were expressed in mg of Trolox equivalents (TE) per gram of dry sample. All samples were analyzed in triplicate.

e) Sensory Evaluation:

For the sensory evaluation, 250 g of coffee beans from each batch were used, which were roasted for 12 minutes following a medium roast curve suitable for cupping. For the preparation of each cup, 11 g of ground coffee, with a medium grind and particles of 500 μm, were used in 150 ml of water at approximately 87°C. The samples were evaluated by 7 tasters. All tasters were approved as SCAA Grade Q tasters as recommended by Barbosa et al., (2019). Those who used an SCAA evaluation sheet, according to the cupping criteria of the Specialty Coffee Association of America (2013). The methodology applied to evaluate the sensory profile of the beverages was carried out according to the SCA Tasting Protocol (Lingle, 2011) which included fragrance, aroma, acidity, flavor, body, sweetness, aftertaste, cleanliness of the cup, balance and general appreciation. Ratings on this scale are divided into categories such as good (6.0-6.75), very good (7.0-7.75), excellent (8.0-8.75), and extraordinary (9.0-9.75). This evaluation made it possible to calculate the final score and determine the quality of the coffee (Q-cup quality) based on a score that for specialty coffees the score must be at least higher than 80. Between 80 and 85 the sample is considered to be of very good quality, between 85 and 90 is of excellent quality, and from 90 to 100 is of exceptional quality. The final score is the sum of the individual scores of the 10 characteristics that were evaluated.

f) Data Analysis

The data were analyzed using the IBM SPSS Statistics 25 software to perform a one-factor ANOVA (α=0.05). Subsequently, Tukey's tests were applied to compare the effects of aerobic and anaerobic fermentation methods on the physical, physicochemical, chemical and sensory characteristics of cup coffee, in order to determine the treatment that improves the quality of cup coffee.

3 RESULTS AND DISCUSSIONS

3.1 Physical, physicochemical and chemical characteristics of green coffee

Table 1 presents the results of the mean values of % moisture, weight in gold (g), % yield, and density (Kg/L). These results show differences in the physical parameters of green coffee, influenced by the type of fermentation.

Table 1 Average values of physical, physicochemical and chemical characteristics and green coffee

	Natural fermentation		Anaerobic wet fermentation		Wet fermentation Aerobic	
	$\bar{\chi}$	D.E	$\bar{\chi}$	D.E	$\bar{\chi}$	D.E
Gold weight (g)	224.67N. S	22,05	227.33N. S	18,48	245.33N. S	5,51
Exportable Yield (%)	56.17N. S	5,51	57.09N. S	4,17	61.33N. S	1,38
Density (kg/l)	730.93N. S	35,11	740.13N. S	17,55	750.67N. S	13,32
Humidity (%)	11.00N. S	1,67	11.17N. S	0,92	11,13N. S	2,49

Note: n= 3 replications, one factor ANOVA was established with a 95% confidence level. N.S denote no significance between the types of fermentation.

The results indicate that there are no significant differences in the parameters evaluated (p>0.05). These characteristics are crucial for coffee quality, as they influence quality control, machinery design, and production processes in the coffee industry (Jian et al., 2022). The weight in gold is an indicator of the density and quality of the coffee bean. In this study, the average values obtained were 224.67 g for natural fermentation, 227.33 g for anaerobic wet fermentation and 245.33 g for aerobic wet fermentation. Although no significant differences were found between treatments (p>0.05), the slight variation suggests that fermentation methods may influence the final mass of the grain. According to Abebe et al. (2014), the weight of the beans is a crucial factor in the classification and assessment of coffee quality, since heavier beans generally indicate a higher density and better quality.

Exportable yield is an important measure for the coffee industry, as it determines the proportion of beans that meet quality standards for export. In this study, the exportable yield values were 56.17% for natural fermentation, 57.09% for anaerobic wet fermentation and 61.33% for aerobic wet fermentation. Despite no significant differences (p>0.05), these results are indicative that aerobic fermentation could potentially improve exportable yield. Jang et al. (2017) found that coffee processing, including fermentation, significantly affects the yield and quality of the final product.

The density of green coffee is an indicator of the quality and consistency of the bean. The values obtained in this study were 730.93 Kg/L for natural fermentation, 740.13 Kg/L for anaerobic wet fermentation and 750.67 Kg/L for aerobic wet fermentation, with no significant differences between treatments (p>0.05). High density is generally associated with better quality beans (Jaramillo et al., 2015), and the values obtained in this study suggest that all fermentation methods produce high-quality beans.

Moisture content is crucial for the stability and preservation of green coffee. The average humidity values were 11.00% for natural fermentation, 11.17% for anaerobic wet fermentation and 11.13% for aerobic wet fermentation, all within the range established by the NTP 209.027 (2018) regulation which stipulates a moisture content between 10% and 12%. These results indicate that the fermentation methods used in this study are effective in maintaining adequate moisture levels, essential for the prevention of mold and grain degradation (Corrêa et al., 2010).

3.2 Physical, physicochemical and chemical characteristics of coffee

After roasting and grinding the coffee, its physicochemical characteristics were evaluated, including color, pH, soluble solids, antioxidant capacity, and phenolic compounds (Table 2).

Table 2 Average values of physical, physicochemical and chemical characteristics and coffee

	Natural fermentation		Fermentation Anaerobic Wet		Fermentation Aerobic Wet	
	$\bar{\chi}$	D.E	$\bar{\chi}$	D.E	$\bar{\chi}$	D.E
ΔL	-	-	0.78	-	-5.32	-
Δa*	-	-	0.52	-	4.11	-
Δb*	-	-	8.27	-	0.28	-
ΔE*	-	-	4.22	-	9.84	-
pH*	5.09NS	0,02	5.05NS	0,04	5.10NS	0,03
%Soluble solids*	30.17NS	0,15	28.73NS	3,25	28.67NS	2,39
Antioxidant capacity (μmol trolox/g sample)*	0.26NS	0,02	0.31NS	0,15	0.38NS	0,09
Phenolic compounds (mg EAG/g sample)*	4.59NS	0,17	4.13NS	0,33	4.19NS	0,467
%Acidity (Ac. Citrus)*	1.03NS	0,03	0.98NS	0,08	0.95NS	0,16
% Moisture*	1.53NS	0,11	1.96NS	0,44	1.97NS	0,16
% Ash*	4.03NS	0,28	3.62NS	0,69	3.46NS	0,57

Note: n= 3 repetitions, values of <3 is small and values of >5 is perceptible, * $\Delta E^* \pm \Delta E^* \pm$ANOVA was established from one factor with a 95% confidence level. N.S denote no significance between the types of fermentation.

There are no significant differences in the parameters evaluated (p>0.05), which suggests adequate control of the treatment of the samples. The values of humidity and ash are within the ranges established by the NTP-ISO 3726 standard (maximum 4% humidity and 5% ash) (NTP 209.028:2015). In relation to the pH of coffee, Yu et al. (2023) mention that the typical pH range of coffee is between 4.85 and 5.10, which coincides with the results of this study (5.09-5.10). The acidity of coffee directly influences its sensory profile and is affected by the processing method and roast level (Sanchez-Bridge et al., 2016). The soluble solids, which vary between 28.67% and 30.17%, did not show significant differences, indicating that fermentation does not significantly affect their concentration. Król et al. (2019) mention that polyphenols and other soluble compounds can vary depending on roasting and storage conditions, but in this study, the variations were not significant. The antioxidant capacity of coffee, measured in μmol trolox/g sample, varied between 0.26 and 0.38, with no significant differences between treatments (p>0.05). Phenolic compounds, such as chlorogenic acids, contribute significantly to this ability (Farah & Donangelo, 2006). The stability of these compounds can be affected by the roasting process, as indicated by Mehaya and Mohammad (2020), who point out that the roasting temperature can influence the preservation of antioxidants. Phenolic compounds are responsible for many of the health benefits associated with coffee, as well as its antioxidant capacity. The values obtained in this study ranged from 4.13 to 4.59 mg EAG/g sample, with no significant differences (p>0.05). This suggests that fermentation did not have a considerable impact on the concentration of these compounds. Acosta-Otálvaro et al. (2021) highlight the importance of phenolic compounds in the diet due to their ability to capture free radicals.

The acidity of coffee, measured as a percentage of citric acid, varied between 0.95% and 1.03%, with no significant differences (p>0.05). Acidity is a key sensory attribute that influences the flavor profile of coffee. Sunarharum et al. (2014) point out that the perceived acidity in coffee can vary depending on the variety, processing method, and growing conditions. In this study, the differences in acidity between the fermentation methods were not significant. Moisture content is critical to the quality and shelf life of coffee. The values obtained vary between 1.53% and 1.97%, with no significant differences (p>0.05). NTP 209.028:2015 sets a maximum of 4% moisture for roasted coffee, and all values in this study are within this range. Lim et al. (2022) indicate that humidity control is essential to maintain freshness and prevent coffee spoilage. The ash content indicates the amount of minerals present in the coffee. The values ranged between 3.46% and 4.03%, with no significant differences (p>0.05). This parameter is important for evaluating the purity of coffee. Bicho et al. (2012) mention that ash content can vary depending on the origin of the coffee and the degree of roasting. In this study, the values obtained comply with NTP-ISO 3726, which establishes a maximum of 5%. The difference in luminosity (ΔL*) indicates the change in the brightness of the coffee samples. Anaerobic fermentation did not produce a significant change in luminosity compared to natural fermentation, suggesting that both methods maintain a similar level of brightness, probably due to the retention of pigments and compounds from the Maillard reaction (Wei et al., 2012). The parameter a* represents the chromaticity on the red-green axis. The values show a Δa* of 0.78 between natural and anaerobic fermentation, and a Δa* of -5.32 between natural and aerobic fermentation, indicating a significant reduction in red-to-green tones in aerobic fermentation, possibly due to the degradation of colored compounds (Mariyam et al., 2022). The parameter b* measures chromaticity on the yellow-blue axis. The results show a Δb* of 0.52 between natural and anaerobic fermentation, and 4.11 between natural and aerobic fermentation, with a significant increase in yellow tones during aerobic fermentation, probably due to the oxidation of phenolic components (Farah and Donangelo, 2006). The ΔE* value represents the total color difference between two samples. The ΔE* between natural and anaerobic fermentation is 4.22, while between natural and aerobic fermentation it is 9.84, the latter being visually perceptible, indicating that aerobic fermentation has a greater impact on the color of coffee (Polytechnic University of Valencia, 2019). These findings suggest that fermentation methods can be used strategically to modify and optimize the visual characteristics of coffee (Sunarharum et al., 2014).

3.3 Sensory characteristics of coffee

The coffee samples from the different fermentations were subjected to sensory evaluation by 7 certified tasters. The total scores of the evaluation are presented in Table 3.

Table 3 Total Qualification Scores of Sensory-Evaluated Coffee

Types of fermentation	Average Score	D.E
Natural fermentation	84.40Control	0,28
Anaerobic wet fermentation	86.77th	0,097
Aerobic humidity fermentation	83.63b	0,23

Note: n= 3 repetitions, the sensory evaluation was carried out with 7 SCAA Grade Q tasters

The total evaluation scores of coffee obtained by anaerobic wet fermentation obtained the highest rating score (86.77 points), followed by naturally fermented coffee (84.40 points) and aerobic wet fermentation coffee (83.63 points). According to SCAA standards, these scores classify anaerobic fermentation coffee as excellent specialty and the other two as very good specialty (SCAA, 2013). These results are consistent with the findings of Vega et al. (2021), who demonstrated that coffee processed under anaerobic fermentation has exceptional organoleptic qualities. Sensory evaluation is crucial to validate coffee quality, and the scores obtained reflect the effectiveness of fermentation processes (Worku et al., 2016).

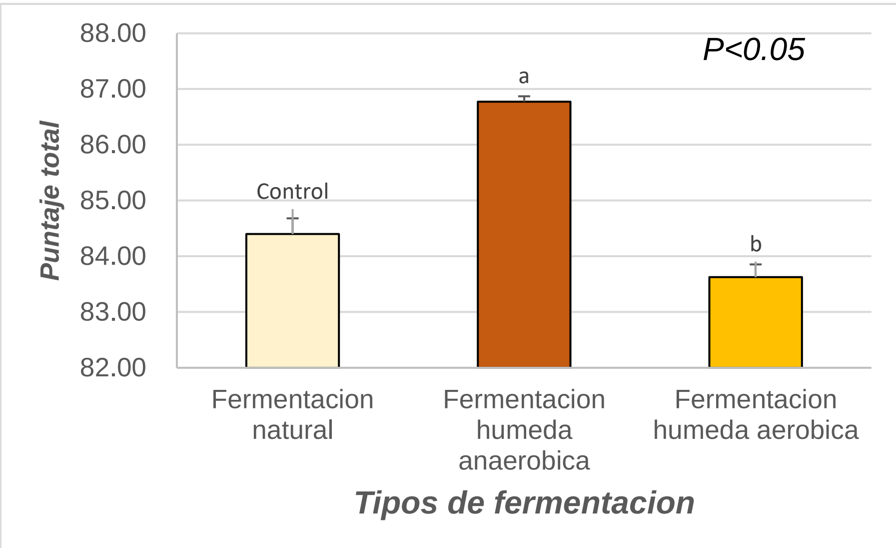

Figure 3. Tukey Mean Comparison Test at 95% Confidence Level. In original language Spanish

Figure 3 shows the results of Tukey's mean comparison test applied to the total qualification scores of sensory-evaluated coffee, with a confidence level of 95%. This test was performed to determine if there are significant differences between the types of fermentation: natural, wet anaerobic and wet aerobic. The results indicate that the mean score of natural fermentation was 84.40 points, while that of anaerobic wet fermentation was 86.77 points, this difference being statistically significant ($p<0.05$). This finding suggests that the anaerobic fermentation process markedly improves the sensory characteristics of coffee compared to natural fermentation. In contrast, the differences between natural fermentation and aerobic wet fermentation are not statistically significant ($p>0.05$), indicating that aerobic fermentation does not improve the sensory characteristics of coffee compared to natural fermentation.

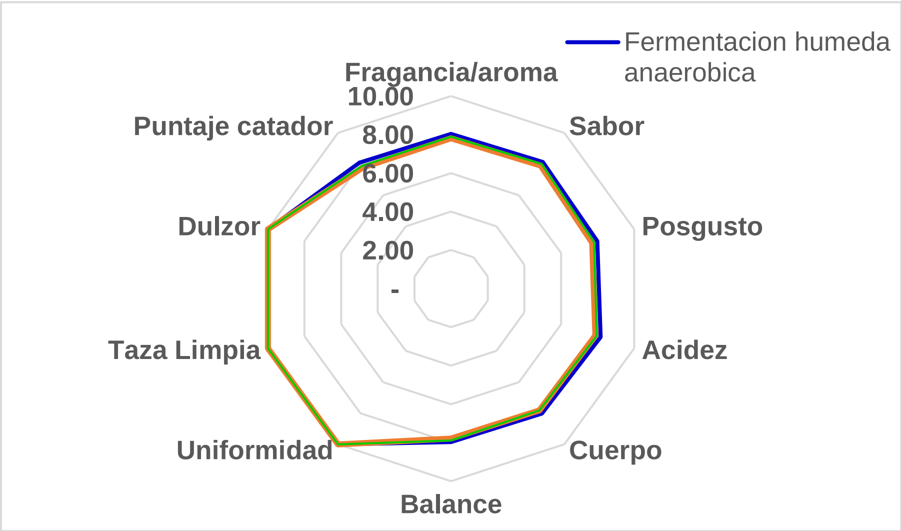

Figure 4. Descriptives of the sensory attributes of the coffee produced in the different types of fermentation . In original language Spanish

Figure 4 presents the results of the sensory evaluation of the attributes of coffee produced under different types of fermentation: natural, anaerobic wet and aerobic wet. Attributes evaluated include fragrance/aroma, flavor, aftertaste, acidity, body, balance, uniformity, clean cup, sweetness, and taster's score. Coffee fermented in anaerobic wet conditions obtained the best scores in most sensory attributes, standing out in fragrance/aroma, flavor and acidity, which suggests a better preservation and development of volatile compounds responsible for aroma and flavor. These findings are consistent with research indicating that anaerobic fermentation may enhance the formation of compounds that contribute to a more complex and enjoyable sensory profile (Silveira et al., 2016). In conclusion, anaerobic wet fermentation stands out as the most effective method for improving the sensory quality of coffee from Villa Rica, Peru, making it a preferred technique for specialty coffee production.

4. CONCLUSION

The findings of this research highlight the importance of anaerobic wet fermentation for the coffee industry in Villa Rica, Peru. This method not only optimizes the sensory profile of coffee, increasing its value in the specialty coffee market, but also underscores the need to control fermentation conditions to ensure product consistency and quality. Future studies should focus on the microbial community involved and how it affects the sensory profile, as well as on identifying specific volatile compounds responsible for the observed differences.

The implementation of anaerobic bioreactors for coffee fermentation represents a crucial innovation to improve the sensory quality of coffee, this process not only enhances sensory attributes, but could also translate into higher incomes for producers by positioning coffee in higher value markets. In addition, it is essential to explore how agricultural practices and storage conditions influence the final quality of coffee to ensure a product of excellence.

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WORKS CITED

Abebe, B., Yirgalem, B., Ataklti, A., Dagne, C., Hyung, K. K., & Yoon-Hwae, H. (2014). Discrimination of Defective and Nondefective Coffee Beans by Their Physical Properties. Journal of Food Process Engineering. doi:10.1111/JFPE.12113

Acosta-Otálvaro, E., Domínguez-Perles, R., Mazo-Rivas, J., & García-Viguera, C. (2021). Bioavailability and radical scavenging power of phenolic compounds of cocoa and coffee mixtures. Food Science and Technology International, 28(6), 514-523. https://doi.org/10.1177/10820132211023258

AOAC., Official Methods of Analysis of AOAC International, 18th Ed., AOAC International, Maryland, USA (2010). [Links]

Arenas, A., Hincapie, A., & Ocampo, G. (2022). Effects of post-harvest process on volatile - sensory profile for coffee in colombia. Coffee Science, 17, 1-14. https://doi.org/10.25186/.v17i.2016

Barbosa, M. D. S. G., dos Santos Scholz, M. B., Kitzberger, C. S. G., & de Toledo Benassi, M. (2019). Correlation between the composition of green Arabica coffee beans and the sensory quality of coffee brews. Food Chemistry, 292, 275-280.

Bicho, North Carolina; Leitão, AE; Ramalho, JC; Lidon, FC Application of color parameters to evaluate the quality of arabica and robusta green coffee.Emir. J. Food agriculture.2014 ,26, 9-17. [Google Scholar] [CrossRef] [Green version]

Bicho, N., Leitão, A., Ramalho, J., & Lidon, F. (2012). Use of colour parameters for roasted coffee assessment. Food Science and Technology, 32(3), 436-442. https://doi.org/10.1590/s0101-20612012005000068

Brand-Williams, W., Cuvelier, M. E., Berset, C. (1995). Use of a free radical method to evaluate antioxidant activity. LWT – Food Sci. Technol., 28(1), 25–30. https://doi. org/10.1016/S0023-6438(95)80008-5

Bressani, A. P. P., Martinez, S. J., Sarmento, A. B. I., Bor´em, F. M., & Schwan, R. F. (2020). Organic acids produced during fermentation and sensory perception in specialty coffee using yeast starter culture. Food Research International, 128, Article 108773. https://doi.org/10.1016/j.foodres.2019.108773.

Cândido, T., Sepini, P., Abrão, P., Oliveira, R., Campos, K., & Paiva, L. (2019). EFFECT OF INDUCED BIOLOGICAL FERMENTATIONS ON THE SENSORY QUALITY OF COFFEE. Coffee Science, 14, 473-476. https://doi.org/10.25186/cs.v14i4.1617 .

Chervin, C.; Franz, P.; Birrell, F. Calibration tile slightly influences assessment of color change in pears from green to yellow using de L,a,b space. Horticultural Science, v. 31, p. 471, 1996.

Ciriaco, J. (2013). Coffee sensory evaluation guide. Editorial Académica Española.

Corrêa, P., et al. (2010). Moisture sorption isotherms and isosteric heat of sorption of coffee in different processing levels. International Journal of Food Science & Technology. https://doi.org/10.1111/j.1365-2621.2010.02373.x

Farah, A. & Donangelo, C. (2006). Phenolic compounds in coffee. Brazilian Journal of Plant Physiology, 18(1), 23-36. https://doi.org/10.1590/s1677-04202006000100003

Haile, M. and Kang, W. (2019). The role of microbes in coffee fermentation and their impact on coffee quality. Journal of Food Quality, 2019, 1-6. https://doi.org/10.1155/2019/4836709

Halagarda, M. (2023). Influence of post-harvest processing on functional properties of coffee (coffea arabica l.). Molecules, 28(21), 7386. https://doi.org/10.3390/molecules28217386

Hanjing, Wu., Claudia, González, Viejo., Sigfredo, Fuentes., Frank, R., Dunshea., Hafiz, Ansar, Rasul, Suleria. (2023). The Impact of Wet Fermentation on Coffee Quality Traits and Volatile Compounds Using Digital Technologies. Fermentation, doi: 10.3390/fermentation9010068

Jang, S., et al. (2017). Processing method of green coffee beans.

Jaramillo, M. F., Chaves, B., & Ceballos, J. (2015). Evaluation of the physical and sensory quality of coffee produced at different altitudes in the Colombian coffee region. Brazilian Journal of Agricultural and Environmental Engineering. https://doi.org/10.1590/1807-1929/agriambi.v19n8p769-775

Jiang, S., et al. (2014). Effect of fermentation on the quality and sensory properties of coffee beans. Food Research International, 62, 424-431.

Jiménez-Ochoa, W., & Gutierrez, M. (2021). Impact of fermentation on the sensory profile of coffee. Journal of Food Science, 86(3), 923-932.

Król, K., Gantner, M., Tatarak, A., & Hallmann, E. (2019). The content of polyphenols in coffee beans as roasting, origin and storage effect. European Food Research and Technology, 246(1), 33-39. https://doi.org/10.1007/s00217-019-03388-9

Lim, G. C. W., Hou, C., Hsieh, L., Wu, S., & Ciou, J. (2022). Influence of saccharomyces boulardii inoculation on post-harvest processing methods on coffee quality. Journal of Food Processing and Preservation, 46(12). https://doi.org/10.1111/jfpp.17273

Lingle, T. R. (2011). Systematic guide to the sensory evaluation of Coffee's flavor. In Specialty Coffee Association of America (Ed.), The coffee cupper's handbook (pp.1–66). Specialty Coffee Association of America. @

Mariyam, S., Kistanti, A., Karyadi, J., & Widiyastuti, R. (2022). Improving coffee quality through yeast addition in the fermentation process to support sustainable coffee production. IOP Conference Series: Earth and Environmental Science, 1005(1), 012012. https://doi.org/10.1088/1755-1315/1005/1/012012

Mariyam, S., Kistanti, A., Karyadi, J., & Widiyastuti, R. (2022). Improving coffee quality through yeast addition in the fermentation process to support sustainable coffee production. IOP Conference Series: Earth and Environmental Science, 1005(1), 012012. https://doi.org/10.1088/1755-1315/1005/1/012012

Márquez-Romero, F. R., Huamán, S., Carrión Sánchez, H. M., Peña Valdeiglesias, J., & Cabrera Márquez, S. (2020). Characterization of the physical and sensory quality of Cirialo coffee – The Cusco-Peru Convention.TAYACAJA,3(2). https://doi.org/10.46908/rict.v3i2.106

Martínez, S., Rabelo, M., Bressani, A., Mota, M., Borém, F., & Schwan, R. (2021). Innovative stainless steel tanks improve the quality of coffee fermentation. Food Research International, 139, 109921. https://doi.org/10.1016/j.foodres.2020.109921

Mehaya, F. & Mohammad, A. (2020). Thermostability of bioactive compounds during roasting process of coffee beans. Heliyon, 6(11), e05508. https://doi.org/10.1016/j.heliyon.2020.e05508

Mendoza Marcillo, B. F., Pincay Menéndez, J. D., & Bravo Zamora, R. C. (2023). Influence of the harvest of ripe and green coffee on the physical and organoleptic quality of coffee (Coffea arabica L.).Agroforestry and Environment,1(1), 14–25. https://doi.org/10.47230/agrosilvicultura.medioambiente.v1.n1.2023.14-25

Mulyara, B., Supriyadi, S., Rahmadian, Y., & Ichsan, OAN (2021). Sensory properties and volatile compound profile of anaerobic fermented gayo arabica coffee in unwashed processing. Pelita Perkebunan (Journal of Coffee and Cocoa Research), 37(3), 239-254. https://doi.org/10.22302/iccri.jur.pelitaperkebunan.v37i3.464

Oliveira, E., Luz, J., Castro, M., Filgueiras, P., Guarçoni, R., Castro, E., Silva, M., & Pereira, L. (2021). Chemical and sensory discrimination of coffee: impacts of planting and fermentation altitude.European food research and technology, 248, 659 - 669.https://doi.org/10.1007/s00217-021-03912-w.

INTERNATIONAL ORGANIZATION FOR STANDARDIZATION. ISO 6673 : Green coffee - determination of mass loss at 105 degrees C. Geneva: ISO, 2003. 4p.

Peñuela-Martínez, A., Zapata-Zapata, A., & Durango-Restrepo, D. (2018). Performance of the different fermentation methods and effect on coffee quality (Coffea arabica L.). Coffee science. https://doi.org/10.25186/CS.V13I4.1486 .

Puerta, G. I., & Echeverry-Molina, G. (2015). Controlled coffee fermentation: Technology to add value to quality.

Quispe, M. A., Valenzuela, J. A. P., Cruz, A. R. H. D. L., Silva, C. R. E., Quiñonez, G. H., & Cervantes, G. M. M. (2021). Optimization of ultrasound-assisted extraction of polyphenols from globe artichoke (Cynara scolymus L.) bracts residues using response surface methodology. Acta Scientiarum Polonorum Technologia Alimentaria, 20(3), 277-290.

Ramalakshmi, K. & Kubra, IR (2007). Physicochemical characteristics of green coffee: comparison of classified and defective beans. Journal of Food Science, 72(5). https://doi.org/10.1111/j.1750-3841.2007.00379.x

Sanchez-Bridge, B., Renouf, M., Sauser, J., Beaumont, M., & Actis-Goretta, L. (2016). The roasting process does not influence the extent of conjugation of coffee chlorogenic and phenolic acids. Biofactors, 42(3), 259-267. https://doi.org/10.1002/biof.1268

SCA— Specialty Coffee Association (2013). Available in: https://sca.coffee/research /protocols-best-practices.

SCAA. (2013). SCAA Protocols | Cupping Specialty Coffee.

Silva, L. (2024). Enhancing sensory quality of coffee: the impact of fermentation techniques on coffea arabica cv. Catiguá MG2. Foods, 13(5), 653. https://doi.org/10.3390/foods13050653

Silveira, J., et al. (2016). The role of anaerobic fermentation in coffee quality. Journal of Food Processing and Preservation, 40(2), 345-355.

Sulaiman, I. and Hasni, D. (2022). Microorganism growth profiles during fermentation of gayo arabica wine coffee. IOP Conference Series Earth and Environmental Science, 951(1), 012076. https://doi.org/10.1088/1755-1315/951/1/012076

Sunarharum, W. B., Williams, D. J., & Smyth, H. E. (2014). Complexity of coffee flavor: A compositional and sensory perspective. Food Research International, 62, 315-325.

Polytechnic University of Valencia. (2019, December 3). Description of the color in the CieLab* space. [Video]. YouTube. https://www.youtube.com/watch?v=Q7afXHJNpnQ

Vega, A., et al. (2021). Sensory evaluation of anaerobically fermented coffee. Journal of the Specialty Coffee Scientific Association, 34(1), 45-60.

Vega, A., León, J. A. D., Reyes, S. M., & Gallardo, J. M. (2021). Mathematical model to determine the correlation between physicochemical parameters and the sensory quality of Geisha and Pacamara coffee from Panama. Information technology, 32(1), 89-100.

Wang, S.-J., & Zhong, J.-J. (2007). Bioreactor engineering. In S.-. T. Yang (Ed.), Bioprocessing for value-added products from renewable resources (pp. 131–161). Elsevier Inc.. https://doi.org/10.1016/B978-044452114-9/50007-4

Wei, F., Furihata, K., Koda, M., Hu, F., Miyakawa, T., & Tanokura, M. (2012). Roasting process of coffee beans as studied by nuclear magnetic resonance: time course of changes in composition. Journal of Agricultural and Food Chemistry, 60(4), 1005-1012. https://doi.org/10.1021/jf205315r

Worku, M., et al. (2016). The impact of fermentation methods on coffee quality. Coffee Science, 11(1), 23-30

Yu, G., Fengying, Z., Chun, X., Peng, Q., Kuaile, J., Huabo, D., Meng, Z., Yunfeng, L., Butian, W., Xuedong, S., Xuejun, L., & Chuanli, Z. (2023). Effects of Different Altitudes on Coffea arabica Rhizospheric Soil Chemical Properties and Soil Microbiota. Agronomy. https://doi.org/10.3390/agronomy13020471

Zhang, S., Bruyn, F., Pothakos, V., Torres, J., Falconi, C., Moccand, C., ... & Vuyst, L. (2019). Following coffee production from cherries to cup: microbiological and metabolomic analysis of wet processing of coffea arabica. Applied and Environmental Microbiology, 85(6). https://doi.org/10.1128/aem.02635-18