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Life Cycle Assessment – Evaluating the Physical and Sensory Quality of Bondowoso Arabica Coffee through Precision Fermentation

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Abstract

Coffee production is vital for the economic activities of smallholders for annual income, Arabica Coffee Bondowoso, Indonesia. Smallholder coffee farms can increase prices and break the long sales chain with quality specialty coffee. This study aims to understand in-depth precision fermentation as an evaluation of the physical and sensory quality of Green Beans (GB). A Life Cycle Assessment (LCA) was applied to evaluate the Global Warming Potential (GWP). Observation and experimentation were chosen for the coffee process: anaerobic. Primary data were combined with secondary data calculations using the ReciPe 2016 method, Simapro v9.3.03. The results of this study provide coffee category grade two, including coffee scores of 84.25, respectively, for anaerobic. GWP from processed Cherry Beans (CB) to Coffee Powder (CP) are 1.39 kg CO2-eq for one kg CP, respectively. Keywords: Life cycle assessment (LCA), Global warming potential (GWP), anaerobic, precision fermentation, sensory quality.

1. Introduction

Coffee production underpins rural livelihoods across many tropical countries and remains especially critical for smallholders, who contribute a substantial proportion of global supply and rely on coffee sales as a primary source of household income. In Indonesia, coffee is an export-oriented strategic commodity, and current development efforts increasingly emphasize quality improvement at both the farm and post-harvest stages to enable access to higher-value specialty markets. Indonesia cultivates both Arabica (*Coffea arabica*) and Robusta (*Coffea canephora*). While Robusta typically dominates national production in volume, Arabica contributes a smaller share yet provides higher economic value because it is closely associated with specialty-grade characteristics and origin-based differentiation. Arabica is generally grown at higher elevations (commonly ≥ 700 m a.s.l.), whereas Robusta is more tolerant of lower elevations and warmer conditions, resulting in distinct production landscapes, harvesting calendars, and post-harvest processing choices.

The commercialization of specialty coffee is closely linked to standardized sensory evaluation and market systems that reward consistent cup quality. The Specialty Coffee Association (SCA) uses a 100-point cupping framework in which coffees scoring ≥ 80 points are commonly classified as “specialty.” High-performing lots may further enter premium competitions and auctions such as the Cup of Excellence (COE), which applies multi-stage sensory screening and recognizes top-scoring coffees with substantial market premiums. In practice, participation in COE-type mechanisms can motivate farmers and processors to implement stricter cherry selection, improved defect control, and better traceability, thereby discouraging quality mixing and supporting a shift from commodity-grade coffee toward differentiated specialty lots. This pressure to meet international benchmarks is intensified by the global scale of coffee production; FAO records indicate that coffee is produced in more than 80 producing countries and territories, highlighting the strong competition in quality-based export markets.

Post-harvest processing is a major determinant of final cup quality because it regulates the chemical and biochemical transformations that occur between harvest and drying. Broadly, coffee is processed

using wet (washed) or dry (natural) methods, and both approaches can produce high-quality products depending on cultivar, ripeness, processing hygiene, and environmental conditions. Fermentation—whether spontaneous or controlled—is particularly influential because microorganisms modify sugars, acids, and aroma precursors in the mucilage and bean surface environment, which later shape the sensory attributes after roasting. Recent studies demonstrate that manipulating fermentation duration (including extended fermentation up to ~ 96 h), oxygen exposure (anaerobic or self-induced anaerobiosis), and the use of inoculation/starter cultures can generate distinct chemical profiles and sensory outcomes. Consequently, “precision fermentation” has emerged as a promising concept in specialty processing, aiming to improve reproducibility by controlling key parameters such as time, temperature, and mass transfer.

Anaerobic fermentation performed in a controlled fermentor is especially important because it converts fermentation from a highly variable, artisanal step into a standardized and repeatable unit operation. Conventional anaerobic-style processing (e.g., sealed bags or drums under ambient conditions) often experiences uncontrolled temperature changes, uneven contact between mucilage and microbial communities, inconsistent oxygen exclusion, and variable contamination from the surrounding environment. These factors influence microbial succession and metabolic pathways, thereby affecting the formation of organic acids, alcohols, and aroma-active intermediates. As a result, sensory outcomes may vary markedly between batches, and the risk of defects—such as over-fermentation, unbalanced acidity, harsh/solvent-like notes, or undesirable “ferment” characteristics—may increase. Importantly, evidence from fermentation research indicates that relatively small deviations in fermentation time and temperature can meaningfully shift volatile composition and aroma profiles, reinforcing the need for tight operational control when targeting specialty-grade consistency.

A fermentor-based approach enables control of three parameters that are particularly decisive in anaerobic coffee processing: (i) oxygen management, (ii) temperature regulation, and (iii) mixing/agitation. First, reliable oxygen limitation stabilizes anaerobic conditions and reduces uncontrolled microbial contamination, improving the predictability of fermentation trajectories. Second, temperature control is essential because fermentation kinetics are temperature dependent; without regulation, accelerated reactions can drive rapid acidification and excessive metabolite accumulation, increasing the likelihood of defects. Third, controlled mixing improves mass transfer and batch uniformity by reducing local gradients (e.g., hotspots, stagnant zones, uneven mucilage breakdown), which helps ensure consistent biochemical conversion across the entire batch. In addition to quality benefits, a closed and controlled fermentor strengthens environmental assessment because it enables systematic monitoring of process outputs, including gas production, and facilitates a more reliable mass-balance for life cycle inventory development.

Moreover, improving coffee quality must be evaluated alongside environmental performance. Coffee processing can generate high-strength wastewater and emissions, and unmanaged by-products may contribute to local pollution as well as climate impacts. Coffee effluents often contain high organic loads (reflected in elevated COD and BOD) and suspended solids, which can degrade receiving water bodies if

discharged without adequate treatment. From a climate perspective, energy use, wastewater handling (including potential methane generation under anaerobic conditions), and by-product management can significantly influence Global Warming Potential (GWP) outcomes in Life Cycle Assessment (LCA). Anaerobic streams may also provide mitigation opportunities if captured and valorized (e.g., through biogas recovery); however, this requires measurement-based inventory data, transparent assumptions, and appropriate system boundaries.

In this study, Arabica coffee was selected because it is more strongly associated with the specialty segment and typically commands higher price premiums than Robusta when quality attributes (floral/fruity notes, acidity balance, and aroma complexity) are achieved consistently. Arabica is also generally more sensitive to post-harvest processing conditions, meaning that variations in fermentation temperature, duration, oxygen exposure, and mixing can lead to pronounced changes in organic acid formation, volatile precursor development, and ultimately cup profile. This sensitivity is advantageous for process research because it allows the effect of controlled fermentation to be detected more clearly through cup testing and quality grading. In addition, Arabica in Indonesia is commonly cultivated at higher altitudes, where cooler conditions and slower cherry maturation can support higher sensory potential, but this potential can be lost if fermentation is uncontrolled or inconsistent. Therefore, using Arabica provides a relevant and high-impact case to test whether a controlled fermentor can deliver repeatable specialty-quality improvements while also enabling more reliable measurement of emissions and wastewater characteristics for LCA and GWP accounting.

2. Materials and Methods

2.1 Study area

The study was carried out with the Bondowoso Coffee Group in Pakis Village, Bondowoso Regency, East Java Province, Indonesia. The plantations were located at 1,048–1,400 m above sea level (latitude −7.9231361, longitude 113.708889), representing a typical upland Arabica production zone.

2.2 Raw material selection

Fully ripe red cherries were collected during the Arabica harvest season (May–June 2025) from plantations managed by the Bondowoso Coffee Group in the Argopuro Mountain region. The coffee trees in the study area have been cultivated for approximately 33 years. Cherries were manually sorted to remove visible defects (e.g., insect damage, mold, broken skin, and underripe/overripe fruit). The soluble solids content of cherry juice ranged from 11% to 17% °Brix, measured using an automatic temperature-compensated (ATC) optical refractometer.

2.3 Processing design and treatments

Post-harvest processing was designed as controlled anaerobic fermentation in a closed fermentor followed by washing and drying. Freshly harvested ripe cherries were pulped to obtain coffee beans with mucilage (CB). The pulped CB were transferred into the fermentor and fermented for 96 h under

anaerobic conditions. A controlled water addition was applied to support uniform fermentation and facilitate mucilage breakdown prior to subsequent washing and drying. Three experimental groups were evaluated: (i) control (no fermentation), (ii) anaerobic fermentation at 30°C, and (iii) anaerobic fermentation at 35°C.

2.4 Fermentor system

A 5 kg per batch fermentation system was developed through collaborative research between the University of Jember and PT SAS (Jember), supported by BRIN funding [21]. The fermentor was equipped with an automatic stirrer (≈ 25 rpm), a water-jacket heater for temperature regulation (30–35°C) [22–24], and a radiator-based cooling unit to prevent overheating when jacket temperature exceeded ~ 36–40°C. Fermentation pH was monitored as an indicator of process progression [9]. Electricity demand was measured and reported as kWh per hour and per batch (Fig. 2).

2.5 Physical quality assessment (SNI)

Green bean (GB) grade was determined using the Indonesian National Standard (SNI) defect-point system [18]. Approximately 300 g of beans were sampled after sorting. Defect values were summed to obtain a total defect score, which was then used to classify the coffee into Grades 1–6 (Table 1).

Table 1
Defect parameter score SNI.

Grade Quality	Defect Parameters Score
Grade 1	11
Grade 2	12–25
Grade 3	26–44
Grade 4	45–80
Grade 5	81–150
Grade 6	151–225

2.6 Sensory evaluation (SCA/CQI)

Sensory evaluation was performed at the Indonesian Coffee and Cocoa Research Institute (ICCRI) [2] following the SCA cupping protocol and evaluated by at least two certified Q Arabica Graders [17]. All samples were roasted to medium roast (Agtron 55) [20]. Attribute scores and total score were recorded, including any taint/defect notes.

2.7 Gas and wastewater measurements

Fermentation headspace gas was captured and analyzed by gas chromatography (GC) at the University of Jember to determine CO_2 and CH_4 concentrations. While liquid effluent from fermentation process

was measured chemical oxygen demand (COD), biochemical oxygen demand (BOD), and total suspended solid (TSS) [11].

2.8 Life cycle assessment

The functional unit was 1 kg of coffee powder (CP). Primary data from observations and experiments were combined with secondary background data in SimaPro v9.3.0.3. Impact assessment was performed using the ReCiPe 2016 Midpoint (H) method [19, 20]. Electricity consumption was modeled using the local grid supply. Process-stage energy demand is summarized in Table 2, and the mass balance is summarized in Table 3.

Table 2
Energy demand at every stage*

Materials Arabica	**Process**
Flow Processing	Anaerobic
Motor Cycle (Petrol), litre	0.25
Washing Cherry Beans, litre	5
Depulping, kWh	0.06
Fermentor, kWh	2.13
Dehulling, kWh	0.04
Roasting Coffee, kWh	0.44
Roasting Coffee Skin, kWh	-
Grinding Coffee, kWh	0.19
*Data were measured.	

Table 3
Mass balance by processing method for Bondowoso Arabica coffee*

Stages process	Anaerobic
Cherry Beans, kg	5
Depulping, kg	2.5
Inject water, kg	2.3
Fermentation, kg	4.8
Drying CB/Pulp, kg	2.3
Dehulling, kg	2.3
Hand Sorting, kg	2.0
Roasting GB, kg	1.4
Grinding, kg	1.4
*Data were measured.	

3. Results and Discussion

3.1 Physical processing and green bean defects

On-farm and post-harvest handling influence bean integrity and defect formation. Field-related defects can arise from insect damage, notably the coffee berry borer (Hypothenemus hampei), which can reduce bean density and promote spoilage [25]. Processing and storage can also introduce defects such as cracked beans, parchment fragments, and discoloration associated with improper moisture control. Based on SNI grading, the final defect score for the anaerobic sample was 13.5, corresponding to Grade 2 (Table 4). Maintaining Grade 2 (defect score 12–25) reduces the likelihood of taint/defect attributes during cupping and supports specialty market targeting.

Table 4
Defect score analysis.

No	Type of Defect (Seed)	Defect score	QS An	SV An
1	1 Black seed	1	0	0
2	1 Half seed	0.5	1	0.5
3	1 Cracked black	0.5	0	0
4	1 Dried cherry	1	0	0
5	1 Dark brown	0.25	20	5
6	1 HS big-sized	1	0	0
7	1 HS medium-sized	0.5	0	0
8	1 HS small-sized	0.2	0	0
9	1 Parch skin seed	0.5	0	0
10	1 Parch big-sized	0.5	2	1
11	1 Parch medium-sized	0.2	0	0
12	1 Parch small-sized	0.1	0	0
13	1 Cracked seed	0.2	20	4
14	1 Pale seed	0.2	0	0
15	1 Hole seed	0.1	10	1
16	1 Hole (more than 1)	0.2	5	1
17	1 Freckles seed	0.1	10	1
18	1 Branch big-sized	5	0	0
19	1 Branch medium-sized	2	0	0
20	1 Branch small sized	1	0	0
Final defect score				**13.5**
Quantity seeds = QS; Score value = SV; Anaerobic = An				

3.2 Sensory quality

Cupping results are summarized in Table 5, with descriptive notes in Table 6. The 35°C treatment achieved the highest total score (84.50), with improved balance and sweetness-associated descriptors relative to the control and 30°C treatment. These results align with reports that controlled anaerobic fermentation and inoculation can yield fruit-forward profiles and specialty-level scores [26, 27]. Because

SCA commonly classifies scores of 80–84.99 as ‘Very Good’ and ≥ 85 as ‘Excellent’, the coffees in this study fall within the Very Good–Specialty range [17].

Table 5
Sensory quality attributes for Bondowoso Arabica coffee*

Cup test	**Sample**		
Atributes	**Control**	**30^0C**	**35^0C**
Fragrance	7.63	7.50	7.88
Flavor	7.50	7.50	7.88
Aftertaste	7.50	7.50	7.75
Acidity	7.50	7.38	7.63
Body	7.50	7.38	7.88
Uniformity	10	10	10
Balance	7.50	7.38	7.75
Clean Cup	10	10	10
Sweetness	10	10	10
Overall	7.50	7.38	7.50
Total Score	**82.63**	**82.00**	**84.50**
*Data were measured from the panelist ICCRI			

Table 6
Total score, classification, and description of Bondowoso Arabica

Processing	**Compile**	**Quality**	**Notes**
Method	**Score**	**Classification**	**Description**
Control	82.63	Excellent-Specialty	Toasty, nutty, soybean aroma, grassy, spicy-chili, brown sugar
30^0C	82.00	Excellent-Specialty	Nutty, soybean aroma, grassy, potato
35^0C	84.50	Excellent-Specialty	Brown sugar, nutty, honey, spicy-chili-honeyed-tea rose, black tea
*Data were measured from panelist ICCRI			

3.3 Emissions and wastewater characteristics

Gas production profiles (Fig. 5) showed peak CO_2 on day 2 (≈ 34,550 ppm) followed by a decline by day 4 (≈ 11,340 ppm). CH_4 was detected at lower concentrations (≈ 1.96 ppm on day 1 to ≈ 3.2 ppm on day 3), but was included due to its higher climate impact per unit mass. Wastewater COD, BOD, and TSS (Fig. 6) were measured and included in the life cycle inventory to represent effluent burden [11].

3.4 GWP results and hotspot analysis

The modeled GWP from CB to CP was 1.39 kg CO_2-eq per 1 kg CP (Table 7). Electricity consumption for fermentor operation (2.13 kWh per batch) was a major contributor, accounting for 0.67 kg CO_2-eq of the total, while the remaining stages contributed 0.72 kg CO_2-eq. These results indicate a quality–environment trade-off: controlled fermentation improves reproducibility and sensory performance but can increase GWP via electricity demand. Optimizing insulation, heating efficiency, batch scheduling, and using lower-carbon electricity could reduce this hotspot.

Table 7
Results of this study on the anaerobic process.

Coffee processing	Stages	
	CB to GB	CB to CP
Anaerobic	0.9 kg CO_{2-eq}	1.39 kg CO_{2-eq}

Declarations

Author Contribution

AA and EH: Writing – original draft, Conceptualization, and Methodology. NN, J, and JK: Formal analysis.NA and TL: Data curation. YW and NP: Project administration.

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References

1. R. N. Valenzuela Antezana and G. I. Luna-Mercado, “Effect of processing methods (washed, honey, natural, anaerobic) of catimor coffee on physical and sensory quality in Alto Inambari, Peru,” *Coffee Sci.*, vol. 18, 2023, doi: 10.25186/.v18i.2111.

2. A. W. Susilo, D. Nugroho, I. A. Sari, and D. F. S. Hartatri, “Katalog Produk dan Jasa Unggulan Pusat Penelitian Kopi dan Kakao Indonesia,” *Pus. Penelit. Kopi dan Kakao Indones.*, pp. 1–35, 2019.
3. P. Data, D. A. N. Sistem, and I. Pertanian, “OUTLOOK KOMODITAS,” 2022.
4. M. I. Sulaiman *et al.*, “Making biodiversity work for coffee production. A case study of Gayo Arabica coffee in Indonesia,” *MOJ Ecol. Environ. Sci.*, vol. 6, no. 4, pp. 156–162, 2021, doi: 10.15406/mojes.2021.06.00228.
5. M. Ibnu, P. Glasbergen, A. Offermans, and B. Arifin, “Farmer Preferences for Coffee Certification: A Conjoint Analysis of the Indonesian Smallholders,” *J. Agric. Sci.*, vol. 7, no. 6, pp. 20–35, 2015, doi: 10.5539/jas.v7n6p20.
6. W. For and O. Use, “Wipo for official use only,” 1999.
7. “Auction Results - Alliance For Coffee Excellence.pdf.”.
8. G. Dunn, “Annual Review The International Coffee Organization (ICO),” *Build. Eng.*, vol. 95, no. 1, p. 36, 2022.
9. S. J. Martinez, M. H. S. Rabelo, A. P. P. Bressani, M. C. B. Da Mota, F. M. Borém, and R. F. Schwan, “Novel stainless steel tanks enhances coffee fermentation quality,” *Food Res. Int.*, vol. 139, no. April 2020, 2021, doi: 10.1016/j.foodres.2020.109921.
10. W. dos S. Gomes *et al.*, “Changes in the Chemical and Sensory Profile of Coffea canephora var. Conilon Promoted by Carbonic Maceration,” *Agronomy*, vol. 12, no. 10. 2022, doi: 10.3390/agronomy12102265.
11. M. Banti and E. Abraham, “Coffee Processing Methods, Coffee Quality and Related Environmental Issues,” *J. Food Nutr. Sci.*, vol. 9, no. 6, pp. 144–152, 2021, doi: 10.11648/j.jfns.20210906.12.
12. C. Feathers, U. Liquid-, and S. A. Digestions, “Using Liquid- and Solid-State Anaerobic Digestions,” 2021.
13. D. M. de J. Cassimiro *et al.*, “Wet fermentation of Coffea canephora by lactic acid bacteria and yeasts using the self-induced anaerobic fermentation (SIAF) method enhances the coffee quality,” *Food Microbiol.*, vol. 110, no. September 2022, 2023, doi: 10.1016/j.fm.2022.104161.
14. Z. Jiarong, S. Xuequan, L. Pinhe, Z. Tongze, J. J. A, and C. Harold, “Preliminary Characterization of Phytochemicals and Novel Compounds,” *Foods*, vol. 11, pp. 1–19, 2022.
15. B. Girma and A. Sualeh, “A Review of Coffee Processing Methods and Their Influence on Aroma,” *Int. J. Food Eng. Technol.*, vol. 6, no. 1, p. 7, 2022, doi: 10.11648/j.ijfet.20220601.12.
16. M. Várady, J. Tauchen, P. Klouček, and P. Popelka, “Effects of Total Dissolved Solids, Extraction Yield, Grinding, and Method of Preparation on Antioxidant Activity in Fermented Specialty Coffee,” *Fermentation*, vol. 8, no. 8, 2022, doi: 10.3390/fermentation8080375.
17. SCA, “Protocols and Best Practices,” p. 20, 2018, [Online]. Available: https://www.scith.coffee/wp-content/uploads/2021/03/SCA-Protocols-_-Best-Practices.pdf.
18. BSN (Badan Standardisasi Nasional), “SNI 01-2907-2008: Biji Kopi,” *Badan Standarisasi Nas.*, pp. 1–16, 2008.

19. E. Catalán, D. Komilis, and A. Sánchez, “Environmental impact of cellulase production from coffee husks by solid-state fermentation: A life-cycle assessment,” *J. Clean. Prod.*, vol. 233, pp. 954–962, 2019, doi: 10.1016/j.jclepro.2019.06.100.
20. A. Irawan and B. C. McLellan, “Study on biogas production from coffee wastes and cow-dung fermentation and its use towards reducing emissions from coffee roasting,” *IOP Conf. Ser. Earth Environ. Sci.*, vol. 1201, no. 1, p. 012004, 2023, doi: 10.1088/1755-1315/1201/1/012004.
21. N. L. Hal *et al.*, “Direktorat pendanaan riset dan inovasi,” 2023.
22. R. Reta *et al.*, “Fermentation of Arabica Coffee Beans Using Ohmic Heating Technology in Producing Specialty Coffee,” *Pelita Perkeb. (a Coffee Cocoa Res. Journal)*, vol. 36, no. 3, pp. 226–235, 2020, doi: 10.22302/iccri.jur.pelitaperkebunan.v36i3.452.
23. D. Sagita *et al.*, “Experimental investigation of heating pattern, energy requirement and electrical conductivity in a batch ohmic heating system for coffee fermentation,” *Innov. Food Sci. Emerg. Technol.*, vol. 76, no. November 2021, p. 102946, 2022, doi: 10.1016/j.ifset.2022.102946.
24. G. Adolfo and F. Campos, “Wet-coffee processing production wastes: Quality, Potentials, and Valorization Opportunities,” 2022, [Online]. Available: https://doi.org/10.25932/publishup-55882.
25. J. H. Gómez, P. Benavides, J. D. Maldonado, J. Jaramillo, F. E. Acevedo, and Z. N. Gil, “Flower-Visiting Insects Ensure Coffee Yield and Quality,” *Agriculture*, vol. 13, no. 7, p. 1392, 2023, doi: 10.3390/agriculture13071392.
26. E. J. M. Jimenez *et al.*, “Influence of anaerobic fermentation and yeast inoculation on the viability, chemical composition, and quality of coffee,” *Food Biosci.*, vol. 51, no. November 2022, 2023, doi: 10.1016/j.fbio.2022.102218.
27. N. Córdoba, F. L. Moreno, C. Osorio, S. Velásquez, M. Fernandez-Alduenda, and Y. Ruiz-Pardo, “Specialty and regular coffee bean quality for cold and hot brewing: Evaluation of sensory profile and physicochemical characteristics,” *Lwt*, vol. 145, no. January, 2021, doi: 10.1016/j.lwt.2021.111363.
28. K. C. Yadav *et al.*, “Utilizing coffee pulp and mucilage for producing alcohol-based beverage,” *Fermentation*, vol. 7, no. 2, pp. 1–13, 2021, doi: 10.3390/fermentation7020053.
29. A. Heeger, A. Kosińska-Cagnazzo, E. Cantergiani, and W. Andlauer, “Bioactives of coffee cherry pulp and its utilisation for production of Cascara beverage,” *Food Chem.*, vol. 221, pp. 969–975, 2017, doi: 10.1016/j.foodchem.2016.11.067.
30. D. Turck *et al.*, “Safety of dried coffee husk (cascara) from Coffea arabica L. as a Novel food pursuant to Regulation (EU) 2015/2283,” *EFSA J.*, vol. 20, no. 2, 2022, doi: 10.2903/j.efsa.2022.7085.
31. A. Bobková *et al.*, “Comparative Analysis of Selected Chemical Parameters of Coffea arabica, from Cascara to Silverskin,” *Foods*, vol. 11, no. 8, 2022, doi: 10.3390/foods11081082.

Figures



Figure 1

Scope of coffee processing for this study.

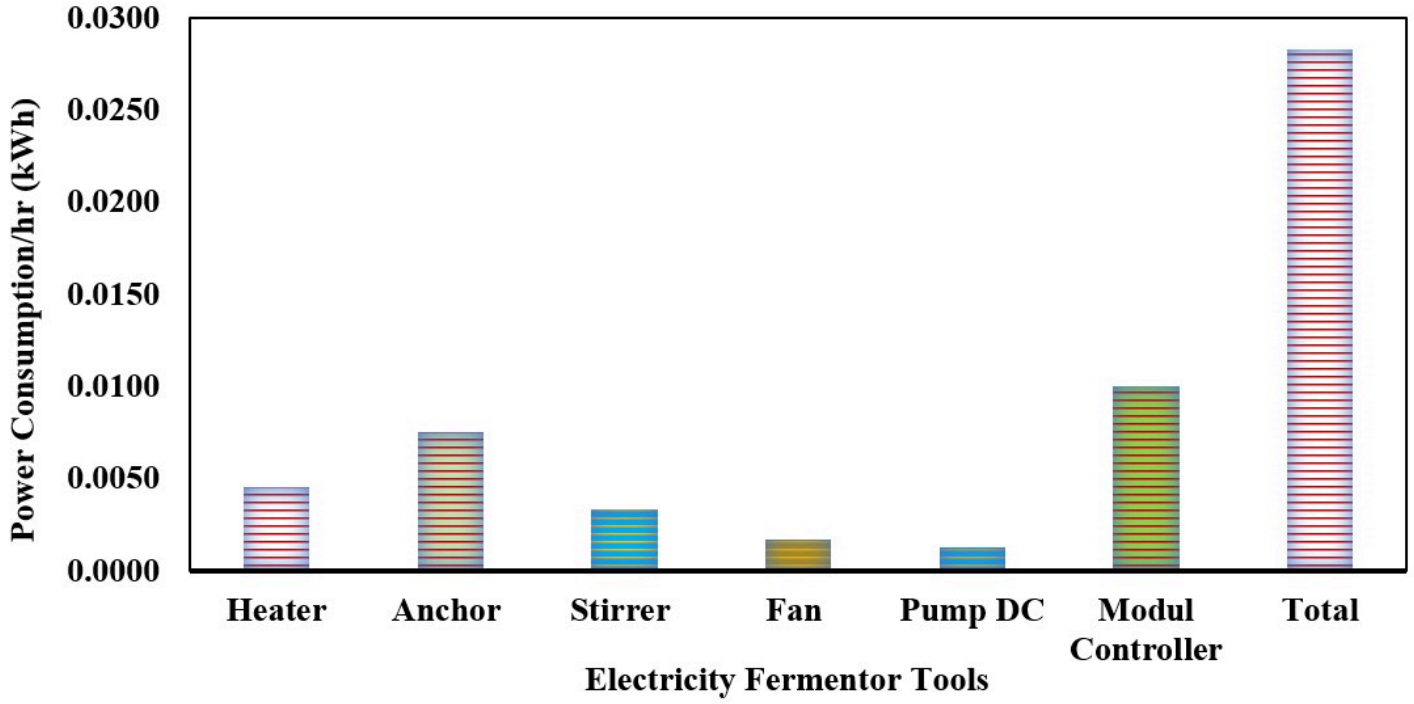


Figure 2

Electricity consumed within one hour using coffee fermentor.

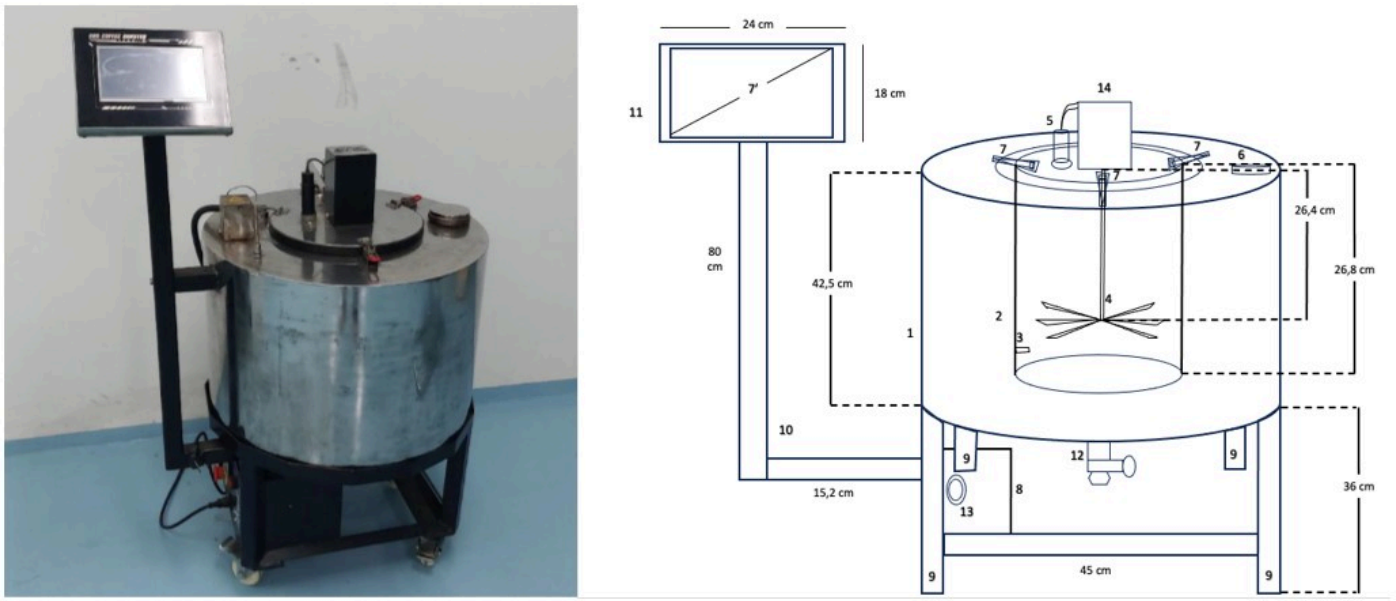


Figure 3

(a) Visualization of the coffee fermentor (b) sketch of the coffee fermentor.

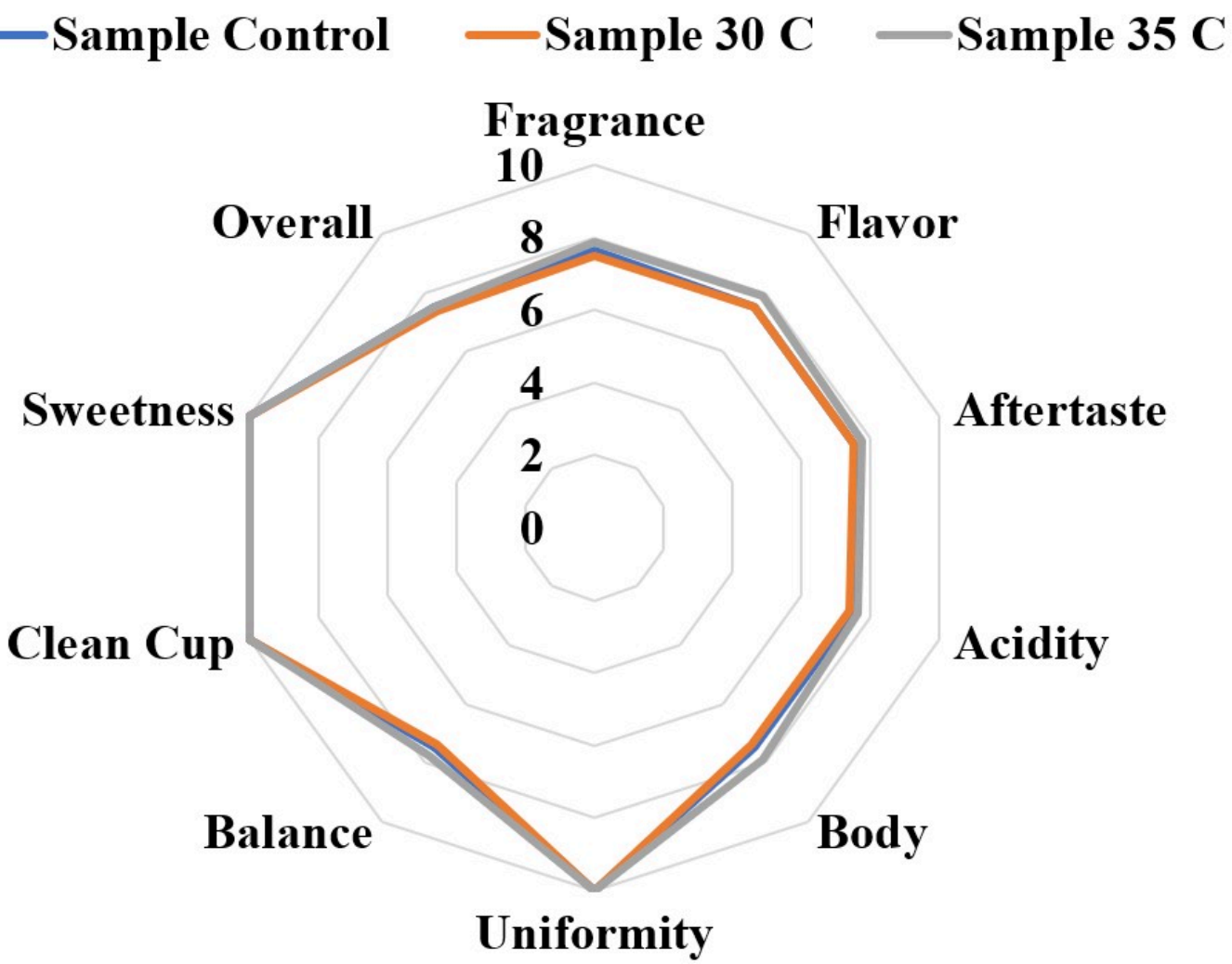


Figure 4

Sensory diagram of Bondowoso Arabica coffee from Fermentation.

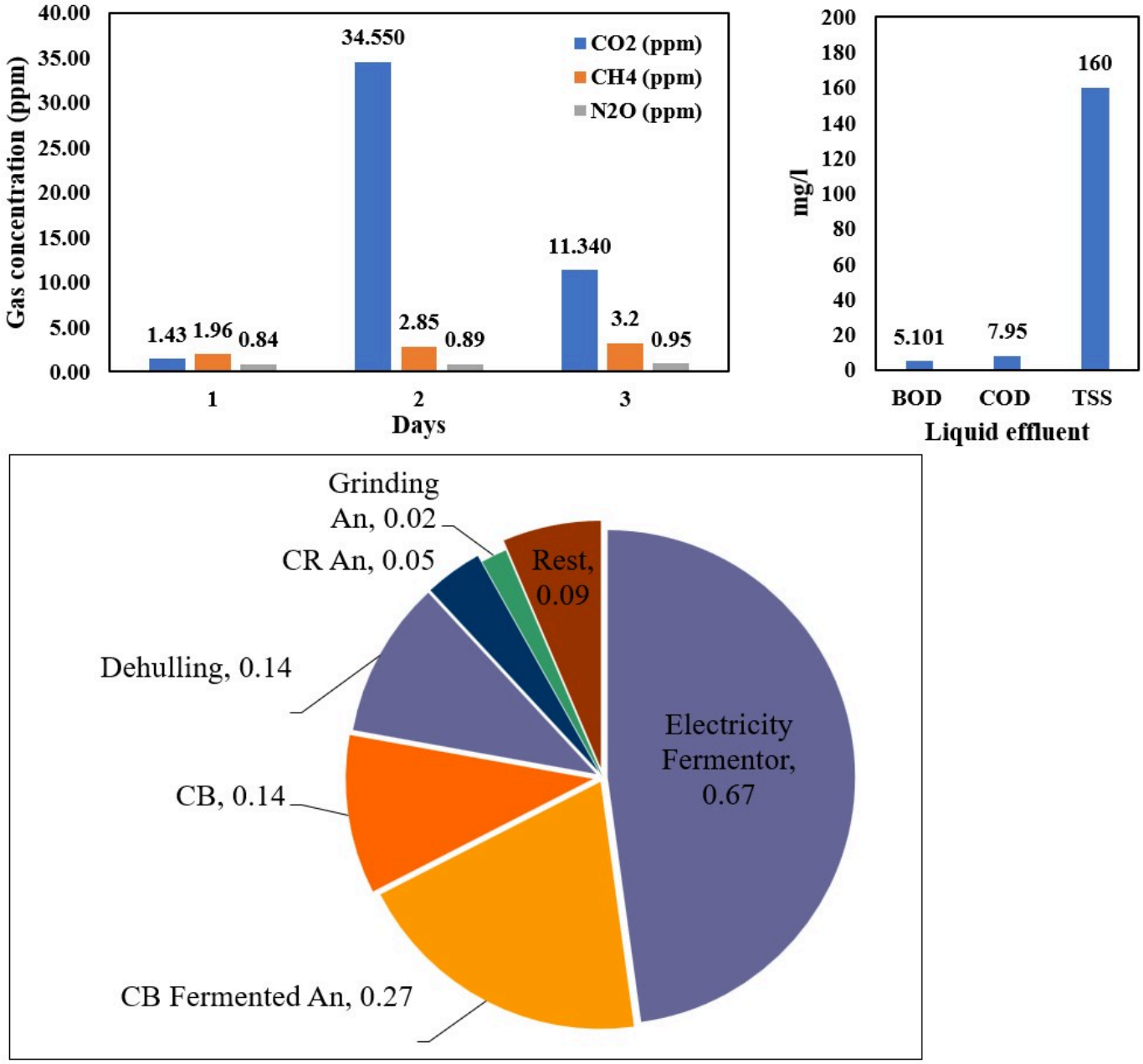


Figure 5

(a) Gasproduction during fermentation (b) COD, BOD, and TSS in anaerobic (c) contribution of anaerobic.