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Influence of water quality on CO_2 degassing and sensory attributes in lampung robusta espresso

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ABSTRACT

Water quality plays a crucial role in shaping the sensory attributes and overall taste experience of Espresso Coffee (EC). This study aimed to investigate the influence of water quality parameters, specifically acidity (pH) and total dissolved solids (TDS), on CO_2 degassing kinetics and sensory characteristics in Lampung Robusta espresso. Five different brands of bottled water were utilized for EC extraction, and their impact on CO_2 degassing behavior, pH, TDS, and sensory attributes was evaluated. Analysis of variance (ANOVA) and Tukey's Honest Significant Difference (HSD) post-hoc tests were employed to assess the significance of differences in CO_2 degassing levels among water brands. Two-way ANOVA was used to examine variations in pH and TDS before and after espresso extraction. Sensory evaluation by trained panelists was conducted to assess sensory characteristics. ANOVA revealed significant differences in CO_2 degassing levels among water brands (F= 41.21, p= 1.41E-16), with specific brand pairs exhibiting significant variations identified by Tukey's HSD test. Brand D water maintained the lowest average CO_2 emissions (865 ppm) compared to other brands, indicating its potential in stabilizing the release of CO_2 during the EC extraction. Two-way ANOVA demonstrated significant differences in pH (F= 38380.37, $p < 0.001$) and TDS (F= 1178385, $p < 0.001$) among water brands before and after espresso extraction. The highest TDS elevation observed in brand A post-extraction (7258 ppm) suggests a potential for over-extraction. The lowest final pH in EC was recorded with brand B (5.11) and the highest final pH of brand A (5.32) Sensory evaluation revealed variations in aroma, acidity, bitterness, body, crema, sweetness, mouthfeel, and flavor notes among espresso samples prepared with different water brands. This study highlights the significant impact of water quality on CO_2 degassing and sensory attributes in Lampung Robusta espresso.

Key words: Espresso; acidity; CO_2 degassing; Lampung robusta; sensory analysis.

1 INTRODUCTION

Coffee, a globally revered beverage, transcends its role as a mere stimulant or comfort drink (Colonna-Dashwood, 2017). It embodies a sophisticated interplay of chemical and physical processes, each stage from bean to brew critically influencing the ultimate sensory experience it imparts (Williams et al, 2022; Febrianto; Zhu, 2023; Ziska et al, 2018).

Water is the second most important ingredient in coffee brewing, after coffee beans. The quality of the water can have a significant impact on the taste of the coffee (Navarini; Rivetti, 2010). Early studies have shown that the ionic content of water can affect the taste of coffee. In particular, carbonates and bicarbonates can make coffee taste bitter and flat. This is because these ions bind to the coffee's flavor compounds, preventing them from being extracted into the water (Manzocco; Nicoli, 2007; Schmieder, 2023).

Espresso is a coffee beverage made by forcing hot water through finely-ground coffee beans. The extraction process is complex and affected by a number of factors, including the grind size, the brewing time, and the water quality (Masella et al, 2015). Espresso coffee (EC) can be made using a variety of devices and methods. It is defined as a brew made by percolating hot water under pressure through a compacted cake of roasted ground coffee. The energy of the water pressure is spent within the cake, extracting flavors from the coffee (Ludwig et al, 2012).

Total Dissolved Solids (TDS), which represent the total amount of substances dissolved in water, significantly influence the extraction process and taste profile of espresso (Varady et al., 2022). Elevated TDS levels typically boost the extraction of flavor compounds from coffee, potentially resulting in a more aromatic and flavorful brew. However, surpassing an ideal TDS level can lead to over-extraction, yielding a bitter and unpalatable espresso.

The acidity of water can have a significant impact on espresso extraction. Acidity can affect the solubility of coffee compounds (Derossi et al, 2018; Eltri et al, 2022; Navarini; Rivetti, 2010). Water with a certain level of acidity is used to brew coffee, it can affect the rate at which CO_2 is released from the coffee grounds. This is because the acidity of the water can alter the chemical environment, potentially affecting the rate of CO_2 degassing (Haviz et al., 2023; Rawitch; Macpherson; Brookfield, 2019).

Building on the understanding of water quality and espresso extraction, is important to delve into the role of carbon dioxide (CO_2) during the extraction process (Ishwarya;

Nisha, 2021). CO_2 is intrinsically linked to both the quality of the water and the method of extraction in brewing espresso. The presence and release of CO_2 during brewing, known as degassing, is a key factor that bridges the influence of water quality on the sensory characteristics of the coffee (Smrke; Eiermann; Yeretzian, 2024). The scheme of CO_2 degassing in coffee bean can be seen in Figure 1.

CO_2 is a byproduct of the roasting process, where green coffee beans are transformed into the aromatic brown beans (Varady et al., 2022). During roasting, a series of chemical reactions occur, leading to the generation of CO_2 within the cellular structure of the beans (Tarigan et al., 2022). Post-roasting, these beans undergo a process known as degassing, where CO_2 is gradually released from the beans over time (Alfernando et al., 2020; Zhang, 2020). This degassing process continues when the coffee is ground and brewed. CO_2 degassing, the process by which dissolved CO_2 is released from the coffee solution during brewing, is a crucial phenomenon that affects the perception of acidity, brightness, and overall balance in the final cup (Liang; Chan; Ristenpart, 2021).

The CO_2 content and its degassing are not just incidental byproducts of the coffee preparation process. CO_2 contributes to the 'bloom' in coffee brewing, especially in methods like espresso, where a correct bloom can enhance the extraction efficiency and flavor profile of the brew (Mukherjee et al., 2021). Moreover, CO_2 trapped within the beans acts as a natural barrier against oxidation, preserving the freshness of the beans (Silva et al., 2023).

However, the relationship between CO_2 degassing, and the sensory attributes of coffee is complex and multifaceted. Factors such as the degree of roast, grind size, brewing method, and even the water quality can impact CO_2 degassing and, consequently, the taste of the coffee.

Lampung, a province located in southern Sumatra, Indonesia, is renowned for its exceptional Robusta coffee, prized for its distinctive flavor profile and robust character (Analianasari, 2022; Kurniasari et al., 2023; Ramadhani; Nisa; Yuanita, 2023; Yani; Novitasari, 2024). However, the impact of water quality on the CO_2 degassing behavior and resulting sensory attributes of Lampung Robusta espresso remains largely unexplored.

This research delves into the impact of variations in water quality parameters, specifically acidity and Total Dissolved Solids (TDS), on CO_2 emissions during espresso extraction. The research investigates how variations in these parameters affect CO_2 emissions during espresso extraction and how these changes translate into differences in the sensory characteristics of the resulting beverage. By exploring this less-explored area of CO_2 dynamics in coffee brewing, this research aims to contribute valuable insights to the ongoing quest for the balanced cup of espresso from LRG.

2 MATERIAL AND METHODS

2.1 Material Preparation

Five brands of bottled water were chosen for this study, based on their availability and popularity in the Indonesian local market. The brand names and labels of the water samples are not disclosed to avoid any bias or influence on the results.

The physical and chemical properties of the water samples were measured using standard methods and instruments based on (Indonesian Government Standard, 2017). The parameters analyzed included pH, total dissolved solids (TDS), hardness, alkalinity, conductivity, and mineral content.

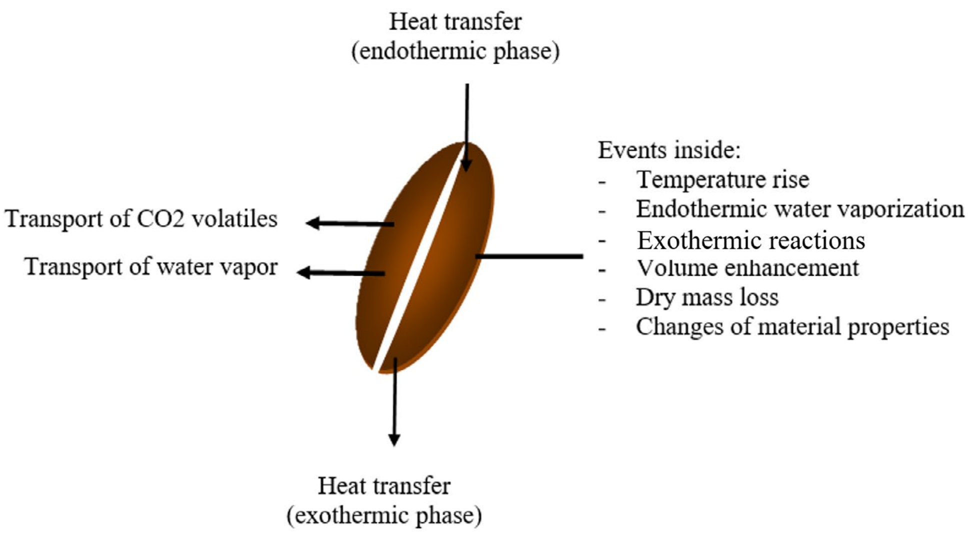

Figure 1: The scheme of CO_2 degassing, mass and heat transfer of coffee bean (Wang, 2014).

2.2 Espresso Extraction

LRG was obtained from the local coffee shop in Bandar Lampung with medium-dark roasting degree or 41-50 of agtron number (De carvalho et al., 2021).

Espresso extraction was performed using a semi-automatic machine (Delonghi Stilosa EC230-BK) with a 51 mm portafilter. The machine has a 15-bar pump pressure and a thermoblock heating system. The coffee beans were ground using a burr grinder (Latina T-60) to a fine consistency. The ground coffee was weighed to 12 grams and distributed evenly in the portafilter. The portafilter was then tamped with a calibrated tamper (Espro Calibrated Tamper) with a 30-pound force (Schmieder et al., 2023). The portafilter was locked into the group head and the extraction was started by pressing the single-shot button. The extraction time was set to 25 seconds and the yield was measured to 24 grams (Khamitova et al., 2020; Smrke; Eiermann; Yeretzian, 2024). Figure 2 presents the conventional process of EC production.

To investigate the influence of water quality on the extraction process, five different brands of bottled water were used for the extractions. Each brand of water was used to perform the extraction process three times, ensuring the repeatability and reliability of the results. The variations in the physical and chemical properties of the different water brands provided a comprehensive understanding of their impact on the espresso extraction process.

2.3 CO_2 Degassing Measurement

EC then was kept stand and measured the amount of CO_2 release (ppm) from the EC every 10 seconds for 120 seconds by using a CO_2 detector (HT-2000). The schematic tools arrangement for CO_2 measurement can be seen in Figure 3.

From Figure 3, after the EC extraction was finished, the CO_2 data logger started the measurement and it was integrated to the computer (Smrke; Eiermann; Yeretzian, 2024). Software installed in computer was from the data logger manufacturer, it can be used for recording the data every single second. In this study, data was kept recorded every 10 seconds for 120 seconds (Mukherjee et al., 2021).

2.4 Acidity and TDS Measurement

The acidity of the espresso samples was determined using a calibrated pH meter. Prior to each measurement, the pH meter was calibrated according to the manufacturer's instructions (Yeager et al., 2022). The experiment utilized five commercially available bottled water brands. For each brand, espresso was brewed three separate times (replicates) to ensure consistency. Following brewing, all samples were allowed to cool to room temperature prior to measurement. The electrode tip of the pH meter was rinsed in deionized water before being immersed in the espresso sample. The pH value was recorded once the readings on the meter stabilized. After each measurement, the electrode was cleaned with deionized water to prevent cross-contamination.

The TDS level in the water used for brewing the espresso was measured using a calibrated TDS meter. A sample of the brewing water was collected for each measurement. The TDS meter was immersed in the water sample and the TDS value, displayed on the meter in parts per million (ppm), was recorded once the measurement stabilized. The TDS meter was rinsed with distilled water after each use to prevent cross-contamination (Varady et al, 2022).

These methods allowed for a comprehensive analysis of the factors influencing the taste profile of the espresso samples. The pH and TDS measurements provided insights into the role of water quality in espresso brewing, contributing to a deeper understanding of optimal brewing practices.

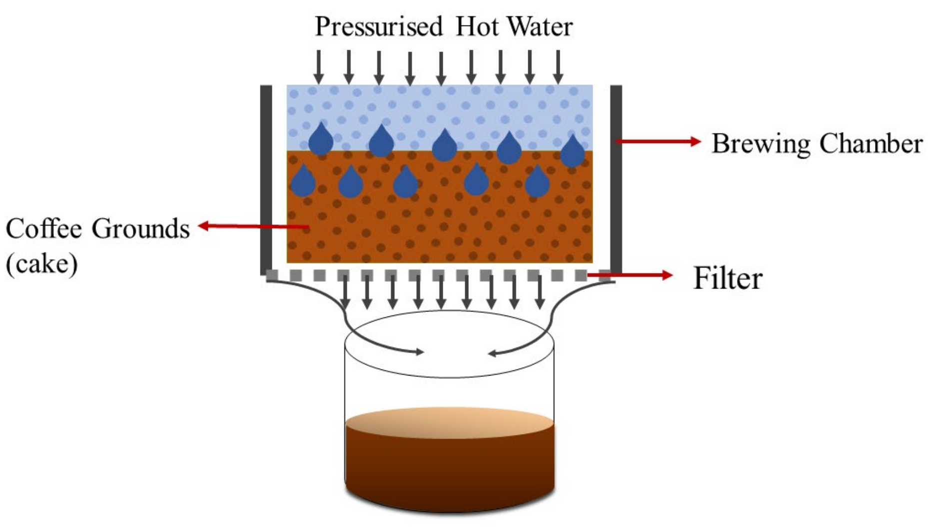

Figure 2: The conventional process of EC production.

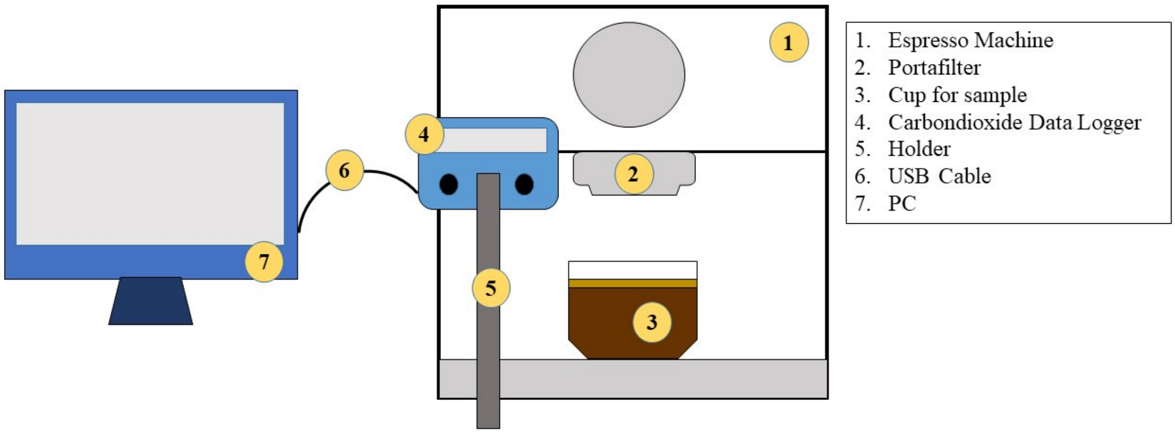

Figure 3: Schematic tools arrangement for CO_2 released on EC.

2.5 Sensory Evaluation

The sensory characteristics of each espresso sample were meticulously evaluated by a panel of three trained individuals. These panelists were selected based on their extensive experience and proven ability to discern and describe the sensory attributes of coffee. (Barrera-López, 2024).

The evaluation process was conducted using a standardized scorecard, which allowed for a consistent and objective assessment of each sample. The scorecard encompassed various sensory attributes of espresso, limited to flavor profile, intensity, acidity levels, taste notes. Each attribute was rated on a scale, and the panelists were instructed to cleanse their palate between samples to ensure an unbiased evaluation (Braga et al., 2022.).

The use of a standardized scorecard and trained panelists ensured that the sensory evaluation was both reliable and replicable. The results of this evaluation provided valuable insights into the influence of water quality parameters on the sensory characteristics of Lampung Robusta espresso (David et al., 2023).

2.6 Statistical Analysis

• Analysis of Variance (ANOVA) for CO_2 Degassing:

To assess the influence of different water brands on CO_2 degassing during espresso extraction, a single-factor Analysis of Variance (ANOVA) was employed. This statistical technique allows for the comparison of means across multiple groups, in this case, the various water brands (A, B, C, D, and E). ANOVA provides valuable insights into whether there are statistically significant differences in CO_2 degassing levels among the different water samples.

ANOVA Two-Factor with Replication had been applied to assess the pH and TDS of water samples before and after espresso extraction, in relation to CO_2 degassing. This method allows for the examination of two independent variables and their interaction effect on a dependent variable. The interaction between pH and TDS in relation to CO_2 degassing will be investigated to understand their combined impact on espresso quality (Frost; Ristenpart; Guinard, 2020).

• Experimental Design:

The experiment involved using the same batch of Lampung Robusta coffee beans for each trial, maintaining consistency in the coffee source and roast profile (Renaldo et al., 2023).

Espresso extractions were conducted under controlled conditions, including temperature, pressure, and grind size, to isolate the influence of water properties on CO_2 degassing.

• Data Collection:

CO_2 degassing was measured and recorded for each extraction, capturing the release of carbon dioxide during the brewing process.

The data included multiple replicates for each water brand to ensure robust statistical analysis.

• ANOVA Procedure:

The CO_2 degassing data were subjected to a single-factor ANOVA, treating the different water brands as the independent variable.

The null hypothesis assumed no significant difference in CO_2 degassing levels across the various water brands.

• Post-hoc Analysis:

In the event of a significant F-statistic from the ANOVA, post-hoc tests, such as Tukey's Honestly Significant Difference (HSD) test, were planned to identify specific differences between pairs of water brands. The Tukey's HSD test calculates a range of significance based on the studentized range distribution, which accounts for the number of groups being compared and the degrees of freedom in the ANOVA model (Semedo et al., 2021). If the absolute difference between the means of two groups exceeds this calculated range, the difference is considered statistically significant at the specified level of significance (typically 0.05). The results of the Tukey's HSD test are presented in the form of a table, displaying the pairwise comparisons, the corresponding Q statistic, p-value, and inference regarding the significance of the difference between the pairs (Angeloni et al., 2020; Angeloni et al., 2021).

This comprehensive analysis aims to provide a deeper understanding of how water quality parameters influence CO_2 degassing and the sensory attributes of Lampung Robusta espresso.

3 RESULTS

3.1 Water Properties

The examination of water properties, encompassing both chemical and physical attributes, played a pivotal role in unraveling the intricacies of the espresso extraction process. Table 1 is detailed analysis of the water properties associated with five distinct bottled water brands, denoted as A, B, C, D, and E, measured using standard methods and instruments based on (Indonesian Government Standard, 2021).

The physical and chemical properties of five different brands of water, labeled A to E, were analyzed. All brands were at a temperature of 29°C. All of the brands exhibited no color, turbidity, or taste & odor. Electrical conductivity varied among the brands with brand A having the highest at 24 mS/cm and brand D the lowest at 12 mS/cm.

In terms of chemical properties, pH levels ranged from 7.35 (Brand C) to 7.65 (Brand E). Total Dissolved Solids (TDS) was highest in Brand C (147±2.160 mg/L) and lowest in Brand D (63±3.559 mg/L). Concentrations of Chromium (Cr), Iron (Fe), Zinc (Zn), Cadmium (Cd), and Chloride ions (Cl) were also provided for each brand. The variations in these properties could potentially influence various processes, such as CO_2 emissions during espresso extraction, and ultimately the sensory characteristics of the brew.

3.2 Acidity and TDS

Two-way ANOVA with replication was employed to discern the statistical significance of variations within our sample groups and across different treatments. Our comprehensive analysis aimed to determine the influence of these variables on the initial and final measurements of pH and TDS, thereby providing insights into the efficacy of the treatments applied. Table 2 presents Two-way ANOVA with replication for pH of water-espresso (initial-final).

For the analysis of initial and final pH, the two-way ANOVA with replication revealed a significant difference among the sample groups ($F(1,20) = 38380.37$, $p < 0.001$) and among the columns/treatments ($F(4, 20) = 58.90$, $p < 0.001$). Additionally, there was a significant interaction effect between the sample groups and columns/treatments ($F(4,20) = 124.95$, $p < 0.001$). Table 3 presents Two-way ANOVA with replication for TDS of water-espresso (initial-final).

Similarly, for the analysis of initial and final Total Dissolved Solids (TDS), the two-way ANOVA with replication showed a significant difference among the sample groups ($F(1,20) = 1178385$, $p < 0.001$) and among the columns/treatments ($F(4, 20) = 2736.63$, $p < 0.001$). A significant interaction effect was also observed between the sample groups and columns/treatments ($F(4,20) = 2421.71$, $p < 0.001$).

3.3 CO_2 Degassing

Figure 4 presents the CO_2 degassing behavior during espresso extraction for 120 seconds using different brands of bottled water.

Table 1: Properties of 5 different brands of bottled water.

Water Properties	Brand of Water				
	A	B	C	D	E
			Physical Properties		
Temperature	29	29	29	29	29
Colour	No	No	No	No	No
Turbidity	No	No	No	No	No
Taste & Odor	No	No	No	No	No
Electrical conductivity (mS/cm)	24	20	16	12	14
			Chemical Properties		
pH	7.49± 0.029	7.95±0.016	7.35±0.025	7.38±0.009	7.65±0.041
TDS (mg/L)	136±6.342	100±2.055	147±2.160	63±3.559	67±1.247
Cr (mg/L)	<0.015	<0.015	<0.015	<0.015	<0.015
Fe (mg/L)	0.043±0.000	0.025± 0.013	0.0107± 0.013	0.077± 0.014	0.026± 0.000
Zn (mg/L)	0.085±0.000	0.115± 0.006	0.045± 0.002	0.04± 0.003	0.0019± 0.001
Cd (mg/L)	< 0.0008	< 0.0008	< 0.0008	< 0.0008	< 0.0008
Cl (mg/L)	10.635±0.000	10.635±0.000	10.635±0.000	10.635±0.000	10.635±0.000

Table 2: ANOVA Two-Factor Results for pH of water-espresso.

Anova: Two-Factor With Replication						
Summary	A	B	C	D	E	Total
Initial pH						
Count	3	3	3	3	3	15
Sum	22.47	23.85	22.07	22.16	22.95	113.5
Average	7.49	7.95	7.356667	7.386667	7.65	7.566667
Variance	0.0013	0.0004	0.000933	0.000133	0.0025	0.051381
Standard Error	0.000433	0.000133	0.000311	4.44E-05	0.000833	
Final pH						
Count	3	3	3	3	3	15
Sum	15.97	15.36	15.82	15.52	15.73	78.4
Average	5.323333	5.12	5.273333	5.173333	5.243333	5.226667
Variance	0.000633	0.0007	0.000933	0.000533	0.002633	0.006352
Standard Error	0.000211	0.000233	0.000311	0.000178	0.000878	
Total						
Count	6	6	6	6	6	
Sum	38.44	39.21	37.89	37.68	38.68	
Average	6.406667	6.535	6.315	6.28	6.446667	
Variance	1.409107	2.40311	1.30283	1.46992	1.739667	
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Sample	41.067	1	41.067	38380.37	2.59E-34	4.351244
Columns	0.2521	4	0.063025	58.90187	8.79E-11	2.866081
Interaction	0.534767	4	0.133692	124.9455	7.55E-14	2.866081
Within	0.0214	20	0.00107			
Total	41.87527	29				

This figure graphically represents the illustration of CO_2 degassing curves for each water brand over the 120-second extraction period. The x-axis represents the time (in seconds), while the y-axis represents the CO_2 degassing levels (in ppm).

The analysis of variance (ANOVA) results, shown in Table 4, revealed a statistically significant difference in CO_2 degassing levels among the water brands (F = 41.21, p = 1.41E-16).

Table 4 presents the results of the one-way analysis of variance (ANOVA) conducted to determine if there are significant differences in CO_2 degassing levels among the five water brands. The table includes the source of variation, sum of squares (SS), degrees of freedom (df), mean square (MS), F-statistic, and p-value.

This bar chart in Figure 5 visually represents the mean CO_2 degassing levels for each water brand, averaged over the 120-second extraction period. The x-axis shows the different water brands, while the y-axis displays the mean CO_2 degassing levels (in ppm)

Figure 5 illustrates the mean CO_2 degassing levels for each water brand, averaged over the 120-second extraction period with their standard error based on ANOVA. Brand A exhibited the highest mean CO_2 degassing of 944.15 ppm, followed by Brand D (866.54 ppm), Brand C (849.46 ppm), Brand B (852.92 ppm), and Brand E (805.15 ppm).

To identify the specific pairs of water brands that differed significantly in their CO_2 degassing behavior, Tukey's Honest Significant Difference (HSD) post-hoc test was conducted. Table 3presents the results of Tukey's Honest Significant Difference (HSD) post-hoc test, which was conducted to identify the specific pairs of water brands that differed significantly in their CO_2 degassing behavior. The table includes the treatment pairs, Tukey's HSD Q statistic, p-value, and the inference (significance level) for each pairwise comparison.

Table 3: ANOVA Two-Factor Results for pH of water-espresso.

Summary	A	B	C	D	E	Total
Initial TDS						
Count	3	3	3	3	3	15
Sum	409	299	441	189	200	1538
Average	136.3333	99.66667	147	63	66.66667	102.5333
Variance	60.33333	6.333333	7	19	2.333333	1294.41
Standard Error	20.11111	2.111111	2.333333	6.333333	0.777778	
Final TDS						
Count	3	3	3	3	3	15
Sum	22115	17827	20986	20931	17600	99459
Average	7371.667	5942.333	6995.333	6977	5866.667	6630.6
Variance	1792.333	46.33333	185.3333	9	584.3333	398840
Standard Error	597.4444	15.44444	61.77778	3	194.7778	
Total						
Count	6	6	6	6	6	
Sum	22524	18126	21427	21120	17800	
Average	3754	3021	3571.167	3520	2966.667	
Variance	15705756	10241047	14069978	14341030	10092235	
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Sample	3.2E+08	1	3.2E+08	1178385	3.49E-49	4.351244
Columns	2969063	4	742265.8	2736.632	4.47E-27	2.866081
Interaction	2627393	4	656848.4	2421.71	1.51E-26	2.866081
Within	5424.667	20	271.2333			
Total	3.25E+08	29				

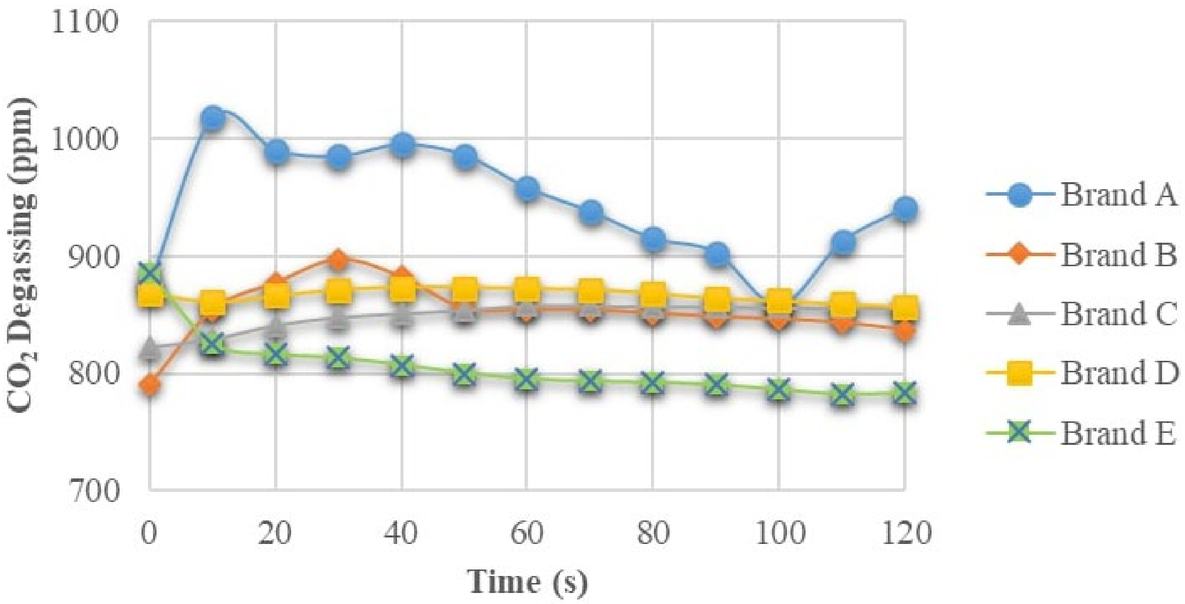

Figure 4: CO_2 Degassing Curves During Espresso Extraction.

Table 4: ANOVA Single-Factor Results for CO_2 Degassing Levels Among Water Brands.

Summary						
Groups	Count	Sum	Average	Variance		
A	13	12274	944.1538462	2465.141		
B	13	11088	852.9230769	646.9103		
C	13	11043	849.4615385	138.1026		
D	13	11265	866.5384615	30.26923		
E	13	10467	805.1538462	752.141		
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	132956.0923	4	33239.02308	41.21326	1.41E-16	2.525215
Within Groups	48390.76923	60	806.5128205			
Total	181346.8615	64				
Total	7196224.218	77				

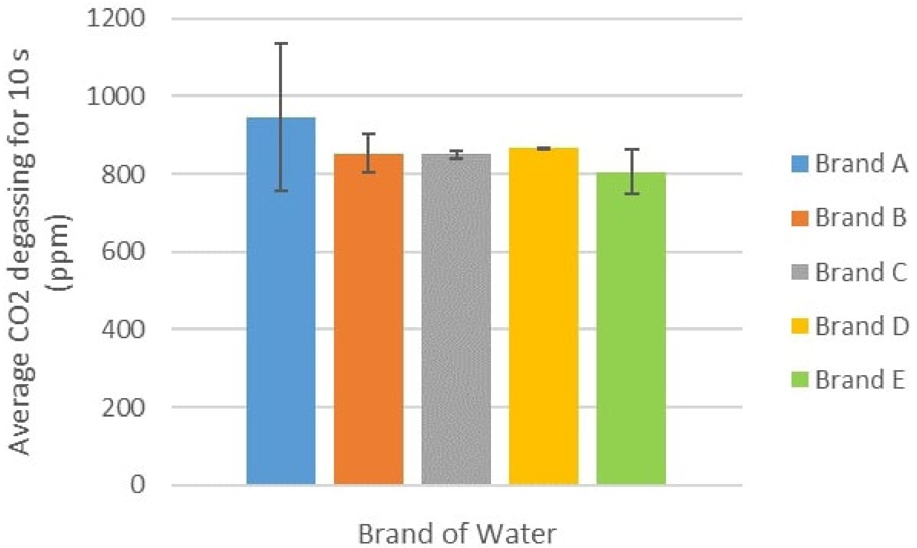

Figure 5: Mean CO_2 Degassing Levels by Water Brand.

The results, presented in Table 5, indicate that Brand A differed significantly from all other brands ($p < 0.01$). Additionally, Brand E differed significantly from Brand B ($p < 0.01$), Brand C ($p < 0.01$), and Brand D ($p < 0.01$). However, no significant differences were observed between Brand B and Brand C ($p = 0.9$), Brand B and Brand D ($p = 0.71$), or Brand C and Brand D ($p = 0.54$).

To conduct the sensory analysis, trained panelists would evaluate each espresso sample and rate or describe the intensity or quality of each sensory attribute using a predetermined scale or descriptors. The ratings or descriptions would then be recorded in the corresponding cells for each brand.

3.4 Sensory Analysis Result

Table 6 provides the sensory analysis results, the comprehensive overview of the sensory characteristics of the different espresso samples, allowing for comparisons and identification of potential differences or similarities that may be influenced by the water quality and CO_2 degassing during the preparation process.

Based on the Table 6, brand B and brand E exhibited high aroma and flavor intensity, potentially due to better CO_2 degassing and retention of volatile compounds. Brand C had a low aroma and flavor intensity, suggesting possible loss of volatile compounds due to excessive CO_2 degassing or other factors affecting water quality.

Brand C also had a dense and persistent crema, which could be related to the water quality's impact on CO_2 dissolution and foam stability. Brand B and brand E had pronounced sweetness, possibly due to better extraction of sugars or retention of volatile compounds contributing to perceived sweetness. Brand A and brand D exhibited moderate or balanced sensory attributes across most categories.

Table 5: Tukey's HSD Post-hoc Test Results for CO_2 Degassing.

Treatments pair	Tukey HSD Q Statistic	Tukey HSD p-value	Tukey HSD interfence
A vs B	11.5826	0.0010053	** $p<0.01$
A vs C	12.0221	0.0010053	** $p<0.01$
A vs D	9.854	0.0010053	** $p<0.01$
A vs E	17.6474	0.0010053	** $p<0.01$
B vs C	0.4395	0.8999947	insignificant
B vs D	1.7286	0.7131312	insignificant
B vs E	6.0648	0.0010053	** $p<0.01$
C vs D	2.1681	0.5398463	insignificant
C vs E	5.6253	0.0017211	** $p<0.01$
D vs E	7.7934	0.0010053	** $p<0.01$

Table 6: Sensory Analysis Result of Espresso from 5 Different Brands Bottled Water.

Sensory Attribute	Brand A	Brand B	Brand C	Brand D	Brand E
Aroma Intensity	Moderate	High	Low	Moderate	High
Acidity	Medium	High	Low	Medium	High
Bitterness	Moderate	Low	High	Moderate	Low
Body	Medium	Light	Full	Medium	Light
Crema Appearance	Uniform	Patchy	Dense	Uniform	Patchy
Crema Persistence	Moderate	Short	Long	Moderate	Short
Sweetness	Mild	Pronounced	Mild	Moderate	Pronounced
Mouthfeel	Smooth	Thin	Velvety	Smooth	Thin
Flavor Intensity	Moderate	High	Low	Moderate	High
Specific Flavors	Nutty, Caramel	Fruity, Floral	Roasty, Bitter	Nutty, Chocolate	Fruity, Citrus

These results suggest that differences in water quality and CO_2 degassing during the espresso preparation process can influence various sensory attributes, such as aroma, flavor, acidity, body, crema quality, and mouthfeel.

The specific sensory attributes and evaluation methods may vary depending on the study's objectives, panelist and the established sensory analysis protocols for espresso.

4 DISCUSSION

4.1 Water Properties and CO_2 Degassing

The significant differences in CO_2 degassing behavior observed among the water brands can be attributed to variations in their chemical compositions and physical properties (Illy; Navarini, 2011) Water quality parameters, such as pH, total dissolved solids (TDS), mineral content, and alkalinity, are known to influence the solubility and degassing dynamics of CO_2 during espresso extraction (Wellinger; Smrke; Yeretzian, 2016).

Brand A, which exhibited the highest mean CO_2 degassing level, may possess chemical characteristics that facilitate more efficient CO_2 release from the espresso solution. Factors such as lower mineral content or specific mineral compositions could contribute to reduced CO_2 solubility, thereby promoting more rapid degassing during the extraction process (Wellinger; Smrke; Yeretzian, 2016).

On the other hand, Brand E, which showed the lowest mean CO_2 degassing level, might possess properties that enhance CO_2 solubility or inhibit its release from the espresso solution. Higher mineral content, alkalinity, or specific ionic compositions could potentially increase the solubility of CO_2, leading to a slower degassing rate (Angeloni et al., 2021).

It is noteworthy that brand B and brand C exhibited similar CO_2 degassing behaviors, suggesting that their water quality parameters may be comparable in terms of their effect on CO_2 solubility and degassing dynamics (Angeloni et al, 2021). Similarly, CO_2 degassing behavior in brand D was not significantly different from brand B and brand C, indicating potential similarities in their water chemistry.

The Tukey's HSD test results reveal important insights into the effects of different water brands on the pH and TDS levels during espresso extraction. For pH, the significant differences observed in the final pH values but not in the initial pH suggest that the espresso extraction process can alter the pH of the water depending on the brand used (Barrera-López et al., 2024; Salamanca et al., 2017). These pH changes could potentially impact the sensory characteristics of the espresso, such as perceived acidity or brightness.

Regarding TDS, the significant differences observed in both initial and final TDS levels among the water brands highlight the varying mineral compositions and dissolved solid contents of the waters (Cordoba et al., 2020). These differences in TDS can influence the extraction efficiency, flavor compound solubility, and overall taste profile of the espresso. pH and TDS are not the only water quality parameters that can impact espresso extraction (Illy; Navarini, 2011). Other factors, such as alkalinity, hardness, and specific mineral compositions, may also play significant roles in shaping the sensory attributes of the final beverage (Barrera-López et al., 2024).

It is important to note that the CO_2 degassing behavior during espresso extraction is a complex phenomenon influenced by multiple factors, including water chemistry, temperature, pressure, and the intrinsic properties of the coffee beans themselves (Varady et al., 2022). Further investigation into the specific water quality parameters and their interactions with the coffee compounds would be necessary to fully understand the underlying mechanisms driving the observed differences in CO_2 degassing.

4.2 Sensory Analysis

The sensory analysis results highlight the potential impact of water quality and CO_2 degassing on the sensory characteristics of espresso (Baggenstoss et al., 2007). Brands with high aroma and flavor intensity, such as brand B and brand E, may have benefited from better CO_2 retention and dissolution during the extraction process (Poltronieri; Rossi, 2016). Adequate CO_2 levels can enhance the perception of volatile aroma and flavor compounds, contributing to a more intense and complex sensory experience (Hasni et al., 2023; Ishwarya; Nisha, 2021).

On the other hand, brand C exhibited low aroma and flavor intensity, which could be attributed to excessive CO_2 degassing or other water quality factors affecting the retention and extraction of volatile compounds. The dense and persistent crema observed in Brand C's espresso suggests that the water quality may have influenced the CO_2 dissolution and foam stability, potentially due to differences in pH or TDS levels (Illy; Navarini, 2011; Navarini; Rivetti, 2010; Wang et al., 2019).

The pronounced sweetness noted in brand B and brand E could be related to better extraction and retention of sugars, facilitated by optimal water properties and CO_2 levels (Cordoba et al., 2019; Da Silva et al., 2022). Adequate CO_2 dissolution can enhance the extraction efficiency of sugars and other soluble compounds, contributing to a sweeter and more balanced flavor profile (Batali et al., 2020).

The variations in acidity, bitterness, body, and mouthfeel across the different brands might also be influenced by the interplay between water quality, CO_2 degassing, and the extraction of specific compounds from the coffee grounds (Wang; Lim, 2014; Wang et al., 2019). For instance, higher TDS levels or certain pH ranges could affect the solubility and extraction of acids, phenolic compounds, and other substances responsible for these sensory attributes (Cordoba et al., 2020; Schmieder et al., 2023). Overall, these findings suggest that water quality parameters, such as pH and TDS, can significantly impact CO_2 degassing and dissolution during the espresso preparation process.

5 CONCLUSIONS

This comprehensive study has demonstrated the profound influence of water quality on CO_2 degassing dynamics and sensory attributes in Lampung Robusta espresso. The findings underscore the importance of carefully considering water properties, such as pH and TDS, in the pursuit of exceptional espresso experiences.

A two-way ANOVA analysis was conducted to investigate the changes in pH and TDS levels pre and post espresso extraction. Trained panelists performed sensory evaluations to determine the distinct sensory characteristics. The ANOVA results indicated notable differences in CO_2 degassing rates across different water brands ($F= 41.21$, $p= 1.41E-16$) with Tukey's HSD test pinpointing specific brands that differed significantly. Water from Brand D showed the lowest CO_2 emission average (865 ppm), suggesting it may help stabilize CO_2 release during espresso extraction. Significant disparities in pH ($F= 38380.37$, $p < 0.001$) and TDS ($F= 1178385$, $p < 0.001$) among the water brands were also observed through two-way ANOVA, both before and after espresso extraction. Brand A exhibited the greatest increase in TDS post-extraction (7258 ppm), indicating possible over-extraction which could affect taste and lead to a larger environmental impact through heightened CO_2 emissions. The final pH measurements in espresso coffee (EC) ranged from the lowest with Brand B (5.11) to the highest with Brand A (5.32). Sensory assessments detected differences in aroma, acidity, bitterness, body, crema, sweetness, mouthfeel, and flavor profiles in espressos made with various water brands.

Furthermore, the two-way ANOVA analysis revealed significant differences in pH and TDS levels among the water brands, both before and after the espresso preparation. These variations in water quality parameters were found to have a substantial impact on the sensory characteristics of the final espresso beverage, as evidenced by the sensory evaluation conducted by trained panelists. The sensory analysis revealed notable differences in aroma intensity, acidity, bitterness, body, crema appearance and persistence, sweetness, mouthfeel, and flavor notes among the espresso samples prepared with different water brands. These sensory distinctions were attributed to the intricate interplay between water quality parameters, CO_2 degassing dynamics, and the extraction of flavor compounds from the coffee grounds.

6 AUTHORS' CONTRIBUTIONS

Conceptual Idea: Haviz, M.; Rina, O.; Djana, M. Methodology design: Haviz, M.; Eltri, A.P.; Nandini, N. P. A. Data collection: Eltri, A.P.; Nandini, N. P. A.; Fahrani, N. A. Data analysis and interpretation: Brawn, J.P.; Haviz, M.; Rina, O.; Fahrani, N. A. Writing and editing: Haviz, M.; Fahrani, N. A.; Djana, M.

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