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Impacts of brewing methods on sensory perception and organoleptic compounds of coffee

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A R T I C L E I N F O

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A B S T R A C T

Coffee beverage presents unique organoleptic characteristics of aroma and taste. These sensory attributes depend on the chemical composition of the brewed coffee. Our objectives were to determine the sensory quality of the coffee beverage obtained by different brewing methods as assessed by untrained tasters and to characterize the solid residues of this extraction using the medium infrared spectrum. Four brewing methods were evaluated by 124 untrained consumers. The infusion method presented better global impression and preference of these consumers than the other brewing methods. Significant changes in the chemical composition of the coffee residues were observed. These changes influenced the acceptance of the consumers and can be due to the potential of retention or filtering of organic compounds by the brewing method. Thus, there was a sensory quality difference among the brewing methods and the infrared spectrum indicated the need to distinguish the classes of organic compounds for a better understanding of how coffee brewing interacts with the chemical composition.

1. Introduction

Currently, about two billion coffee cups are consumed daily worldwide (De Bruyn et al., 2017, Pereira et al., 2020, Pickard et al., 2013). The flavor, representing the convergence of the aroma and taste, is a unique organoleptic characteristic of this beverage (Assis et al., 2019, Pereira et al., 2020). Furthermore, the chemical composition of brewed coffee depends on numerous factors, for example, harvest and post-harvest processing, and the brewing method employed (De Bruyn et al., 2017, Joët et al., 2010, Pereira et al., 2020). In recent decades, many coffee-based beverages obtained by using different extraction techniques have entered the market (Angeloni et al., 2019).

Steeping using a French press, filtration or dripping in a Hario V60, AeroPress, cold drip technique, and boiling are brewing methods used in the production of coffee beverages. These methods may differ in the grain size of ground coffee, types of extraction, and amount of coffee and water used in the process (Angeloni et al., 2019).

Sensory evaluation techniques are critical in the development, production, and quality maintenance of foodstuffs (Civille & Oftedal, 2012). In this analysis, tasters use their gustatory sensibilities to assign a score (0 to 100 points) to sensory attributes (e.g., fragrance, flavor, aftertaste, acidity, body, balance, sweetness, and uniformity) (SCAA, 2013). According to Pereira et al. (2020), gustatory sensibilities are obtained through the professional experience of each panelist (Q-Grader).

Many studies have observed a positive linear correlation between the sensory attributes of the coffee beverage and Q-grader scores (Adhikari et al., 2019, De Bruyn et al., 2017, Pereira et al., 2020). However, in this study we used untrained tasters to assess the sensory perception of specialty coffee (sensory score > 80 points). In addition, sensory quality is related to the chemical composition of roasted coffee beans (Pereira et al., 2020, Bellumori et al., 2021). Thus, we carried out an analysis in the medium infrared (Mid-infrared) spectrum band of the solid residues from the beverage extraction. The Mid-infrared spectrum is an important analytical technique for the chemical discrimination of

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coffee beans and can provide relevant data regarding changes in the chemical composition of coffee beverage produced using different brewing methods (Zhang et al., 2016).

Thus, the objectives of this study were to determine the sensory quality of the coffee beverage obtained by different brewing methods as assessed by untrained tasters and to characterize the solid residues of this extraction using the Mid-infrared spectrum. These analyses are important for the sensorial acceptance of the coffee beverage by consumers and the spectral bands can show differences in the extraction of sensorial compounds among the preparation methods.

2. Material and methods

This study was submitted to and approved by Plataforma Brasil and by the Research Ethics Council, according to protocol CAAE: 07739319.3.0000.5072.

2.1. Raw materials

Thirty kg of arabica coffee, processed by the wet method, scored at 84 points by the SCA protocol were used in this study (SCAA, 2013). In the post-harvest processing wash, the coffee fruits were immersed in a box containing potable water (500 L) to remove dirt (soil, leaves, and stalks) and to separate floating fruits (Pereira et al., 2020, De Bruyn et al., 2017). Floating fruits and water were discarded while the fruits that sank, which have a greater density than the floating fruits, were dried in the sun. The coffee husk was removed in a peeler before the coffee bean roasting process.

The coffee samples were selected by a Q-Grader with more than ten years of experience in sensory analysis.

2.2. Roasting procedure

The skin and peel of coffee fruits were removed using pre-cleaning equipment for coffee samples (Pinhalense-DRC laboratory line), being then selected by size, in a 16 # UP sieve.

The samples were roasted in a Probat roaster (Probatino model, year 2018), using LP gas, with a maximum capacity of 1.2 kg. The initial roasting parameters were 140°C with completion at 190 ± 5 °C, with an average roasting time of 8 min and 47 s. The period used for sample roasting, between 8 and 12 min, was based on the Specialty Coffee Association sample roasting protocol (SCAA, 2013).

2.3. Extraction and brewing of coffee

Four brewing methods of coffee were evaluated in this study (Supplementary material 1).

The Hario V60, Chemex, and French press methods involved scalding for pre-cleaning and preheating of the equipment, and used about 10 g of ground coffee for every 100 ml of water at a temperature setting of 94°C (Supplementary material 1). Coarse ground, 30 s of pre-infusion of the powder in about 10% of the total water, and a filtration time greater than 2 min were used in these methods (Supplementary material 1). Grinding of coffee beans was performed in a Bunn© model coffee mill (Bunn-O-Matic Corporation, Springfield, IL).

The Espresso coffee extraction used a Delonghi - ECAM 23.210B super-automatic coffee extraction machine with a 1450-watt motor, frequency: 50 ~ 60 Hz, and a pressure of 15 bar per cup, with the capacity to extract two cups of coffee per batch (Supplementary material 1). An 18-gram portion of ground coffee was produced using the fine adjustment of the mill with grade # 1, according to the machine's technical standard. It was considered a strong extraction, with 90 mL output for two cups, according to technical specifications (Delonghi Ecam, 2020).

Table 1
Sensory acceptance by a 9-point hedonic scale and preference ordering test of the untrained tasters concerning coffee brewing methods.

Extraction methods	Sensorial evaluation				
	Appearance	Aroma	Taste	Global impression	Sum of orders[†]
Hario V60	6.44 ab	6.41 a	5.55 ab	6.02 a	334 a
Chemex	5.94 b	6.60 a	5.73 a	6.19 a	355 a
French Press	5.27 c	5.77 b	4.73 c	5.17 b	248 c
Espresso	6.96 a	6.71 a	4.90 bc	5.58 ab	293 b
Average	6.15	6.38	5.22	5.74	-

Means followed by at least one same letter vertically do not differ by Tukey's test at 5% probability.
[†] Ordination preference test.

2.4. Panelists

A panel of untrained tasters was recruited randomly from regular coffee consumers, aged at least 18, among students and workers from the Federal Institute of Espírito Santos, Brazil (69 men, 55 women, aged 18 to 67 years old). None of the participants was informed about the extraction methods or the type of coffees available. The Human Research Ethics Committee of this Federal Institute approved the study.

2.5. Sensory analysis

Coffee samples, obtained by four different brewing methods, were analyzed by affective methods, according to Meilgaard et al. (2006). Initially, the tasters' sensory perception was assessed using the sensory acceptance test for attributes, in which each sample was evaluated for appearance, flavor, and overall impression, with a 9-point hedonic scale (1 = extremely like to 9 = extremely dislike). In the second stage, a ranked sensory preference test was adopted. Thus, the tasters were instructed to rank the coffee samples, with the most preferred sample having a score of 4 until the least preferred with a score of 1. The four coffee samples, encoded with random three-digit numbers, were served simultaneously in both tests. Each one was served in a plastic cup with about 20 mL, at 80°C. Between samples, they were instructed to rinse their mouths with water.

2.6. Medium infrared analysis

The residual coffee grounds from the four brewing methods subjected to the preference and acceptance tests were dried for sampling (at 80°C until constant weight, for 8 h). Those samples plus a sample of unbrewed coffee for reference were submitted to Mid-infrared spectroscopy analysis.

A 10-g aliquot of each sample (0.074 mm - mesh sieve, standard US Standards) was placed in a glass desiccator until it reached room temperature (25 ± 2°C), and then, the Mid-infrared analysis was performed.

The spectra of the roasted and ground coffee samples with fine granulometry were obtained in a model Cary 630 Fourier Transform Infrared (FTIR) spectrometer from the manufacturer Agilent Technologies, in an ATR diamond accessory with a reflection angle of 45°, 1 mm diameter, 200 µm of active area and approximately 2 µm of penetration depth in the sample, using a reflectance detector of zinc selenide (ZnSe). The medium infrared spectra of the samples were obtained as the average of 8 consecutive scans, with a resolution of 4 cm^{-1} in the wavelength range from 4000 to 650 cm^{-1}, that is, in the region of the Medium infrared electromagnetic spectrum, considering that this spectral region presents a large amount of information that can be used for the functional characterization of organic compounds (Silverstein et al., 2007).

2.7. Experimental design and statistical analysis

The experiment was conducted in a completely randomized design with 124 replications using untrained consumers who evaluated the

Table 2
Similarity assessment of untrained consumers by the Tocher method of coffee beverage obtained by Hario V60, Chemex, French press, and Espresso extraction method.

Group	Number of consumers / tasters	Consumers/tasters belonging to the group
		Hario V60
1	83	107 119 87 110 72 77 54 99 113 4 8 112 96 30 6 29 1 22 49 74 55 46 53 51 2 26 32 71 123 19 111 64 40 90 57 37 5 56 48 115 65 68 69 35 78 12 25 16 89 41 94 28 36 38 106 33 27 50 97 114 98 108 7 121 3 83 11 58 17 13 42 105 101 9 18 45 104 102 88 124 84 23 76
2	26	95 120 44 92 59 118 10 82 75 86 66 70 24 14 93 85 100 109 43 21 62 39 122 103 91 15
3	5	73 116 81 80 20
4	3	67 117 31
5	2	52 63
6	1	34
7	1	47
8	1	60
9	1	61
10	1	79
		Chemex
1	74	114 124 74 58 36 112 12 24 95 93 69 46 8 105 6 15 2 14 41 38 113 49 59 109 32 71 62 7 1 115 57 16 48 13 102 104 28 54 22 64 110 97 92 51 26 19 123 45 78 55 75 30 3 5 90 33 120 40 108 29 23 68 56 21 70 25 106 118 96 72 76 11 83 99
2	3	53 119 4
3	25	37 88 100 101 85 9 44 98 86 121 17 80 50 39 52 18 122 35 43 107 27 77 73 20 91
4	4	89 94 116 10
5	7	42 66 47 111 34 117 87
6	3	84 103 79
7	2	81 82
8	2	61 65
9	1	31
10	1	60
11	1	63
12	1	67
		French Press
1	65	108 109 19 35 96 1 112 83 22 13 75 37 120 59 72 25 116 70 117 48 8 7 105 95 77 21 122 11 64 49 98 14 67 28 32 54 107 71 79 61 68 36 56 92 124 84 12 115 121 3 114 51 44 6 76 106 38 53 45 16 9 50 111 88 99
2	30	40 93 17 100 5 62 101 73 18 74 65 85 29 66 42 27 39 94 20 41 86 69 47 91 46 90 30 78 33 80
3	7	4 123 58 104 119 113 26
4	3	31 82 103
5	5	2 24 34 102 55
6	2	60 110
7	5	43 97 57 118 15
8	2	52 63
9	1	10
10	1	23
11	1	81
12	1	87
13	1	89
		Espresso
1	42	108 115 40 88 69 121 98 91 112 85 41 118 56 35 31 83 73 50 117 89 86 105 94 77 4 58 28 122 113 70 120 25 119 20 33 96 74 64 3 71 68 27
2	24	38 44 72 97 16 114 75 9 47 59 29 23 36 5 110 93 37 84 92 81 101 1 32 7
3	17	22 26 8 104 109 78 95 13 21 48 90 18 10 124 49 30 19
4	5	42 116 55 53 103
5	7	2 51 46 6 99 17 62
6	7	45 65 39 102 66 82 100
7	3	61 106 15
8	3	12 63 107
9	2	57 111
10	2	14 43
11	2	52 87
12	1	11
13	1	24
14	1	34
15	1	54
16	1	60
17	1	67
18	1	76
19	1	79
20	1	80
21	1	123

(continued on next page)

Table 2 (*continued*)

Table 3
Contribution of sensory variables (%) in the Tocher method grouping of the coffee beverage obtained by different brewing methods Hario V60, Chemex, French press and Espresso extraction method.

Brewing methods	Contribution of sensorial variables (%)			
	Appearance	Aroma	Taste	Global impression
Hario V60	32.6	27.8	24.5	15.1
Chemex	33.1	27.3	27.0	12.6
French Press	26.3	30.5	25.6	17.5
Espresso	29.8	29.4	23.1	17.6

sensorial attributes of the coffee from four brewing methods: Chemex, Hario - V60, French Press, and Espresso.

Sensory acceptance was determined through analysis of variation and the averages compared by the Tukey test with 5% probability. In the evaluation of the similarity among the brewing methods, a matrix was elaborated with the averages of the variables and, later, a dendrogram was constructed using the Average Euclidean distance to measure the distances between the brewing methods and the single-link hierarchical grouping method.

To assess the similarity among the sensory evaluations of the 124 untrained consumers, the Tocher optimization grouping method was used, using the Average Euclidean distance to measure the distances among the 124 consumers/tasters, for each coffee extraction method - Chemex, Hario - V60, French Press, and Espresso. The SPSS program version 19 was used for statistical analysis.

Considering the results of the classification test of the preferences of the tasters, the final score was obtained by the sum of orders compared by the Friedman test in the table of Newell and McFarlane (Meilgaard et al., 2006).

The original spectra organized in a matrix had each replicate as a sample. All calculations were performed using Matlab software version R2013a. The data were centered on the mean and subsequently submitted to exploratory analysis using the multivariate principal component analysis (PCA) technique.

3. Results and discussion

For the appearance attribute, the coffee extraction by the French press method had a value lower than the other methods (Table 1). The filtered methods, Chemex and Hario V60, had no statistical difference ($p > 0.05$) in this sensory attribute. The coffee produced by the French Press method is turbid and with a light brown color, which may have led to the rejection of this method by untrained consumers. The attributes of color, appearance, and brightness of coffee are the main attributes responsible for discriminating coffee sensory characteristics (Scholz et al., 2013). Our data show the importance of understanding and discussing this behavior about the appearance of coffee. Furthermore, the visual characteristics of the product are, for consumers, an indicator of quality, placing their mind in an anticipatory or predictive model that can

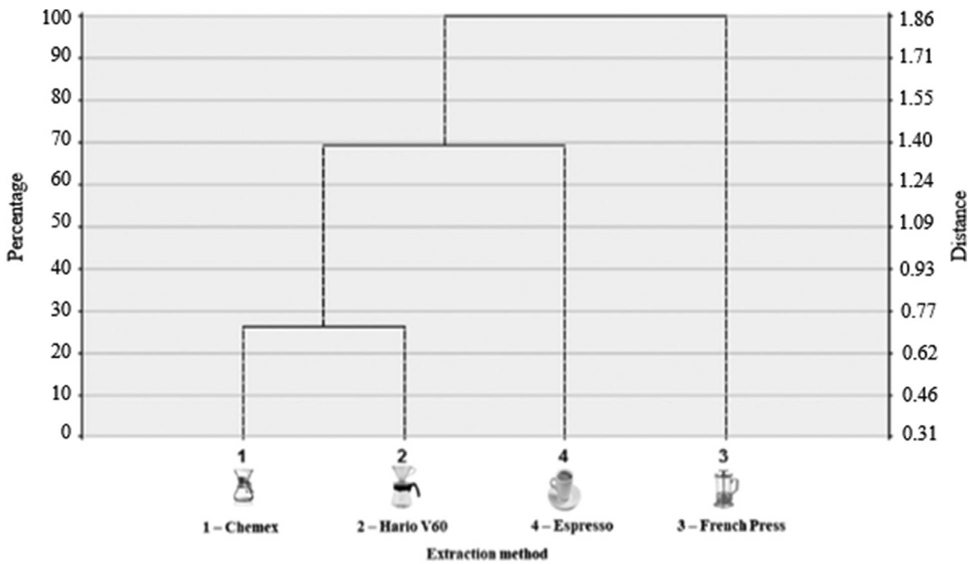

Fig. 1. Dendrogram (Average Euclidean distance – Complete connections) obtained among the four coffee extraction methods (1 – Chemex; 2 – Hario V60; 3 – French Press; and 4 – Espresso) regarding the group of untrained consumers.

be powerful enough to modify the activation pattern observed in the primary sensory regions (Carvalho & Spence, 2018).

The Chemex, Hario V60, and Espresso methods did not show statistical differences (p> 0.05) in the score for the aroma (Table 1). The aroma score of the French Press was lesser than the scores of other methods (Table 1). Nevertheless, the pressure exerted on the extraction of Espresso coffee may release more intensely odorous compounds than the infusion methods (Firestein, 2001).

Although aroma and taste are characterized by the origin of green coffee, the roasting process controls the developmental progress of the volatile compounds, resulting in differences in the complexity of coffee aroma with different roast degrees and conditions (Bhumiratana et al., 2011). Furthermore, the form of extraction also generates a different perception concerning the aroma of coffee due to the increase in the retention or filtration of aroma compounds (López-Galilea et al., 2008).

The flavor variable presented low variation in the methods used (Table 1). The Hario V60 method does not show statistical differences (p> 0.05) with the Chemex and Espresso methods. Espresso and French press methods also had no statistical differences and they were rejected according to flavor with means scores like "moderately dislike" (4.0) and "neither like nor dislike" (5.0). The flavor score of the infusion extraction methods (Table 1) confirms the data obtained by Machado et al. (2008). Brazilians consume, on average, about 220 mL of infusion coffee per day (Machado et al., 2008, Soares et al., 2019) which may explain the rejection of other brewing methods. Furthermore, flavor is arguably the most important aspect of good coffee. This sensory variable is extremely complex and arises from numerous chemicals during roasting and cup preparation (Sunarharum et al. 2014). The knowledge of flavor precursors, as well as the formation mechanism and kinetics of the key flavor compounds, is essential in the development of high-quality coffee (Poisson et al., 2017).

The Chemex and Hario V60 had better global impression and preference according to untrained consumers than other brewing methods (Table 1). These results can be confirmed in the dendrogram of the sensory analysis and extraction methods, which suggests the existence of two homogeneous groups (Fig. 1). Group A formed by the Chemex, Hario V60, and Espresso methods of extraction, and group B by the French Press method. These two groups can be related to the granulometry of the coffee grind. Only the Espresso method had fine ground (Supplementary material 1). The variability of the particle size distribution of coffee grounds significantly affects the percolation rate, caffeine level, solid content, pH, and acidity as a consequence of changes in the microstructural properties of the coffee, such as porosity and the percolation pathway (Severini et al., 2016).

Despite the French Press being an infusion extraction method, it presented the worst results in the preference test with untrained consumers, indicating that the high acidity that the method produces, in addition to the denser body due to the contact with the powder, may have negatively influenced the perception of consumers (Fig. 1, Table 1). It may be explained by the small differences in the acidity of the different extraction methods in the sensory evaluation (Gloess et al., 2013), since the coffee obtained with the Hario V60 method presented low acidity and body (Zapata et al., 2019). Nevertheless, French Press is the choice for brewing specialty coffee that produces delicious coffee with intense flavor according to Suastuti et al. (2020). Thus, the results of this study disagree with those authors' findings.

The French Press also has a lot of contact with the coffee grounds, releasing microparticles that suggest more density on the palate at the time of consumption, thus impairing the sensory perception of untrained consumers, or even because this method is not commonly used for daily coffee consumption at home. Another factor associated with the French Press, differences can be caused by factors such as the environmental temperature, and the delay between serving and consuming the coffee, which can impact its sensory properties (Adhikari et al., 2019). Thus, the results presented in Table 1 indicate that untrained consumers have greater acceptance of coffee by the infusion method through processes that are softer on the palate, in this case, the Chemex and Hario V60 methods, indicating that the attributes of sweetness, flavor, and balance are more pronounced after extraction.

Our results of sensory characteristics of coffee corroborate those of Zapata et al. (2019). For these authors, statistical analysis indicated significant differences (p>0.05) between coffee preparation methods and the sensorial profile of the cup. The coffee obtained with the V60 method presented low acidity and body attributes. The V60 and V60 Kalita methods registered the lowest tannin content (Zapata et al., 2019). Tannins are astringent, bound polyphenols, which precipitate, thus shrinking, proteins, causing the astringency of tannins to manifest in a dry feeling that occurs in the mouth after the consumption of some wines, strong tea, or unripened fruit (Kumar & Upadhyaya, 2012).

3.1. Similarity assessment of untrained consumers by the Tocher method

Twelve groups (average) observed in the Tocher optimization for Hario V60, Chemex and French press methods (Table 2) show the homogeneity in the sensory acceptance of the 124 untrained consumers. The V60 is extremely popular among consumers and industry experts, and it has not been previously investigated in the scientific literature.

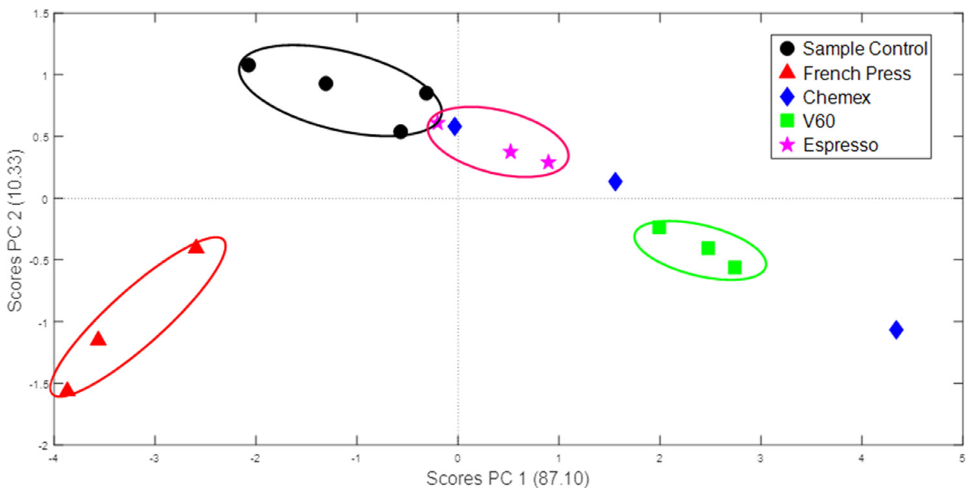

Fig. 2. Spatial distribution of the coffee extraction methods based on Principal Component Analysis, referring to the Chemex, Hario V60, French Press, Espresso methods, followed by the control sample.

In addition, high per-cup levels of caffeine were found for the V60 and Aeropress methods (Angeloni et al., 2019).

The sensory characteristics that most influenced the grouping by Tocher optimization were appearance and aroma (Table 3). In this optimization, global impression had lesser influence than sensory variables.

The Chemex method had a slightly longer brewing time than Hario V60, which allowed a greater perception of all the nuances of the coffee. Thus, the influence of sensory characteristics in the grouping by Tocher optimization for the Chemex method is in agreement with those proposed by Bhumiratana et al. (2011). According to these authors, the aroma of coffee detected by the descriptive panel is mainly affected by the stage of preparation and the consumer evaluations are necessary to identify the key attributes that might impact acceptability.

The grouping for French Press method (Table 2) was similar to the results of Fibrianto et al. (2017). For those authors, the aroma attribute in the French Press technique had higher intensity than the others. Furthermore, the differences in coffee brewing techniques, especially techniques using pressure, have an impact on the concentration of caffeoylquinic acids (Blumberg et al., 2010), which explains the separation of this method by untrained consumers (Fig. 1).

In the Espresso method cream formation was observed, which is a typical characteristic and one of the greater sensorial impacts of this preparation, whereas the French Press method did not present much cream. Because of that, there was a significant difference between samples where the persistence of the cream attribute was compared. The judges described the samples obtained by the Espresso method homogeneously, which could be due to sensory and hedonic expectations that influence the real perception of food (López et al., 2019). On the other hand, grinding increased the surface area and released volatile aromas, hence leading to more intense characteristics as compared to whole roasted beans and brewed coffee (Bhumiratana et al., 2011).

3.2. Mid-Infrared analysis

In this study, the PCA method was applied, generating a distribution of the samples based on the brewing methods of coffee and the control sample, which did not go through any extraction and was added for comparison purposes in the instrumental analysis (Fig. 2). The separation observed in the PCA scores can be better understood when considering the chemical composition of the coffees studied (Fig. 3).

The first principal component (PC1) retains 87.10% of the explained variance, while the second principal component (PC2) explains 10.33% of it. So, more than 97% of the information was contained in the first two main components, that is, both were responsible for the separation of the samples. Furthermore, the four groups of PCA suggests that Sample Control, Espresso, Hario V60, and French Press have differentiation in chemical composition (Fig.s 2 and 3). The samples of coffee obtained by the different coffee extraction techniques did not have the same profiles of volatile and bioactive compounds (Angeloni et al., 2019, Gloess et al., 2013, Zapata et al., 2019).

The brewing methods that differ the most were the French Press and the Hario V60 in the PCA, which may be due to the removal or retention of chemical compounds by each method (Figs. 2 and 3). The greatest hydroxycinnamic acid content was obtained with the V60 method, while the V60 and V60 Kalita methods retained the lowest amounts of this compound in coffee samples (Zapata et al., 2019). The hydroxycinnamic acids (e.g ferulic, caffeic, sinapic, and p-coumaric acids) make up about one-third of the phenolic compounds in foods (Teixeira et al., 2015). Furthermore, the brewing methods and water temperature influence caffeine extraction (Bellumori et al., 2021).

The OH-stretching bands at 3500–3100 cm^{-1}, aldehyde absorption bands at 2921 to 2852 cm^{-1} and carbonyl of carboxylic acid, aldehyde, and ester at 1740 cm^{-1}, carbonyl of ketone and amino acid at 1638 cm^{-1}, NH bond of a primary amine at 1585 cm^{-1}, amino acid carboxylate at 1461 cm^{-1}, C-N bond of amine at 1157 cm^{-1}, and CO bond of alcohol were observed in the Mid-Infrared spectrum (Fig. 3). In addition, our study of the chemical composition of brewed coffee was the first to use the Mid-Infrared technique, which is considered the most economical and the fastest compared to other analytical methods.

The OH-stretching of carboxylic acids or alcohols may characterize the coffee sugars and the NH-stretching of primary amines also can be observed at 3500–3100 cm^{-1} (Fig. 3). Primary amines are nitrogenous organic compounds that derive from the substance ammonia (NH_3) by replacing one or more hydrogens with organic radicals, (N–H) and aromatic (C–N) compounds could also be contributed from the Maillard reaction, particularly heterocyclic components such as pyrazines and pyridines that have amine (N–H) and aromatic (C–N) groups. Biogenic amines are nitrogenous organic bases that serve as important indicators of quality in a wide variety of food products, these organic compounds are usually formed by free amino acid decarboxylation as a consequence of physical-chemical and biochemical processes that take place during coffee bean processing (Dias et al., 2012). Furthermore, carbonyl (C=O) and amine (N–H) groups have a negative correlation with the antioxidant activity of coffee extracts (Kurniawan et al., 2017).

The absorption bands observed in the Mid-infrared of coffee samples (Fig. 3) may be due to hydrocarbon oxidation products (Gracia et al., 2011). The lack of oxygen during superheated steam roasting also helps to decrease the content of unsaturated aldehydes which are formed by lipid oxidation and contribute to an undesirable woody, cardboard-like flavor (Chindapan et al., 2019).

The carbonyl group (1740 cm^{-1}) imparts organoleptic qualities of foods due to the effect of the aroma on the taste centers in the nose

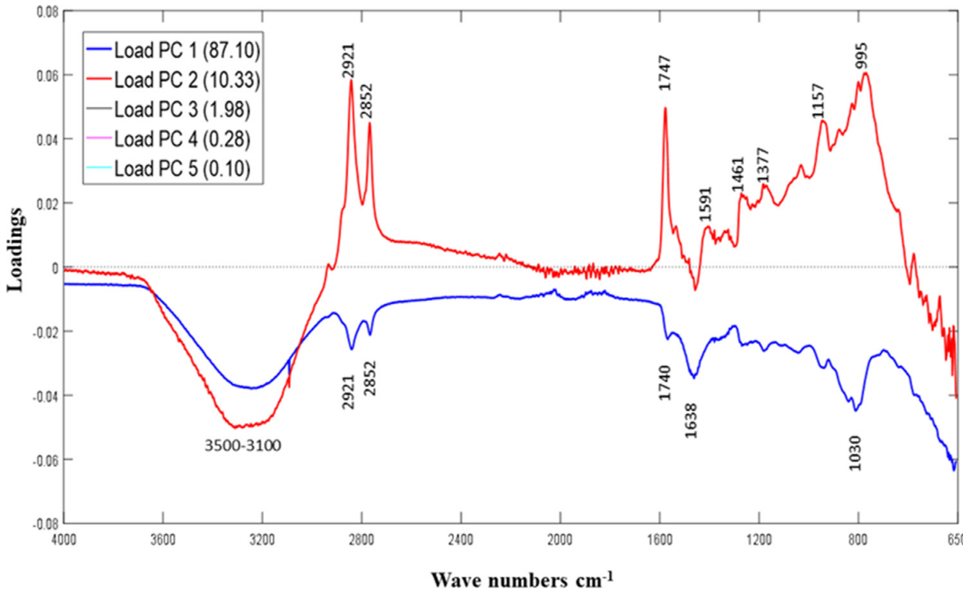

Fig. 3. Distribution of wavelengths cm $^{-1}$, Principal Component Analysis, referring to the coffee extraction methods applied in this study: Chemex, Hario V60, French Press, and Espresso.

and mouth (Lyman et al., 2003) and the carbonyl of the 1800- 1680 cm^{-1} region (Fig. 3) provides a flavor that appears to be consistent with the taste and aroma perceived by coffee cuppers (Lyman et al., 2003).

Carbonyl was also associated with bands at 1712, 1705, 1697, 1689, 1638 cm^{-1} of ketone and carboxylic acid (Fig. 3). The most abundant volatile compounds in coffee are aldehydes and ketones, and some of them are also Maillard reaction products (Ludwig et al., 2014). Furthermore, medium-roasted coffee has a more full-bodied flavor, an improved balance of taste and aroma, and a more pronounced citrus taste than light-roasted coffee (Lyman et al., 2003). According to these authors, the thermal process caused changes to the ester, aldehyde, ketone, and carboxylic acid, increasing the sensory quality of coffee.

Regarding the content of lipids, the methods of preparing the beverage produces variation. In some methods (Turkish and French) prepared with arabica coffee, lipid content was higher than in other methods (Express, Italian, Traditional, and Hario V60) prepared with conilon coffee (Santos & Junior, 2019). Furthermore, triesters and carboxylic acid can also be produced by the thermal degradation of lipids during the roasting and brewing of coffee (Fig. 3). This biomolecule has the organic function of ester and carboxylic acid (Silverstein et al., 2007).

Proteins and amino acids (carboxylate band at 1461 cm^{-1}) are essential for the conversion of reducing sugars into aroma precursors through Maillard reactions (Joët et al., 2010, Poisson et al., 2017) and the negative loadings of these compounds might be related to the suppression of sweetness of the coffee (Versari et al., 2011).

The brewing methods of coffee influence the sensory attributes and the acceptance and preference of untrained consumers. This influence can be due to the potential of retention or filtering of organic compounds of each method. Furthermore, the infusion method (Hario V60 and Chemex) has a better preference than other methods.

4. Conclusion

The Mid-infrared analysis associated with PCA demonstrated efficiency in separating the classes of compounds between the brewing methods French Press and Hario V60, confirming that the technique should be used as a support in quality control. Furthermore, the Mid-infrared results indicate the need to distinguish the classes of organic compounds, aiming at a deeper understanding of the chemical composition that interacts with coffee brewing.

Credit Author Statement

All authors contributed to the article and approved the submitted version.

Declaration of competing interest

The authors declare that they do not have to compete for financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.focha.2023.100185.

References

Adhikari, J., Chambers, E., & Koppel, K. (2019). Impact of consumption temperature on sensory properties of hot brewed coffee. *Food Research International, 115*, 95–104. doi:10.1016/j.foodres.2018.08.014.

Angeloni, G., Guerrini, L., Masella, P., Bellumori, M., Daluiso, S., Parenti, A., & Innocenti, M. (2019). What kind of coffee do you drink? An investigation on effects of eight different extraction methods. *Food Research International, 116*, 1327–1335. doi:10.1016/j.foodres.2018.10.022.

Assis, C., Pereira, H. V., Amador, V. S., Augusti, R., de Oliveira, L. S., & Sena, M. M. (2019). Combining mid infrared spectroscopy and paper spray mass spectrometry in a data fusion model to predict the composition of coffee blends. *Food Chemistry, 281*, 71–77. doi:10.1016/j.foodchem.2018.12.044.

Bellumori, M., Angeloni, G., Guerrini, L., Masella, P., Calamai, L., Mulinacci, N., Parenti, A., & Innocenti, M. (2021). Effects of different stabilization techniques on the shelf life of cold brew coffee: Chemical composition, flavor profile and microbiological analysis. *LWT - Food Science and Technology*, 142, 111043. doi:10.1016/j.lwt.2021.111043.

Bhumiratana, N., Adhikari, K., & Chambers, E. (2011). Evolution of sensory aroma attributes from coffee beans to brewed coffee. LWT - Food Science and Technology, *44*(10), 2185–2192. doi:10.1016/j.lwt.2011.07.001.

Blumberg, S., Frank, O., & Hofmann, T. (2010). Quantitative studies on the influence of the bean roasting parameters and hot water percolation on the concentrations of bitter compounds in coffee brew. *Journal of Agricultural and Food Chemistry, 58*, 3720–3728. doi:10.1021/jf9044606.

Carvalho, F. M., & Spence, C. (2018). The shape of the cup influences aroma, taste, and hedonic judgements of specialty coffee. *Food Quality and Preference, 68*, 315–321. doi:10.1016/j.foodqual.2018.04.003.

Chindapan, N., Soydok, S., & Devahastin, S. (2019). Roasting kinetics and chemical composition changes of robusta coffee beans during hot air and superheated steam roasting. *Journal of Food Science, 84*, 292–302. doi:10.1111/1750-3841.14422.

Civille, G. V., & Oftedal, K. N. (2012). Sensory evaluation techniques - Make "good for you" taste "good. *Physiology & Behavior, 107*, 598–605. doi:10.1016/j.physbeh.2012.04.015.

De Bruyn, F., Zhang, S. J., Pothakos, V., Torres, J., Lambot, C., Moroni, A. V., Callanan, M., Sybesma, W., Weckx, S., & De Vuyst, L (2017). Exploring the impacts of postharvest processing on the microbiota and metabolite profiles during green coffee bean production. *Applied and Environmental Microbiology, 83 e02398-16*. doi:10.1128/AEM.02398-16.

Delonghi Ecam. (2020). Manual do usuário Delonghi Eca*m*: 23.210 http://pt.lastmanuals.com/manual-de-instrucoes/DELONGHI/ECAM-23.210.B (2016).

Dias, E. C., Pereira, R. G. F. A., Borém, F. M., Mendes, E., De Lima, R. R, Fernandes, J. O., & Casal, S. (2012). Biogenic amine profile in unripe arabica coffee beans processed according to dry and wet methods. *Journal of Agricultural and Food Chemistry, 60*, 4120–4125. doi:10.1021/jf2046703.

Fibrianto, K., Fakhruddin, M. H., & Wulandari, E. S. (2017). Effect of mokapot brewing temperature on sensory profiling of dampit and tulungagung ijo coffee. In *IOP Conference Series: Earth and Environmental Science* (pp. 68–74). https://iopscience.iop.org/article/10.1088/1755-1315/230/1/012037.

Firestein, S. (2001). How the olfactory system makes sense of scents. *Nature, 413*, 211–218. doi:10.1038/35093026.

Gloess, A. N., Schönbächler, B., Klopprogge, B., D'Ambrosio, L., Chatelain, K., Bongartz, A., Strittmatter, A., Rast, M., & Yeretzian, C (2013). Comparison of nine common coffee extraction methods: Instrumental and sensory analysis. *European Food Research and Technology, 236*, 607–627. doi:10.1007/s00217-013-1917-x.

Gracia, N., Thomas, S., Thibault-Starzyk, F., Lerasle, O., & Duponchel, L. (2011). Combination of mid-infrared spectroscopy and curve resolution method to follow the antioxidant action of alkylated diphenylamines. *Chemometrics and Intelligent Laboratory Systems, 106*, 210–215. doi:10.1016/j.chemolab.2010.08.017.

Joët, T., Laffargue, A, Descroix, F., Doulbeau, S., Bertrand, B., Kochko, A., & Dussert, S. (2010). Influence of environmental factors, wet processing and their interactions on the biochemical composition of green Arabica coffee beans. *Food Chemistry, 118*, 693–701. doi:10.1016/j.foodchem.2009.05.048.

Kumar, A. P., & Upadhyaya, K. (2012). Tannins are astringent. Journal of Pharmacognosy and Phytochemistry*, 1*, 45–50. www.phytojournal.comwww.phytojournal.com.

Kurniawan, M. F., Andarwulan, N., Wulandari, N., & Rafi, M. (2017). Metabolomic approach for understanding phenolic compounds and melanoidin roles on antioxidant activity of Indonesia robusta and arabica coffee extracts. *Food Science and Biotechnology, 26*, 1475–1480. doi:10.1007/s10068-017-0228-6.

Lyman, D. J., Benck, R., Dell, S., Merle, S., & Murray-Wijelath, J (2003). FTIR-ATR analysis of brewed coffee: Effect of roasting conditions. Journal of Agricultural and Food Chemistry*, 51*, 3268–3272. doi:10.1021/jf0209793.

López-Galilea, I., Andriot, I., De Peña, M. P., Cid, C., & Guichard, E. (2008). How does roasting process influence the retention of coffee aroma compounds by lyophilized coffee extract? *Journal of Food Science, 73*, 165–171. doi:10.1111/j.1750-3841.2008.00672.x.

López, J. E., Flores, F. R., Cuapio, A. A., Chávez, F. B., Oscar, A. C, Hernández, L. S., & López, G. P. M. (2019). Characterization of sensory profile by the CATA method of Mexican coffee brew considering two preparation methods: Espresso and French press. *International Journal of Food Properties, 22*, 967–973. doi:10.1080/10942912.2019.1619577.

Ludwig, I. A., Sánchez, L., De Peña, M. P., & Cid, C. (2014). Contribution of volatile compounds to the antioxidant capacity of coffee. *Food Research International, 61*, 67–74. doi:10.1016/j.foodres.2014.03.045.

Machado, L. M., Araújo, S., Da Silva, E., Donangelo, C., & Da Costa, T. (2008). Coffee consumption associated with physical activity, age, sex, and intake of high-energy, protein-rich foods among workers in the city of Belém, Pará, Brazil. *The Internet Journal of Nutrition and Wellness, 7*, 1–7.

Meilgaard, M. C., Carr, B. T., & Civille, G. V. (2006). *Sensory evaluation techniques* (p. 50). New YorK, USA: CRC Press.

Pereira, L. L., Guarçoni, R. C., Pinheiro, P. F., Osório, V. M., Pinheiro, C. A., Moreira, T. R., & ten Caten, C. S. (2020). New propositions about coffee wet processing: Chemical and sensory perspectives. *Food Chemistry, 310*, Article 125943. doi:10.1016/j.foodchem.2019.125943.

Pickard, S., Becker, I., Merz, K. H., & Richling, E. (2013). Determination of the alkylpyrazine composition of coffee using stable isotope dilution-gas chromatography-mass spectrometry (SIDA-GC-MS). *Journal of Agricultural and Food Chemistry, 61*, 6274–6281. doi:10.1021/jf401223w.

Poisson, L., Blank, I., Dunkel, A., & Hofmann, T. (2017). The chemistry of roasting-decoding flavor formation. in the craft and science of coffee. The Craft and Science of Co*ffee*, 273–309. doi:10.1016/B978-0-12-803520-7.00012-8.

Santos, F. S., & Junior, L. S. S. (2019). Study of the physicochemical characteristics of different methods of preparation of coffee from Arabica varieties (*Coffea arabica* l.) and Robust (*Coffea canephora*) (in portuguese). *Anais Seminário de Iniciação Científica, 22*. doi:10.13102/SEMIC.V0I22.4183.

Specialty Coffee Association of America (SCAA). (2013). *SCAA Protocols cupping specialty coffee. Specialty Coffee Association of America 1–10* http://www.scaa.org/PDF/resources/cupping-protocols.pdf.

Scholz, M. B. S., Silva, J. V. N., Figueiredo, V. R. G., & Kitzberger, C. S. G. (2013). Sensory attributes and physico-chemical characteristics of the coffee beverage from the IAPAR cultivars. *Coffe Science, 8*, 6–16. http://www.coffeescience.ufla.br/index.php/Coffeescience/article/view/297.

Severini, C., Derossi, A., Fiore, A. G., De Pilli, T., Alessandrino, O., & Del Mastro, A (2016). How the variance of some extraction variables may affect the quality of Espresso coffees served in coffee shops. *Journal of the Science of Food and Agriculture, 96*, 3023–3031. doi:10.1002/jsfa.7472.

Silverstein, R. M., Webster, F. X., & Kiemle, D. J. (2007). *Spectrometric identification of organic compounds* (p. 100). Wiley LTC.

Soares, A., Barros, N. M., Saint'Pierre, T. D., Lima, J. D. P., Calado, V., Donangelo, C. M., & Farah, A. (2019). Fortification of ground roasted coffees with iron, zinc, and calcium salts: Evaluation of minerals recovery in filtered and Espresso brews. *Beverages, 5*, 4. doi:10.3390/beverages5010004.

Suastuti, N. L., Eni Juniari, N. K., & Widiastuti, N. M. W. (2020). Characteristic of salak seed coffee with French press brewing method through organoleptic test. In *Advances in Economics, Business and Management Research* (pp. 16–20). doi:10.2991/icoborot-18.2019.18.

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. doi:10.1016/j.foodres.2014.02.030.

Teixeira, J., Gaspar, A., Garrido, M., Garrido, J, & Borges, F. (2015). Hydroxycinnamic acid antioxidants: An electrochemical overview. *BioMed Research International 2013ID 251754*. doi:10.1155/2013/251754.

Versari, A., Parpinello, G. P., Chinnici, F., & Meglioli, G. (2011). Prediction of sensory score of Italian traditional balsamic vinegars of Reggio-Emilia by mid-infrared spectroscopy. *Food Chemistry, 125*, 1345–1350. doi:10.1016/j.foodchem.2010.10.003.

Zapata, A. M. O., Arango, A. O. D., & Rojano, F. A. B. (2019). The effect of gravity-drip filtration methods on the chemical and sensorial properties of coffee (*Coffea arabica* L. var. Castillo). *Coffee Science, 14*, 415–426. doi:10.25186/cs.v14i3.

Zhang, C., Wang, C., Liu, F., & He, Y. (2016). Mid-infrared spectroscopy for coffee variety identification: Comparison of pattern recognition methods. *Jounal of Spectroscopy DI7927286*. doi:10.1155/2016/7927286.