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Influence of Water Pressure on the Final Quality of Arabica Espresso Coffee. Application of Multivariate Analysis

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Water pressure is one of the most important factors which influence the final quality of espresso coffee (EC). However, few studies dealing with this issue have been found. The aim of this work was to study the effect of water pressure on the final quality of Arabica ECs as well as to classify ECs prepared at different pressures (7, 9, and 11 atm) according to their physicochemical and sensory characteristics, key odorants, by means of multivariate analysis. Statistically, principal component 1 (PC1) separated ECs prepared at 7 and 9 atm from ECs prepared at 11 atm and included the main foam and taste characteristics as well as some key odorants and flavor compounds. ECs prepared at 7 and 9 atm were separated by principal component 2 (PC2). Coffees prepared at 9 atm showed consistency of foam and a high percentage of key odorants related to freshness and fruity, malty, and buttery flavors. A simple discriminate function was obtained by discriminate analysis, allowing the classification of ECs prepared at three pressures into their respective groups with a success rate of 100%.

KEYWORDS: Espresso coffee; water pressure; sensory flavor profile; arabica coffee; multivariate analysis

INTRODUCTION

The quality of coffee brews is directly related to the ability to transform the ground coffee into an enjoyable beverage (*1*). There are different methods to prepare a coffee beverage: steeping, decoction, percolation, drip filtration, vacuum filtration, and pressurized infusion, one of the most important methods, which is used to prepare espresso coffee (EC) (*2*). Characteristics such as smell, taste, color, and body are relevant and highly appreciated quality attributes (*3*). The physicochemical and sensory characteristics of a brew coffee obviously depend on certain technical conditions in its preparation (*4*).

The espresso method is a beverage preparation technique based on pressure-induced percolation of a limited amount of hot water through a ground coffee cake, where the energy of water pressure is spent within the cake itself (*2*).

The insoluble substances found in an espresso cup produce the particular effect and sensory perception called "body". In addition, the foam is a characteristic present in EC but absent in other coffee brews; it traps the volatilized aromas and doses their emission to the atmosphere. Persistent foam is of great importance, as it is responsible for the visual acceptance of the drink (*5*).

Several authors have studied the effect of different technical conditions on the final quality of EC. Illy and Viani (*5*), Nunes et al. (*3*), and Maeztu et al. (*6*, *7*) studied the influence of the variety of coffee (Arabica and Robusta) and the degree and type of roasting. Other factors, such as the size of coffee particles and the water-to-coffee ratio, have been studied by other authors (*8*, *9*). EC preparation is a traditional method, the conditions of which are not accurately defined. As described by Petracco (*10*) and Illy and Viani (*5*), there is a lack of standardization in the conditions of EC preparation, namely, the weight of roasted ground coffee used, the beverage volume, and the extraction conditions (pressure and temperature). With regard to temperature, Andueza et al. (*11*, *12*) have carried out some studies in which it was concluded that the best qualities of three samples of EC (Arabica, Robusta Natural Blend, and Robusta Torrefacto Blend) were obtained when the water temperature was 92 °C. Water pressure is one of the most important factors which influences in the final quality of espresso coffee. However, studies regarding the influence of this factor on EC have not been found.

The aim of this work was to study the effect of water pressure on the final quality of Arabica EC as well as to differentiate and classify ECs prepared at different pressures (7, 9, and 11 atm) according to the physicochemical and sensory characteristics, key odorants, by means of multivariate analysis.

MATERIALS AND METHODS

Materials. Roasted coffee samples of Arabica coffee (pure *Coffea arabica* from Colombia, 2.0% water content) were provided by a local factory. Two batches of this coffee sample were used.

Pure reference standards of acetaldehyde, 2-methylpropanal, 3-methylbutanal, 2,3-butandione, 2,3-pentandione, and 2-ethyl-3,5-dimethylpyrazine were purchased from Acros (New Jersey), while

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hexanal, guaiacol (2-methoxyphenol), and propanal were obtained from Sigma (Steinheim, Germany).

EC Samples and Preparation for Analysis. The ECs were prepared from 7.5 g of finely ground (particle size: 50% >500 μm, 21% >400 μm and <500 μm, 25% >300 μm and <400 μm; 2% <200 μm) roasted coffee for a volume of 40 mL, with the use of an experimental EC prototype machine. EC preparation conditions were fixed at 92 °C water temperature (corresponding to erogation temperature 86 ± 2 °C), 21 ± 3 s extraction time, and 38 mm holder filter diameter. Relative water pressures studied were 7, 9, and 11 atm. Twenty ECs of each coffee sample were prepared to be analyzed physicochemically in triplicate.

pH, Density, Viscosity, and Surface Tension. The EC samples were rapidly cooled at 20 °C, and the pH (Orion 420 A benchtop pH meter), density (densimeter), viscosity (Ostwald viscosimeter), and surface tension (Traube estalagmometer) were measured.

Foam Index and Persistence of Foam. The *foam index* was defined as the ratio, as a percentage, of EC foam and liquid volumes measured immediately after the extraction of EC with the use of a 100-mL graduated cylinder. The *persistence of foam* was defined as the time (in minutes) that the liquid phase below the cream layer took to appear during cooling at room temperature.

Total Solids, Extraction, Concentration, and Total Solids on Filtrate. The *total solids* was determined by oven drying 40 mL of EC to a constant weight (14 h, 102 ± 3 °C). The *extraction* was defined as the percentage of total solids with respect to ground roast coffee dose (7.5 g). The *concentration* was defined as the percentage of total solids with respect to the EC volume (40 mL). The *total solids on filtrate* was determined by oven drying 40 mL of EC after filtering with Whatman 1 to a constant weight (14 h, 102 ± 3 °C).

Lipids. The total amount of lipids was determined by liquid−liquid extraction with the use of trichloromethane. Twenty milliliters of EC was extracted by adding 20 mL of tricloromethane three times in a separation funnel. The organic fraction was washed with distilled water three times. The total lipids was quantified by weight after evaporation of the solvent.

Caffeine and Trigonelline. Extract preparation, cleanup, and HPLC analysis have already been described by Maeztu et al. (*6*). HPLC analysis was carried out with an analytical HPLC unit (Hewlett-Packard 1100), equipped with a Rheodyne injector of 20-μL loop, a binary pump, and a diode-array detector. A reversed-phase Hypersil-ODS (5 μm particle size, 250 × 4.6 mm) column was used. The mobile phase was acetonitrile/water (15:85) under isocratic conditions at a constant flow rate of 2.0 mL min^{-1} at 25 °C. Detection was accomplished with a diode-array detector, and chromatograms were recorded at 280 nm.

Chlorogenic Acids (5-CQA). The extraction of 5-CQA and cleanup were carried out according to Bicchi et al. (*13*). The HPLC equipment has been described previously. The conditions used for the gradient solvent system were 100% citrate/acetic acid buffer solution (pH 3.0) for 2 min, 85:15 buffer/methanol for 8 min (both at a flow rate of 0.8 mL min^{-1}), and 85:15 buffer/methanol for 5 min, at a flow rate of 1.2 mL min^{-1} and at 25 °C. The wavelength of detection was 325 nm.

Sensory Descriptive Analysis. The sensory properties of the EC samples were measured using a variation of the quantitative descriptive analysis method (*14*). The judges were recruited among members of the Food Science and Technology Department at the University of Navarra. The method of selection and training used was that which was described by Maeztu et al. (*7*).

The appearance of foam was defined by color (clear, hazelnut, or dark), consistency (consistent or inconsistent), and persistence (with a hole in the center, evanescent, and persistent) and recorded as the percentage of judges that observed each attribute. For attributes such as odor, body, acidity, bitterness, astringency, flavor, and aftertaste intensities, 10-cm line scales, typically anchored with the words "none" (0) and "very high" (10) about 1 cm from each end and marked in the middle with "medium" (5), were used. Means and standard deviation for each attribute in each EC sample were obtained.

The *sensory flavor profile* was included in the same scorecard. The most frequently odor/flavor attributes described by the judges during the training process were written in two columns: one for positive and another for negative flavor attributes. Positive flavor attributes were fruity/winey, malty/cereal, freshness, straw, caramel-like, equilibrate, chocolate-like, spicy, nutty, tobacco, and buttery. Negative flavor attributes were woody/papery, burnt/roasty, acrid, fermented, earthy/musty, rancid, burnt-rubbery, sulfurous, flat, grassy/green/herbal, animal-like, motor oil, and ashy. In both columns, one line for "other flavors" was added. The flavor profiles of each EC sample were defined by the percentage of judges that perceived each positive and negative flavor attribute.

Descriptive evaluation of the EC samples was then carried out in triplicate over a total of six sessions. Three ECs were analyzed per session. Each EC was prepared immediately before taste and served in a white porcelain coffee cup labeled monadically with 3-digit codes. The order of presentation was randomized among judges and sessions. All evaluations were conducted in isolated sensory booths illuminated with white light, in the sensory laboratory, under standardized conditions by UNE 87-004-79 (*14*). Rinse water was provided between individual samples.

Overall Acceptability. Overall acceptability was evaluated by consumers using a 10-cm line structured scale, anchored with the words "very bad" (0) and "very good" (*10*) approximately 1 cm from each end. Overall acceptability evaluation of the EC samples was carried out in triplicate. Each EC was prepared immediately before taste and served in a white porcelain coffee cup labeled monadically with 3-digit codes. The order of presentation was randomized among consumers. Means were obtained for each EC sample.

Volatile Compounds. The profiles of volatile compounds were obtained with the method described by Sanz et al. (*16*), adapted to EC and using static headspace gas chromatography−mass spectrometry (SH-GC-MS). SH-GC analysis was performed with an HP 6890 gas chromatograph (Hewlett-Packard), equipped with a static headspace sampler (Hewlett-Packard model 7694).

Six milliliters of a homogenized EC was introduced into a 10-mL vial, which was immediately sealed with a silicone rubber Teflon cap. Each vial was equilibrated at 60 °C (the temperature at which the EC is drunk) for 20 min in the static headspace sampler. Each vial was pressurized with carrier gas for 12 s, and 3 mL of the coffee headspace sample was injected into an HP-Wax capillary column (60 m × 0.25 mm × 0.5 mm film thickness; Hewlett-Packard). Each EC sample was analyzed in triplicate, using three EC cups.

The injector temperature was set at 180 °C, and the carrier gas (10 mL/min linear speed) was helium. The oven temperature was maintained at 40 °C for 6 min and programmed to 190 °C at 3 °C/min.

Mass spectrometry analysis was carried out using a Hewlett-Packard mass-selective detector (model 5973) coupled to the gas chromatograph. The mass spectrometer operated in the electron impact ionization mode (70 eV), with a scan range of 33−300 amu. The ion source temperature was set at 230 °C.

Identification of the Volatile Compounds. The volatile compounds studied were identified by comparing their mass spectra to those of the Wiley library, and by comparing their retention times with those of standard compounds. The kovats indexes were calculated according to Tranchant (*17*) and compared with available literature data (*18*).

Quantitative Measurements. Methanethiol, acetaldehyde, propanal, 2-methylpropanal, 2-methylbutanal, 3-methylbutanal, 2,3-butanedione, 2,3-pentanedione, hexanal, ethylpyrazine, 2-ethyl-6-methylpyrazine, 2-ethyl-3,5-dimethylpyrazine, and guaiacol (2-methoxyphenol) were quantified as key odorants. The content of the key odorants of each headspace analysis was quantified by integrating the peak areas of the 13 compounds studied. The areas of the peaks were measured by calculating the total area, based on integration of a single ion. The relative percentages of individual compounds were calculated from the total contents of volatiles that were shown on the chromatograms.

Statistical Analysis. Analysis of variance (ANOVA) was applied to the physicochemical and sensory data and volatile compounds. The source of variation was the water pressure. T-Tukey was applied as the test a posteriori, with a level of signification of 95%.

Principal component analysis (PCA) was applied to the analytical and descriptive ratings (based on the Pearson correlation matrix) in order to determine relationships among EC samples prepared at each pressure. Extraction and concentration were excluded because they are mathematically related to total solids. Factors with eigenvalues greater than 1 were selected. The varimax rotation method was applied.

Table 1. Physicochemical Parameters of EC Samples[a]

	7 atm	9 atm	11 atm
pH	5.4 ± 0.0 b	5.4 ± 0.1 b	5.1 ± 0.0 a
density (g/mL)	1.011 ± 0.000 b	1.010 ± 0.000 b	1.007 ± 0.000 a
viscosity (mN/m^2·s)	1.20 ± 0.01 a	1.25 ± 0.03 b	1.26 ± 0.02 b
surface tension (mN/m)	48.48 ± 0.91 a	49.40 ± 2.06 a	47.93 ± 0.00 a
foam index (%)	14.7 ± 0.4 a	15.2 ± 0.1 a	20.7 ± 0.3 b
persistence of foam (min)	24.67 ± 0.52 a	28.17 ± 2.23 b	30.00 ± 0.00 c
total solids (mg/mL)	38.55 ± 0.81 a	39.22 ± 0.84 a	38.39 ± 0.24 a
extraction (%)	20.6 ± 0.4 a	20.9 ± 0.5 a	20.5 ± 0.1 a
concentration (%)	3.9 ± 0.1 a	3.9 ± 0.1 a	3.8 ± 0.0 a
total solids on filtrate (mg/mL)	36.34 ± 0.66 b	37.4 ± 0.7 c	35.43 ± 0.25 a
total lipids (mg/mL)	4.74 ± 0.12 a	5.15 ± 0.03 b	5.09 ± 0.07 b
caffeine (mg/mL)	2.06 ± 0.03 a	2.05 ± 0.03 a	2.01 ± 0.05 a
trigonelline (mg/mL)	1.09 ± 0.06 b	0.94 ± 0.02 a	1.08 ± 0.11 b
chlorogenics acids (5-CQA) (mg/mL)	0.84 ± 0.02 b	1.12 ± 0.02 c	0.81 ± 0.02 a

[a] In each row, different letters (a, b, and c) indicate significant differences ($p < 0.05$) among EC samples. The same letter indicates that there is no significant difference among EC samples in this parameter. For all measurements, n = 6; values are given as mean ± SD.

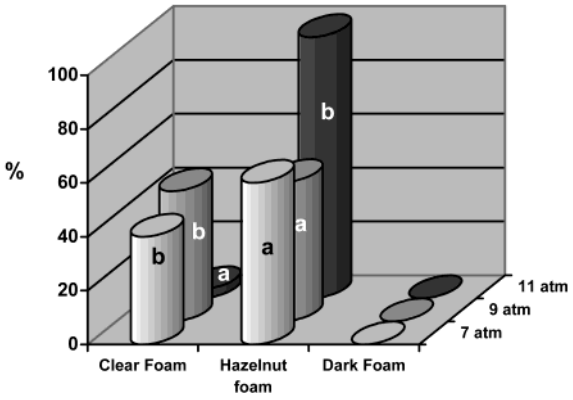

Figure 1. Foam color of EC samples (percentage of judges that observed the foam as clear, hazelnut, or dark). Letters a and b indicate significant differences among EC samples. The same letter indicates that there is no significant difference among EC samples in this parameter.

Discriminant analysis (DA) was performed in order to obtain an easy equation by which EC samples prepared at each pressure could be classified. Wilks's Lambda stepwise method was used. The criteria were 0.05 for maximum significance of F to enter and 0.10 for minimum significance of F to remove.

All statistical analyses were performed using the SPSS v.10.0 software package.

RESULTS AND DISCUSSION

Table 1 shows the ANOVA results of the physicochemical parameters. Significant differences were obtained among the ECs prepared at the three different pressures except for surface tension, total solids (extraction and concentration), and caffeine.

According to Illy and Viani (*5*), hydrodynamic experiments demonstrate that the average flow does not linearly depend on pressure in the proximity of 9 atm, and that an increase in pressure actually causes a decrease in the average flow, despite Darcy's law. In our study, this theory can explain the significant increase of total solids on filtrate, total lipids, and chlorogenic acids when the water pressure increased from 7 to 9 atm, while at higher pressure (11 atm) they decreased or were maintained.

Foam is the essence of the espresso extraction. It is the symbol of a great extraction and a good coffee. In this study, the highest foam index was obtained in coffees prepared at 11 atm. But coffees prepared at three different pressures (7, 9, and 11 atm)

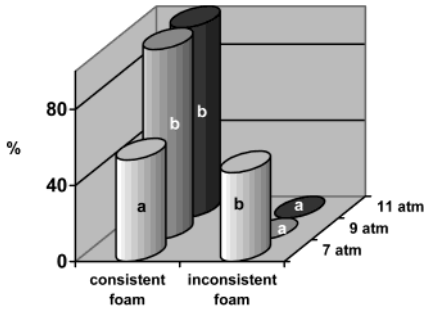

Figure 2. Foam consistency of EC samples (percentage of judges that observed the foam as consistent or persistent). Letters a and b indicate significant differences among EC samples. The same letter indicates that there is no significant difference among EC samples in this parameter.

Table 2. Sensory Attributes of EC Samples[a]

	7 atm	9 atm	11 atm
odor intensity	5.9 ± 0.3 a	6.3 ± 0.8 b	6.9 ± 0.6 c
body	5.9 ± 0.6 b	5.5 ± 0.8 a	6.1 ± 0.7 b
acidity	4.8 ± 0.8 a	6.0 ± 1.2 b	5.0 ± 1.2 a
bitterness	6.2 ± 0.8 a	6.3 ± 1.2 a	7.7 ± 0.9 b
astringency	6.0 ± 1.0 a	6.0 ± 1.4 a	6.9 ± 0.9 b
flavor intensity	6.4 ± 0.6 a	6.7 ± 0.8 a	6.7 ± 0.8 a
aftertaste intensity	6.1 ± 0.9 a	5.8 ± 0.9 a	7.2 ± 0.7 b

[a] In each row, different letters (a, b, and c) indicate significant differences ($p < 0.05$) among EC samples. The same letter indicates that there is no significant difference among EC samples in this parameter. For all measurements, n = 6; values are given as mean ± SD.

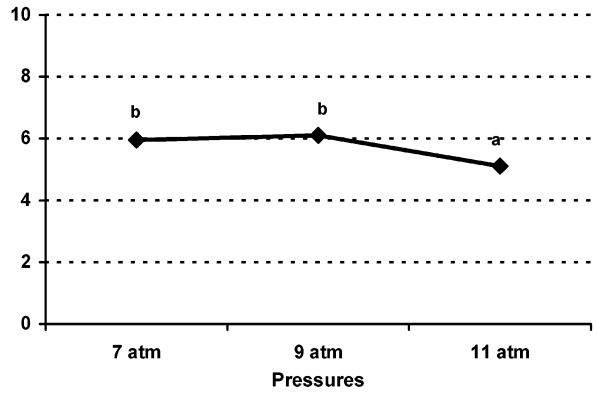

Figure 3. Influence of water pressure on overall acceptability of the EC samples.

showed a foam index higher than 10% (minimum value proposed by Illy et al. (*5*) in a good EC). Another characteristic of foam which has a special importance in EC is the persistence of foam; it should survive at least a couple of minutes before breaking and leaving a first uncovered black spot on the surface of the beverage (*2*). From a sensory point of view (**Figure 1**), coffees prepared at 11 atm showed a hazelnut foam, while in coffees prepared at 7 and 9 atm, 50% of the judges perceived that the foam was clear, probably due to "tiger skin effect". In our study, the persistence of foam increased significantly from 7 to 11 atm, but in all of the samples foam survived more than 2 min (**Table 1**). With regard to consistency of foam (**Figure 2**), the coffees prepared at 9 and 11 atm showed a consistent foam, while in coffees prepared at 7 atm, 50% of judges perceived the foam as inconsistent.

Table 2 shows the ANOVA results of the sensory parameters of taste, mouth feel, and flavor. There were few significative differences between the coffees prepared at 7 and 9 atm, but

Table 3. Influence of Water Pressure on Key Odorants of EC Samples (% Area of Compound/Total Area)[a]

KI[b]	ID[c]	key odorants	7 atm	9 atm	11 atm
635	C	methanethiol	0.06 ± 0.00 a	0.11 ± 0.01 b	0.15 ± 0.01 c
645	A	acetaldehyde	0.32 ± 0.02 a	0.41 ± 0.05 b	0.38 ± 0.00 b
712	A	propanal	0.45 ± 0.03 a	0.57 ± 0.06 b	0.54 ± 0.01 b
747	A	2-methylpropanal	2.13 ± 0.03 a	2.31 ± 0.38 a	2.46 ± 0.15 a
880	C	2-methylbutanal	1.48 ± 0.03 a	1.53 ± 0.20 a	1.95 ± 0.20 b
884	A	3-methylbutanal	2.91 ± 0.1 a	3.54 ± 0.45 b	3.78 ± 0.33 b
962	A	2,3-butanedione	0.41 ± 0.02 a	0.50 ± 0.08 b	0.46 ± 0.02 a b
1058	A	2,3-pentanedione	0.57 ± 0.03 a	0.74 ± 0.14 b	0.59 ± 0.03 a
1084	A	hexanal	0.04 ± 0.00 b	0.07 ± 0.01 c	0.02 ± 0.00 a
1359	A	ethylpyrazine	0.07 ± 0.00 b	0.07 ± 0.01 a b	0.06 ± 0.01 a
1411	A	2-ethyl-6-methylpyrazine	0.04 ± 0.00 b	0.04 ± 0.01 b	0.02 ± 0.00 a
1475	A	2-ethyl-3,5-dimethylpyrazine	0.01 ± 0.00 a	0.01 ± 0.00 a	0.02 ± 0.00 b
	A	guaiacol (2-methoxyphenol)	0.01 ± 0.00 b	0.02 ± 0.01 c	0.00 ± 0.00 a
		Σ (sum)	8.50	9.92	10.43

[a] In each row, different letters (a, b, and c) indicate significant difference ($p < 0.05$) among different temperatures of extraction in each coffee sample. The same letter indicates that there is no significant difference among EC samples in this parameter. For all measurements, n = 6; values are given as mean ± SD. [b] IK, Kovats index calculated for the HP-wax capillary column. [c] The reliability of the identification proposal is indicated by the following: A, mass spectrum, retention time, and Kovats index according to standards; B, mass spectrum and Kovats index according to literature data; C, mass spectrum, compared with Wiley mass spectral databases.

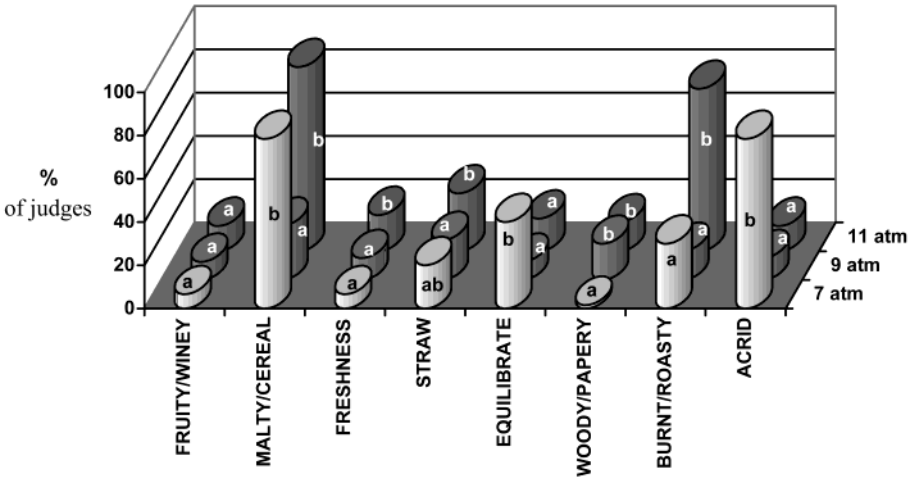

Figure 4. Influence of water pressure on flavor characteristics of EC samples (percentage of judges that perceived each flavor characteristics). Letters a and b indicate significant differences among EC samples. The same letter indicates that there is no significant difference among EC samples in this parameter.

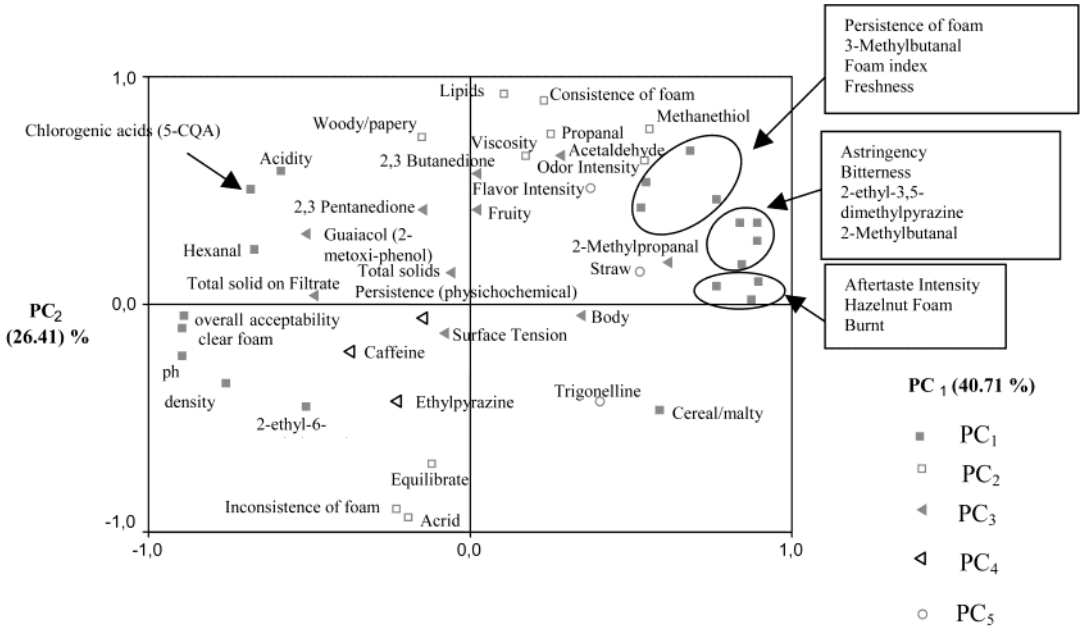

Figure 5. Principal component loadings for EC variables.

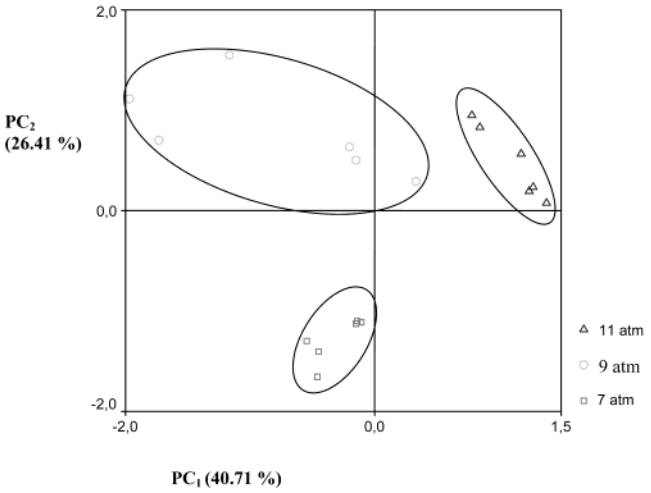

Figure 6. Normalized PCA scores of EC samples.

the coffees prepared at 11 atm were significatively more bitter and astringent and presented more odor and aftertaste intensity. In light of these sensory results, the ECs prepared at 11 atm were the worst qualified (**Figure 3**). With regard to the key odorants of EC samples (**Table 3**), when water pressure increased, more key odorants were detected. These results were in accordance with the value of odor intensity obtained in sensory analysis (**Table 2**).

Principal Component Analysis (PCA). Seven principal components (PCs) with eigenvalues greater than 1 were selected by PCA. PC1 and PC2 explained 67% of the total variance. **Figures 5** and **6** show bidimensional representations of PC1 and PC2 scores for all of the variables and samples, respectively.

PC1 separated ECs prepared at 7 and 9 atm from ECs prepared at 11 atm (**Figure 6**). It explained 40.71% of the total variance. This component included the main foam and taste characteristics of EC and some key odorants and flavor compounds. Coffees prepared at 11 atm presented a hazelnut foam and the highest foam index and persistence of foam, while coffees prepared at 9 atm had a "tiger skin effect", which was identified as clear foam by 48.3% of the panel.

This PC1 included all of the sensory taste parameters (acidity, bitterness, astringency, and aftertaste intensity). Coffees prepared at 11 atm were characterized by the panel of judges as bitter and astringent with high aftertaste intensity (**Table 2**). According to Petracco (*2*), too much pressure can produce a cup of coffee with high astringency and bitter taste.

In addition, PC1 included some key odorants and flavor compounds. ECs prepared at 11 atm showed higher percentages of 2-methylbutanal and 3-methylbutanal (**Table 3**), which can be related to the high percentage of judges who detected cereal/malty notes in these coffees (**Figure 4**). The percentage of 2-ethyl-3,5-dimethylpyrazine was also higher in coffees prepared at this pressure. The high percentage of judges that detected burnt/roasty notes in coffees prepared at 11 atm can be due to the increase of extraction of 2-ethyl-3,5-dimethylpyrazine in these coffees (**Table 3**; **Figure 4**). The lowest overall acceptability was given to coffees prepared at 11 atm (**Figure 3**).

ECs prepared at 7 and 9 atm were separated by PC2. It explained 26.41% of the total variance. The main difference between ECs prepared at 7 and 9 atm was the consistency of foam, which was greater in coffees prepared at 9 atm (**Figure 2**). Coffees prepared at 9 atm showed higher percentages of methanethiol and propanal, key odorants related to freshness and fruity flavor, respectively. In addition, the judges perceived

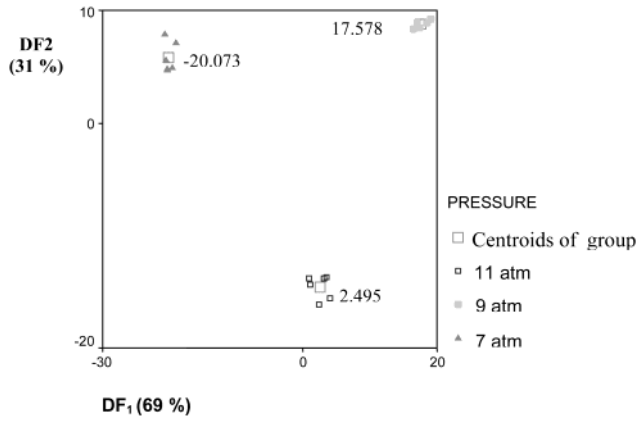

Figure 7. Discriminant scores and centroid values of the EC samples.

Table 4. Classification of Results of EC Samples with DF1

real group ($n = 6$)	experimental group (count, percentage)		
	7 atm	9 atm	11 atm
7 atm	6, 100.0%	0, 0.0%	0, 0.0%
9 atm	0, 0.0%	6, 100.0%	0, 0.0%
11 atm	0, 0.0%	0, 0.0%	6, 100.0%

a high percentage of woody/papery flavor notes. On the other hand, coffees prepared at 7 atm showed a high percentage of acrid notes.

Discriminant Analysis (DA). Two discriminant functions (DFs) were obtained. **Figure 7** shows the different sample results for DF1 and DF2 and the DF1 centroid values. DF1, which explained 69% of the total variance, is as follows:

$$y = 2.42(\text{total solids}) + 72.8(\text{chlorogenics acids}) + 1.965(\text{foam index}) - 0.206(\text{acrid flavor}) - 187.553$$

The DA proposed a function that was very easy to apply because the physicochemical parameters selected in DF1 were very simple to analyze and the sensory attributes were very easy to detect. DF1 permitted classification of the EC samples into their respective groups with a success rate of 100% (**Table 4**). This procedure might be considered as a first valuable approach that should be validated for application to other EC samples.

In conclusion, the ECs prepared at three pressures were perfectly separated by PCA. PC1 separated ECs prepared at 7 and 9 atm from ECs prepared at 11 atm. This component included the main foam and taste characteristics of EC and some key odorants and flavor compounds. ECs prepared at 7 and 9 atm were separated by PC2. Coffees prepared at 9 atm showed a consistent foam and a high percentage of key odorants related to freshness and fruity, malty, and buttery flavor.

A simple discriminate function was obtained by DA, permitting the classification of ECs prepared at three pressures into their respective groups with a success rate of 100%.

ABBREVIATIONS USED

ECs, espresso coffees; DA, discriminant analysis.

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