Foamability, Foam Stability, and Chemical Composition of Espresso Coffee As Affected by the Degree of Roast

Fernando M. Nunes, Manuel A. Coimbra,* Armando C. Duarte, and Ivonne Delgadillo

Department of Chemistry, University of Aveiro, 3810 Aveiro, Portugal

Two coffees of different botanical and geographical origins were used: Brazil coffee (dry-processed Arabica) and Uganda coffee (dry-processed robusta). The samples were roasted, and the foamability and foam stability of the espresso coffee were determined as a function of the degree of roast. Espresso coffees were characterized with regard to the amount of total solids, pH, fat, protein, and carbohydrate. The polymeric carbohydrates were precipitated with ethanol solutions (55 and 75% ethanol fractions), and the component monosaccharides were quantified by gas−liquid chromatography. A principal component analysis was applied to the chemical variables. This study showed that foamability of the espresso coffee increases with degree of roast and depends on the amount of protein in the infusion. Foamability as a function of the degree of roast does not differ significantly for the two coffees. Foam stability of espresso coffee as a function of degree of roast is related to the amount of galactomannan and arabinogalactan present and seems to be independent of the origin of the coffee despite the coffees having shown a different degree of roast for maximum foam stability. The degree of roast as a technological parameter does not allow an espresso coffee with maximum foamability and foam stability to be obtained at the same time.

Keywords: *Espresso coffee; degree of roast; foamability; foam stability; galactomannan; arabinogalactan; multivariate analysis; principal component analysis*

INTRODUCTION

In coffee beverages, characteristics such as the smell, taste, color, and body are relevant and highly appreciated quality attributes. In espresso coffee brew the persistent foam is also of great importance. Besides the visual importance of the persistent foam in espresso coffee, the building up of foam traps the volatilized aromas and slows their emission to the atmosphere (Illy and Viani, 1995).

The technical aspects of espresso coffee (EC) preparation are well documented by Petracco (1989) and Illy and Viani (1995). However, much of the knowledge about espresso coffee foam is empirical (Rosa et al., 1986), and little work has been done on the technological factors of coffee processing that influence foam properties such as foamability and foam stability. Earlier studies (Rosa et al., 1986) showed that espresso coffee foamability and foam stability decrease with increasing water content of the ground roasted coffee, increase with increased degree of compression in the filter holder, and increase with increased quantity of ground roasted coffee used for its preparation.

Espresso coffee preparation is a traditional method whose conditions are not accurately defined. As described by Petracco (1989) and Illy and Viani (1995), 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). All of these parameters are likely to influence the chemical composition of the EC. It was shown for coffee infusions that carbohydrate and protein concentration are dependent on the volume extracted (Petracco, 1989); also, extraction temperature and degree of roast affect carbohydrate composition of coffee extracts (Thaler, 1979; Leloup and Liardon, 1993). A determinant factor for the chemical composition of coffee infusions is the coffee's botanical and geographic origin and type of processing (Smith, 1985; Trugo, 1985). A multitude of variables can affect the EC chemical composition and related sensory characteristics. As far as we know, the chemical composition and its variation with the degree of roast are not accurately established for the EC.

In this work, the chemical factors that could be responsible for the foamability and foam stability of EC were studied as a function of the degree of roast (DR). Special attention was given to the macromolecular components—the proteins as tensioactive agents and the polysaccharides as responsible for conferring viscous properties to liquid solutions.

MATERIALS AND METHODS

Materials. Two green coffee samples, Brazil coffee (*Coffea arabica*, dry-processed Arabica, 11.4% water content) and Uganda coffee (*Coffea canephora*, dry-processed Robusta, 12.4% water content) were provided by a local factory. All chemicals were of analytical grade or the highest purity available.

Coffee Roasting. The coffees were roasted in a laboratory roaster (Probat, Germany) in batches of 130 g at 200 ± 5 °C and were degassed over 2 days at room temperature. The DR was quantified by the percentage weight loss of green coffee beans, on a dry basis. The water content of the roasted coffee was determined in duplicate by oven-drying the ground roasted coffee at 102 ± 2 °C for 4 h. The water content of the green coffee beans was determined using an Agrofarm apparatus (Concessus S.A., Denmark).

EC Samples. All of the EC samples were prepared from 6.0 g of finely ground roasted coffee for a volume of 40 mL of EC using an EC machine (La Cimbali M30 Classic, Italy). The filter holder was cooled for 10 min in water at room temperature before each experiment. The EC temperature was 63.5 ± 1.1 °C ($n = 5$).

Foamability (FA), Foam Stability (FS), and Foam Consistency (FC) of the EC. FA was defined as the volume

* Author to whom correspondence should be addressed (fax 351 34 25143; e-mail mac@dq.ua.pt).

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of EC foam measured immediately after the extraction of EC using a 50 mL graduated cylinder. The FS was defined as the time (in seconds) that the liquid phase below the cream layer took to appear during cooling at room temperature, using a 50 mL beaker. FC was defined as the resistance (in seconds per centimeter) that the consistometer (a laboratory-made apparatus of circular geometry, 2 cm diameter, with a metal net in the center and weighing 1.0 g) takes to penetrate the cream layer. FC was determined immediately after extraction of the EC.

EC Preparation for Chemical Analysis. EC samples were prepared from a set of four espresso coffees. The samples were rapidly cooled, and the pH was measured. Samples were concentrated under reduced pressure at 40 °C, frozen, and freeze-dried.

Fat Content. The fat from the freeze-dried extracts was removed and quantified by Soxhlet extraction with petroleum ether (Riedel, Seelze, Germany; bp 40−60 °C) for 24 h. The solution was kept overnight at −20 °C to precipitate the caffeine that was removed by filtration (0.2 μm filter). The filtrate was diluted to 250.00 mL with the solvent. Fat content was determined in 50.00 mL aliquots by evaporation of the solvent and drying to constant weight (2−3 h at 105 °C). The defatted extract gave the total solids.

Ethanol Precipitation. The total solids (2.0 g) were dissolved in 100 mL of water; the solution was stirred for 1 h at 4 °C and centrifuged at 24400*g* for 20 min at 4 °C. The residue obtained (WIppt) was suspended in water, frozen, and freeze-dried. Absolute ethanol (Riedel; 120 mL) was added, and the solution (55% ethanol, assuming additive volumes) was stirred for 1 h at 4 °C. This solution was then centrifuged, and the residue obtained (Et55) was removed. To the supernatant was added 180 mL of absolute ethanol; the solution (75% ethanol) was stirred for 1 h at 4 °C and centrifuged, and the residue obtained (Et75) was removed from the supernatant solution (EtSN). To remove the ethanol completely, each precipitate was dissolved in water, rotary evaporated, and freeze-dried (Coimbra et al., 1996a).

Protein Analysis. Protein determination was carried out using the Coomassie blue staining procedure as described by Fry (1988) using bovine serum albumin (Sigma, St. Louis, MO) as the protein standard.

Carbohydrate Analysis. Neutral sugars were released by Saeman hydrolysis (Selvendran et al., 1979) and analyzed as their alditol acetates by gas−liquid chromatography (Blakeney et al., 1983; Harris et al., 1988) using a Hewlett-Packard 5890 with a split injector (split ratio 1:60) and a FID detector. A 25 m column CP-Sil-43 CB (Chrompack, Holland) with id 0.15 μm and 0.20 μm film thickness was used. With the injector and detector operating at 220 °C, the following temperature program was used: 180 °C for 5 min and 200 °C for 20 min, with a rate of 0.5 °C/min. Linear velocity of the carrier gas (H_2) was set at 50 cm/s at 200 °C.

Statistics and Statistical Analyses. All determinations were made in triplicate, unless otherwise specified, using the technique of randomization of determinations consulting a random number table. All descriptive statistics and statistical tests were performed using SigmaStat for Windows version 2.0 (Jandel Corp. Erkrath, Germany). Principal component analysis (PCA) with Varimax rotation and cluster data analysis were performed using subroutines of Statistical Package for Social Sciences (SPSS, Chicago, IL). Prior to PCA analysis, all variables were standardized to 0 mean and unit standard deviation. The results obtained from PCA for the samples were subjected to a cluster analysis using Euclidian distance and the single linkage algorithm (Manly, 1986; Dunteman, 1994). The PCA scores for the samples were normalized to 1.

RESULTS AND DISCUSSION

FA, FS, and FC As Affected by the DR. Table 1 shows the values obtained for FA, FS, and FC as a function of the DR for the Brazil coffee. The FA of EC increases linearly with the ($r = 0.970$).

Table 1. FA, FS, and FC of Brazil Espresso Coffee as a Function of the DR[a]

DR (% WL)	FA (mL)	FS (s)	FC (s mL^{-1})
4.0	$1.2 \pm 0.14^{\mathbf{a}}$	$250 \pm 42^{\mathbf{a}}$	$0.63 \pm 0.32^{\mathbf{a}}$
5.5	$2.0 \pm 0.35^{a2,\mathbf{b}}$	$840 \pm 190^{a1,\mathbf{b}}$	0.70 ± 0.45
6.6	$2.0 \pm 0^{a1,\mathbf{c}}$	$1350 \pm 198^{a1,b3,\mathbf{c}}$	0.87 ± 0.54
9.7	$3.0 \pm 0.25^{a1,b2,c3}$	$2033 \pm 235^{a1,b1,c3,\mathbf{d}}$	$1.01 \pm 0.16^{a3,\mathbf{b}}$
12.1	$3.2 \pm 0.52^{a1,b3}$	$760 \pm 85^{a1,c1,d1,\mathbf{e}}$	0.74 ± 0.45
14.1	$3.5 \pm 0.35^{a1,b1,c2}$	$460 \pm 61^{a1,b3,c1,d1,e1}$	0.68 ± 0.20^{b2}

[a] The superscripts indicate significant differences within columns. For example, **a** is significantly different (Student *t* test) from all other a, but these last are not necessarily significantly different from each other. The numbers 1, 2, and 3 are indicative of the probability: 1, $p = 0.01$; 2, $p = 0.02$; 3, $p = 0.05$.

Table 2. Percentage of Water Content of Roast Ground Brazil Coffee As Affected by the DR

DR (% WL)	water content (%)
4.0	2.71 ± 0.05
5.5	1.97 ± 0.11
6.6	1.78 ± 0.01
9.7	2.15 ± 0.01
12.1	1.79 ± 0.03
14.1	1.70 ± 0.01

Table 3. FA, FS, and FC of the Uganda Espresso Coffee as a Function of the DR

DR (% WL)	FA (mL)	FS (s)	FC (s mL^{-1})
3.1	$1.4 \pm 0.14^{\mathbf{a}}$	$242 \pm 95^{\mathbf{a}}$	1.01 ± 1.07
5.7	$2.0 \pm 0^{a2,\mathbf{b}}$	$1326 \pm 102^{a1,\mathbf{b}}$	2.16 ± 1.18
7.6	$2.5 \pm 0.25^{a1,\mathbf{c}}$	$2916 \pm 228^{a1,b1,\mathbf{c}}$	3.48 ± 2.72
9.5	$2.9 \pm 0.14^{a1,b1,\mathbf{d}}$	$806 \pm 204^{a2,b2,c1}$	$1.78 \pm 0.55^{\mathbf{a}}$
15.5	$3.9 \pm 0.14^{a1,b1,c1,d1}$	$953 \pm 102^{a1,b2,c1}$	1.08 ± 0.40^{a3}

[a] The superscripts indicate differences within columns. For example, a is significantly different (Student *t* test) from all other a, but these last are not necessarily significantly different from each other. The numbers 1, 2, and 3 are indicative of the probability: 1, $p = 0.01$; 2, $p = 0.02$; 3, $p = 0.05$.

The FS of EC increases initially with the increase of the DR. After reaching a maximum (DR = 9.7%), the FS decreases with a further increase of the DR.

The variation of FC with the DR is similar to that of the variation of FS (Table 1). There is a high correlation between FC and FS ($r = 0.979$, $p = 0.01$); thus, 96% of the variation of FS of EC can be explained by the variation of FC. These results, and the direct relation shown between foam consistency and foam viscosity (Cheftel et al., 1985), allow one to infer a direct relation between FS and the EC foam viscosity.

The water content of the roasted coffee ranged from 1.70% to 2.71% (Table 2). As reported by Rosa et al. (1986), an influence of this parameter on FA and FS would be expected. Nevertheless, no significant correlation was found ($p = 0.05$), which shows that the influence of the DR on the FA and FS of EC is very much higher than the influence of the water content of the roasted coffee.

When the procedure described was applied to the Uganda coffee, the behavior observed for the FA, FS, and FC as a function of the DR is similar to that previously reported for the Brazil coffee. However, the DR for the maximum FS and FC is 7.6% (Table 3), lower than that found for the Brazil coffee (9.7%). For a DR near 7% (maximum FS for the Uganda coffee), the Brazil coffee showed a FS significantly lower ($p = 0.01$) than the Uganda coffee; for a DR near 10% (maximum FS for the Brazil coffee), the Uganda coffee showed a FS significantly lower ($p = 0.01$) than the Brazil coffee. For the Uganda coffee, the correlation between FC and

Table 4. Chemical Composition of Brazil Espresso Coffee as a Function of the DR

DR (% WL)	total solids (g)	insol solids (WIppt) (mg)	pH	fat (mg)	protein (mg)	CH (mg)	Et55 (mg)	Et75 (mg)
4.0	3.7818	162.6	5.06	176.0	15.79	442.4	253.4	204.2
5.5	4.1643	166.6	5.17	176.0	24.88	583.0	395.6	258.2
6.6	4.2482	140.2	5.37	132.8	29.20	777.4	433.3	169.9
9.7	4.7383	189.5	5.43	88.0	39.93	947.9	639.7	360.1
12.1	4.9476	193.0	5.89	62.4	41.55	826.2	470.0	193.0
14.1	5.0127	150.4	6.38	73.6	44.08	716.9	476.2	57.6

FS was also very high ($r = 0.947$, $p = 0.02$), thus 90% of the variation of FS of EC can be explained by the variation of FC.

Chemical Composition of Brazil EC Extracts As Affected by DR. There is an increase of the total solids of the Brazil EC with increasing DR (Table 4). The same behavior was observed for other infusion methods (Pictet and Rehacek, 1982). The amount of total solids showed a high correlation with the Ln DR ($r = 0.995$). However, the logarithmical dependence was not observed when the data were recalculated for the dry weight of green coffee, where there was an initial increase of the yield of total solids and, after reaching a maximum, there was a slight decrease in the quantity of total solids extracted. The maximum was observed for a DR of 12.1%. For lower DR, in relation to the green coffee, the roast causes an increase in solubilization of water soluble material. For higher DR, it was possible that part of the water soluble products become insoluble; as a consequence, less material was extracted in relation to the dry weight of the green coffee.

The water insoluble material present in the EC (WIppt) represented 3.0−4.3% of the Brazil EC total solids (Table 4). These figures revealed that most of the material present in the total solids was soluble in water.

This study shows a linear increase of the pH of the EC with increasing DR ($r = 0.956$, $p = 0.01$) (Table 4). Early studies showed that the acidity of coffee infusions was higher for medium roasts when compared with darker roasts (Clifford, 1985). Nevertheless, a Santos coffee infusion showed a minimum pH for a medium DR when compared to light and dark roasts (Reymond, 1982). The increase in pH with the DR has been attributed to the destruction of chlorogenic acids, which is characteristic of dark roastings, and to the binding of acids by the bean matrix (Clifford, 1985).

The protein content of the EC increased with increasing DR (Table 4). The quantity of protein extracted showed a very good linear correlation with the Ln DR ($r = 0.989$). The percentage of protein extracted in relation to the dry weight of green coffee showed a high linear correlation ($r = 0.976$), although it has been observed that during the roasting process there is a loss of total protein (Macrae, 1985).

Increasing the DR led to a decrease in the quantity of fat extracted (Table 4). The percentage of fat extracted in relation to the green coffee dry weight shows a linear correlation with the Ln DR ($r = -0.992$).

The carbohydrate content (CH) of the EC shows an initial increase with increasing DR and, after reaching a maximum at DR = 9.7%, decreased with a further increase in DR (Table 4). As verified with the total CH, the amount of water soluble material precipitated with 55% ethanol (Et55) and with 75% ethanol (Et75) increased initially with DR and, after reaching a maximum, decreased with a further increase in DR (Table 4). These fractions show a brown color, which increases with increasing DR. The color arises from the Maillard reaction caused by the high temperature of roast (Steinhart and Packert, 1993). Most of the polymeric carbohydrate material is present in the ethanol precipitated-fractions (Coimbra et al., 1996b).

Table 5. Composition of the Precipitated Fractions of Brazil Espresso Coffee (Milligrams) As Affected by the DR

	Et55				Et75		
DR (% WL)	Ara	Man	Gal	Man/Gal	Ara	Man	Gal
4.0	45.6	89.2	31.7	2.8	30.6	6.3	42.5
5.5	11.5	174.1	41.9	4.2	30.0	23.8	76.4
6.6	73.7	215.4	28.2	7.7	7.0	16.7	37.0
9.7	10.2	247.6	49.9	5.0	11.3	38.3	69.1
12.1	4.2	211.5	21.2	10.0	1.9	13.7	16.0
14.1	4.8	211.9	17.1	12.4	1.3	16.9	10.1

Table 5 shows the sugar composition of the Et55 and Et75 fractions of the Brazil EC. The major sugars are mannose, galactose, and arabinose. Minor quantities of glucose, xylose, and rhamnose are also detected (data not shown).

As the two main extractable polysaccharides of coffee are galactomannan and arabinogalactan (Leloup and Liardon, 1993), it can be inferred that all of the mannose and some of the galactose proceed from galactomannan. The remaining galactose and some of the arabinose proceed from arabinogalactan.

Fraction Et55 represents 68% of the material precipitated with ethanol (Et55 + Et75) and 10% of the total solids. The sugar composition shows that Et55 is rich in mannose and the ratio of Man/Gal of this fraction increases with the DR ($r = 0.884$). The ratio of Man/Gal is related to the degree of branching of the galactomannan as the galactosyl residues occurs as α-(1→6) side chains of the β-(1→4)-D-mannopyranosyl residues of the backbone (Dea and Morrison, 1975; Meier and Reid, 1982). The observed debranching of galactomannan with the DR was previously reported (Clifford, 1985) and may be due to the labile nature of the galactosyl side chain residues caused by the roasting process, which is in agreement with the labile nature of the α-glycosidic bond (Selvendran et al., 1989). The content of galactomannan of the Et55 fraction increased initially with the DR and then decreased with a further increase in DR; the maximum quantity was extracted with a DR of 9.7% (Table 5).

Fraction Et75 represents 32% of the material precipitated with ethanol (Et55 + Et75) and 4% of the total solids of the Brazil EC. The sugar analysis shows that the main constituent sugar is galactose. For the highest DR studied, mannose is the major sugar in the fraction. The mannose content in Et75 is, on average, 9% of the total Et55 + Et75 mannose. As the solubility of polysaccharides in ethanol solutions increases with increased degree of branching and with decreased degree of polymerization (Coimbra et al., 1995), it is possible that the galactomannan present in the Et75 fraction is more branched and has lower molecular weight than the galactomannan in Et55. This inference would be in accordance with the observations that

Table 6. Chemical Compositions of Uganda Espresso Coffee as a Function of the DR

DR (% WL)	total solids (g)	insol solids (WIppt) (mg)	pH	fat (mg)	protein (mg)	CH (mg)	Et55 (mg)	Et75 (mg)
3.1	3.6881	99.6	5.20	92.8	20.3	526.9	232.4	254.5
5.7	4.3840	127.1	5.49	73.6	29.5	609.3	363.9	311.3
7.6	4.9491	94.0	5.64	56.0	36.9	757.2	584.0	331.6
9.5	5.0451	95.9	6.10	41.6	44.4	706.3	464.1	227.0
15.5	5.1420	82.3	6.23	25.6	58.8	714.8	365.1	339.4

Table 7. Composition of the Precipitated Fractions of Uganda Espresso Coffee (Milligrams) As Affected by the DR

DR	Et55				Et75		
(% WL)	Ara	Man	Gal	Man/Gal	Ara	Man	Gal
3.1	14.4	87.2	37.2	2.3	61.6	12.7	89.6
5.7	17.5	186.3	44.0	4.2	22.1	30.8	66.9
7.6	18.1	244.1	52.6	4.6	21.9	24.2	108.1
9.5	6.0	214.9	29.7	8.1	9.3	26.7	58.6
15.5	8.4	163.6	16.1	10.2	8.5	109.3	88.9

galactomannan with higher degree of branching has little tendency to associate (Dea, 1979) and that the molecular weight of the galactomannan decreases with increasing DR (Leloup and Liardon, 1993). As the amount of mannose is lower that of galactose, the ratio of Gal/Ara shows the presence of significant amounts of arabinogalactan in the Et75 fraction. The observed decrease in the ratio of Gal/Ara with DR is expected and was also reported by Leloup and Liardon (1993).

Chemical Composition of Uganda EC Extracts As Affected by DR. The chemical data obtained for the Uganda EC as affected by DR (Table 6) follow the same pattern shown for the Brazil EC: total solids, WIppt, pH, fat, and protein all show the same type of variation; the total CH and Et55 + Et75 show a maximum amount of material for a DR of 7.6%.

As was verified for the Brazil EC, the major sugars of the Et55 and Et75 fractions of the Uganda EC are mannose, galactose, and arabinose (Table 7). The Et55 fraction is composed mainly of galactomannan, which shows an initial increase with the increasing DR and, after reaching a maximum at DR = 7.6%, decreases with further DR. The ratio of Man/Gal increases linearly with the increase of the DR (r = 0.963), showing a regular decrease of the degree of branching of the galactomannan with the DR.

The sugar composition of the Et75 fraction shows a mixture of galactomannan and arabinogalactan. The mannose in this fraction makes up, on average, 26% of the total Et55 + Et75 mannose.

Principal Component Analysis (PCA). To explain the observed variation of the FA and FS in terms of the chemical composition of the EC, a PCA with Varimax rotation was applied to the chemical data.

Figure 1 shows a bidimensional representation of PC1 and PC2 scores for the Brazil and Uganda EC samples. The cluster analysis (Figure 2) of the sample scores shows the formation of four distinct groups according to the FA and FS characteristics of the coffee samples (see Tables 1 and 3). The samples with higher FA show higher PC1 scores, and the samples with higher FS show higher PC2 scores. These results show that the chemical variables are appropriate to explain the variation of FA and FS as a function of the DR of the EC. Figure 3 shows that the variables pH, material soluble in 75% ethanol (EtSN), protein, total solids, and fat are highly correlated with PC1 and are responsible for the discrimination of the samples according to the FA. Figure 3 also shows that the variables Et55, PP55, and

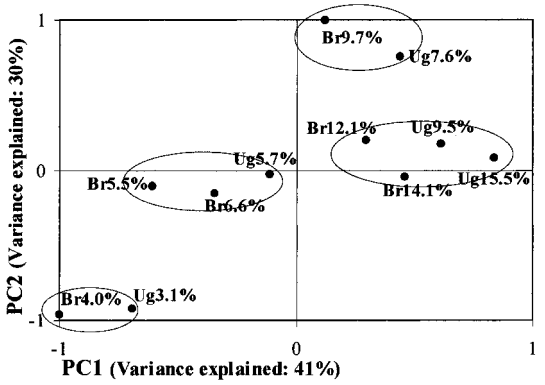

Figure 1. Normalized PCA of the espresso coffee samples: Br, Brazil; Ug, Uganda. The numbers after the letters are indicative of the DR.

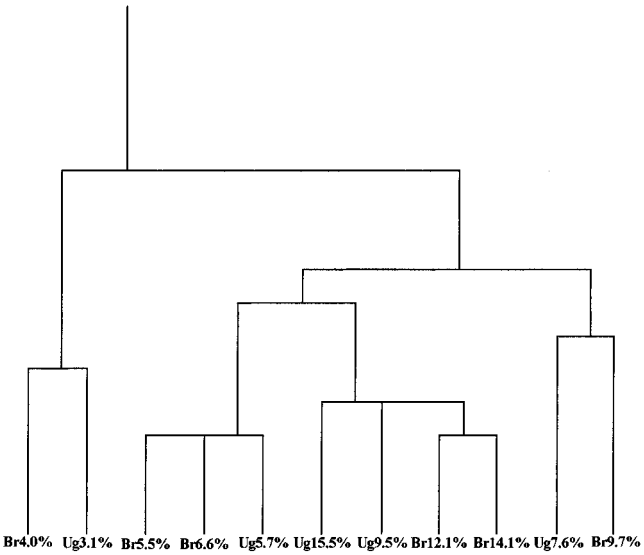

Figure 2. Cluster analysis of the normalized principal component scores for the espresso coffee samples: Br, Brazil; Ug, Uganda. The numbers after the letters are indicative of the DR.

Et55 + Et75 are highly correlated with PC2 and are responsible for the discrimination of the samples according to the FS.

To correlate the FA and FS with the chemical variables, a second PCA was done with the introduction of FA and FS into the data analysis (Figures 4 and 5). As can be seen in Figure 5, the variables with higher correlation coefficients with PC1 are concerned with pH, EtSN, protein, FA, total solids, and fat. These variables correspond to 42% of the total variance. The FA versus protein content of EC shows a very high linear correlation, r = 0.990 and 0.999 for the Brazil and Uganda coffees, respectively, so 98.0% and 99.9% of the FA variation of the EC can be explained by the variation of the protein content of the EC. The formation of a foam implies the diffusion of the soluble proteins to the air−water interface where they denature, concentrate, and install rapidly to decrease the interfacial tension. The FA increases generally with increase total protein

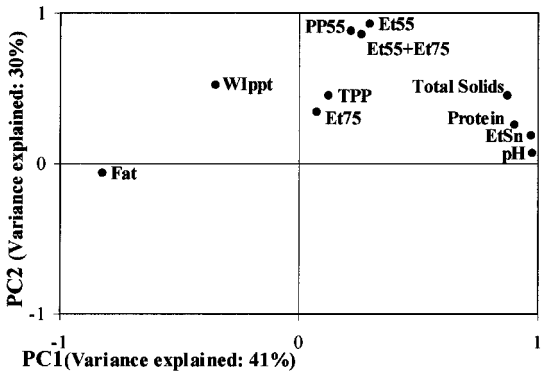

Figure 3. Principal component loadings for all of the espresso coffee variables (for legend see text).

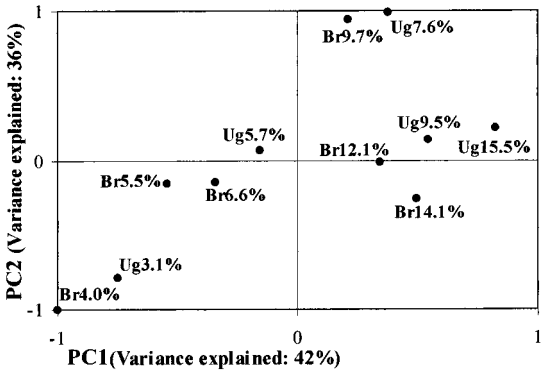

Figure 4. Normalized PCA scores of the espresso coffee samples with the introduction of FA and FS: Br, Brazil; Ug, Uganda. The numbers after the letters are indicative of the DR.

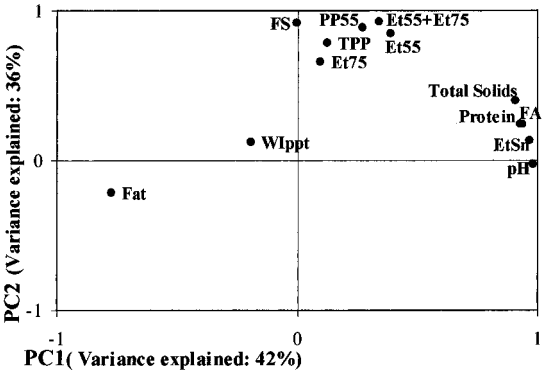

Figure 5. Principal component loadings for all of the espresso coffee variables with the introduction of FA and FS (for legend see text).

concentration until a maximum value is reached (Cheftel et al., 1985). In the EC, the ratio of protein/FA is nearly constant for the range of DR studied, which confirms that the FA is dependent on the protein concentration.

There is also a good correlation between pH and FA. This correlation may be due to the fact that the FA of proteins increases near their isoelectric points (Cherry and McWatters, 1981; Cheftel et al., 1985). In fact, in the case of the EC, the pH lies in the range of the isoelectric point of green coffee proteins (5.7−6.3; Macrae, 1985).

The FS shows mutual interdependence with total precipitated polysaccharides (TPP), polysaccharides precipitated in 55% ethanol (PP55), Et55 + Et75, Et55, and Et75 (Figure 5). These variables are explained by PC2 and correspond to 36% of the total variance.

A high correlation between FS and the fractions containing high molecular weight polysaccharides rich in galactomannan is observed. This correlation could explain the dependence between the FS and the viscosity of the EC foam as the presence of galactomannan is determinant to increase the viscosity of coffee extracts (Ehlers, 1980). The zero shear viscosity (η_0) increases exponentially with the polysaccharide concentration (Morris, 1995) so the dependence of the FS in relation to the polysaccharide amount is expected to show an exponential relation. Indeed, a high correlation of $r = 0.914$ and $r = 0.937$ ($p = 0.02$) is found between Ln FS and Ln TPP for Brazil and Uganda coffees, respectively. The variation of the high molecular weight polysaccharides of the EC explains 84% and 88%, respectively, of the variation of the FS.

The observation that FA and FS are associated with different PC shows that they are not correlated.

General Discussion. The FA of the EC increases linearly with the DR and is dependent on the amount of protein in the infusion. The pH seems also to contribute to the FA of the EC. No significant difference was observed between the two coffees for the variation of FA as a function of the DR.

A variation in the FS of EC as a function of the DR is observed. This variation is related to the amount of polysaccharides extracted from the roasted ground coffee and seems to be independent of the origin of the coffee (Brazil or Uganda) despite the coffees showing different DR for the maximum FS. The EC polysaccharides are mainly galactomannan and arabinogalactan and can be obtained by precipitation in 55% and 75% alcohol solutions. The DR affects the extraction of galactomannan to the EC, and a maximum amount is found for a particular DR dependent on the coffee. Also, increasing DR decreases the degree of branching of the galactomannan present in the EC.

This study shows that the technological parameter DR does not allow an EC with maximum FA and FS to be obtained at the same time.

ABREVIATIONS USED

EC, espresso coffee; DR, degree of roast; FA, foamability; FS, foam stability; FC, foam consistency; WIppt, water insoluble precipitate; Et55, material precipitated with 55% ethanol; Et75, material precipitated with 75% ethanol; EtSN, material soluble in 75% ethanol; PCA, principal component analysis; Ln, logarithm; CH, carbohydrate; Man, mannose; Gal, galactose; Ara, arabinose; PC1, first principal component; PC2, second principal component; TPP, total precipitated polysaccharides; PP55, polysaccharides precipitated in 55% ethanol.

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