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Furan Levels in Coffee As Influenced by Species, Roast Degree, and Brewing Procedures

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ABSTRACT: Brazilian green coffee beans of *Coffea arabica* and *Coffea canephora* species were roasted to light, medium, and dark roast degrees and analyzed in relation to furan content by using an in-house validated method based on gas chromatography coupled to mass spectrometry preceded by headspace solid-phase microextraction. Furan was not detected in green coffees, whereas levels between 911 and 5852 μg/kg were found in the roasted samples. Higher concentrations were found in *Coffea canephora* species and darker ground coffees. Some of the potential furan precursors were observed in significant amounts in green coffee, especially sucrose and linoleic acid, but their concentrations could not be correlated to furan formation. Additionally, coffee brews were prepared from roasted ground coffees by using two different procedures, and furan levels in the beverages varied from <10 to 288 μg/kg. The factor that most influenced the furan content in coffee brew was the brewing procedure.

KEYWORDS: furan, coffee, SPME-GC/MS, roasting, processing contaminant

INTRODUCTION

Furan and its derivatives have long been known to occur in heat-treated foods such as coffee, canned meat, baked bread, and cooked chicken and to contribute to their sensory properties.[1,2] In 2004, the U.S. Food and Drug Administration (US FDA) showed the presence of furan in a number of foods that undergo heat treatment, including canned and jarred foods, with levels ranging from nondetectable to 174 μg/kg.[3]

The occurrence of furan in commonly consumed foods raised for the first time a concern on the potential risks to human health because furan is classified as a possible human carcinogen (group 2B) by the International Agency for Research on Cancer.[4] A recent risk evaluation conducted by the Joint FAO/WHO Expert Committee on Food Additives (JECFA) has confirmed that the exposure to furan in the diet is a public health concern.[5]

Several authors have investigated the furan content in foods, and data available in the literature indicate that roasted coffee contains the highest furan levels in comparison to other products.[6−9] The highest level of furan was reported in roasted coffee beans with mean and maximum values of 3611 and 6407 μg/kg, respectively, while lower concentrations were found in ground and in instant coffee, with average levels of 1807 and 602 μg/kg, respectively.[10]

Furan is present in coffee as part of the volatile aroma components generated during roasting.[1] Although the exact mechanism of the reaction is not completely understood, the pathways proposed to explain the furan formation in foods is mainly based on the thermal degradation of sugars (alone or in the presence of amino acids), thermal degradation of certain amino acids, and thermal oxidation of ascorbic acid and polyunsaturated fatty acids.[11−13] However, it is still difficult to deduce which components are involved in the furan formation in real foods because most published data are based on model studies.

Although there have been several studies on furan content in roasted ground coffee and coffee brew, little information is available on the factors affecting the formation of this contaminant during coffee roasting. Guenther et al.[14] showed that furan levels in roasted coffee are correlated with the roast color, i.e. darker roast colors correspond to higher furan levels. However, the results did not indicate that furan formation potential significantly varies when comparing roasted samples from *C. arabica* and *C. canephora* species.

In relation to coffee brew, the increase in the temperature when pouring hot water into coffee powder to prepare the beverage results in significant losses of furan by all of the usual brewing methods such as percolation, cafetiere, or filtration. Therefore, coffee brew shows lower concentrations of furan than roasted ground coffee powder.[7] Several authors have shown that the transfer rate of furan from ground coffee to coffee brew is mainly determined by the procedure used to prepare the beverage.[6,8,14,15] Automatic coffee machines produce brews with higher levels of furan,because a higher ratio of coffee powder to water is used, giving a lower dilution factor, and because of the closed system favoring retention of furan. Much lower levels were produced by standard home coffee-making machines and by manual brewing. The influence of coffee species and roast degree on furan content in coffee brew has not been investigated.

To contribute to a better understanding of the factors affecting the formation of furan in coffee, the present research reports a preliminary attempt to identify the key components of the reaction by measuring the concentration of some of the suggested furan precursors (sugars, ascorbic acid, and polyunsaturated fatty acids) and by evaluating their potential to generate furan during roasting. This paper has also aimed to provide additional scientific information on the influence of species and roast degree on furan levels in roasted coffee and in coffee brew. Further data on furan content in coffee brew as affected by the brewing procedure are also reported.

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MATERIALS AND METHODS

Standards and Chemicals. Furan and [$^2H_4$] furan (furan-d_4) were obtained from Sigma-Aldrich (Sigma-Aldrich Corp., St. Louis, MO, USA) at purity higher than 98%. Glucose, fructose, sucrose, ascorbic acid, and the mixture of fatty acid methyl esters were also purchased from Sigma-Aldrich. All organic solvents (acetonitrile, methanol, petroleum ether, and hexane) were of HPLC grade and were acquired from Tedia (Tedia Company Inc., Fairfield, OH, USA) and Synth (Labsynth, Diadema, SP, Brazil). Water was purified by reverse osmosis (Gehaka, São Paulo, SP, Brazil). All other chemicals used (potassium hexacyanoferrate (II), zinc acetate, potassium dihydrogen phosphate, sodium hydroxide, ammonium chloride, and sulfuric acid) were of analytical grade and were purchased from Synth.

Samples. Two coffee species cultivated in the region of Campinas SP, Brazil, were evaluated: *Coffea arabica* cv. Catuaí Amarelo IAC-62 and *Coffea canephora* cv. Apoatã IAC-2258. Green coffee beans were obtained by the dry method, where coffee cherries were harvested, dried under the sun until they achieved 12% moisture content, and then the dried outer parts were mechanically removed.

Roasting Experiments. Green coffee beans were roasted in a Probatino roaster (Probat, Emmerich am Rhein, Germany) with temperatures and times varying from 108 to 230 °C and from 3 to 17 min, respectively, in order to obtain three roasting degrees for each species: light, medium, and dark. To evaluate the repeatability of the process, at least two replicates were performed for each degree. The batch size varied from 300 to 900 g of roasted coffee.

The roast degree was determined by the Agtron/SCAA Roast Color Classification System, using an E10-CP Agtron coffee roast analyzer (Agtron Inc., Reno, NV, USA). Samples were analyzed in triplicates. The Agtron disk numbers were correlated with the roasting degree as follows: nos. 75−95 (light), nos. 55−65 (medium), and nos. 25−45 (dark). For the *C. arabica* species, two light, four medium, and four dark roasted samples (n = 10) were obtained, whereas for the *C. canephora* species, four light, two medium, and four dark roasted samples (n = 10) were obtained.

Roasted beans were stored in aluminized valve bags at −18 °C and ground immediately before the analysis and preparation of the beverages. Beans were prepared in a fine grind employing a La Cimbali Special grinder (Gruppo Cimbali, Milan, Italy) using ring nut number 4.

Preparation of Coffee Brews. The samples obtained in the roasting experiments were manually brewed using two different procedures. *Filtered nonboiled coffee* was prepared by letting 500 mL of water (92−96 °C) drip onto 50 g of roasted ground coffee held in a paper filter. *Filtered boiled coffee* was prepared by mixing 500 mL of water (25 °C) with a portion of 50 g of roasted ground coffee, heating the mixture until boiling, and filtering it in a paper filter.

Determination of Sugars. Sugars (glucose, fructose, and sucrose) were determined by liquid chromatography with refractive index detection (HPLC-RI) according to Burgner and Feinberg.[16] The sugars were extracted from ground green coffee (5 g) with 50 mL of water during 2 h. Potassium hexacyanoferrate (II) 0.25 M and zinc acetate 1 M were added for extract clarification. Following filtration, the extract was injected into a Varian Pro Star 350 HPLC-RI system (Varian Inc., Palo Alto, CA, USA) equipped with a Rheodyne 7725i sample injector (Rheodyne, Cotati, CA, USA) with a 10 μL sample loop. The separation was performed on a Luna NH_2 250 mm × 4.6 mm, d_f 5 μm analytical column (Phenomenex Inc., Torrance, CA, USA) using a mixture of acetonitrile−water (80:20, v/v) as mobile phase at a flow rate of 1 mL/min at 40 °C. The detector temperature was 40 °C. Glucose, fructose, and sucrose were determined in green coffee, in duplicate.

Determination of Ascorbic Acid. Ascorbic acid was determined by liquid chromatography with diode array detector (HPLC-DAD) according to Maeda et al.[17] Ascorbic acid was extracted from ground green coffee (5 g) with 50 mL of acidic water (pH 3) during 15 min under agitation. Following filtration, the extract was injected into a Shimadzu SPD-M6A HPLC-DAD system (Shimadzu Corp., Tokyo, Japan) equipped with a Rheodyne 7725i sample injector (Rheodyne) with a 200 μL sample loop. The separation was performed on a Microsorb-MV 100−5 Amino 150 mm × 4.6 mm, d_f 5 μm analytical column (Varian Inc.) using a mixture of KH_2PO_4 50 mM−acetonitrile (25:75, v/v) as mobile phase at a flow rate of 1 mL/min. The detection of ascorbic acid was carried out at the wavelength of 260 nm. Ascorbic acid was determined in green coffee, in duplicate.

Composition of Fatty Acids. The composition of fatty acids was determined by gas chromatography with flame ionization detection (GC-FID) according to Horwitz[18] and Hartman and Lago.[19] The lipid fraction was extracted from ground green coffee (5 g) with 80 mL of petroleum ether, saponified with 6 mL of NaOH 2% in methanol, and esterified with 10 mL of a solution of NH_4Cl and H_2SO_4 in methanol in order to obtain the fatty acid methyl esters. After a partition in 10 mL of hexane, the extract was injected into a Varian 3900 GC-FID system (Varian Inc.). Hydrogen was used as the carrier gas at a flow rate of 30 mL/min in a constant pressure of 13.7 psi. The injector was operated at 270 °C in the split mode with split ratio of 1:75. The separation was performed on a 100 m × 0.25 mm, d_f 0.2 μm Chrompack CP-Sil 88 capillary column (Varian Inc.) and the oven temperature program was: 120 °C (held for 5 min), 3 °C/min to 220 °C, 1 °C/min to 235 °C (held for 17 min). The detector temperature was 310 °C. The composition of fatty acids was determined in green coffee, in duplicate.

Determination of Furan. Furan content was determined by using a gas chromatography mass spectrometry method preceded by headspace solid-phase microextraction (HS-SPME-GC/MS). For roasted ground coffee, a portion of 0.25 g of homogeneous sample was weighed in a chilled 40 mL screw-cap glass vial fitted with a silicone−PTFE septum containing a 15 mm × 5 mm PTFE-coated stir bar. A volume of 150 μL of furan-d_4 working standard solution 2 μg/mL and 1 mL of water were added and the vial immediately closed. For green coffee and coffee brew, a portion of 1 g of homogeneous sample was weighed in the vial and 125 μL of furan-d_4 working standard solution 0.2 μg/mL was added. The SPME was carried out in a 75 μm carboxen-polydimethylsiloxane (CAR-PDMS) fiber (Supelco, Bellefonte, PA, USA) at 35 °C for roasted ground coffee and 25 °C for green coffee and coffee brew, during 30 min, under a constant magnetic agitation rate of 1200 rpm, approximately.

Thermal desorption was carried out into a HP 6890 gas chromatography equipped with a MSD 5973 mass spectrometer (Agilent Technologies, Palo Alto, CA, USA). Helium was used as the carrier gas at a flow rate of 0.7 mL/min. The programmable temperature vaporizing (PTV) injector was operated in the splitless mode under the following temperature program: 40 °C (held for 0.1 min), 700 °C/min to 230 °C (held until the end of the run). The separation was performed on a 60 m × 0.25 mm, d_f 0.25 μm HP-INNOWAX capillary column (Agilent Technologies) and the oven temperature program was: 30 °C (held for 0.1 min), 2 °C/min to 40 °C (held for 3 min), 12 °C/min to 200 °C (held for 2 min). The mass spectrometer was operated in positive electron impact ionization mode (+EI) with 70 eV of electron energy. Selected ion monitoring (SIM) was used for the detection of furan and furan-d_4, using m/z 68/39/69 for furan and m/z 72/42 for furan-d_4. Furan was determined in green coffee, roasted ground coffee, and coffee brew samples in duplicate.

Statistical Analysis. Data were processed by analysis of variance one-way ANOVA and Tukey test for comparisons of means (Statistica 5.5, Stat Soft Inc., Tulsa, OK, USA). The chosen level of significance was 0.05. The term significant is used to indicate differences for which $p \leq 0.05$.

RESULTS AND DISCUSSION

Analytical Method for Furan Determination in Coffee Samples. The samples of green coffee and coffee brew were

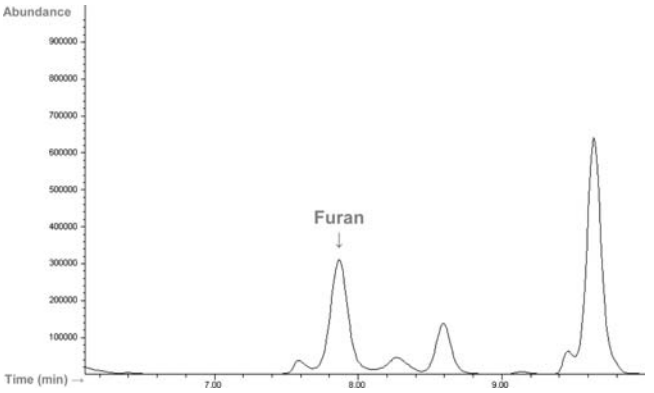

Figure 1. Chromatogram of a roasted ground coffee sample. Carrier gas: helium. Flow rate: 0.7 mL/min. Programmable temperature vaporizing (PTV) injector: 40 °C (held for 0.1 min), 700 °C/min to 230 °C (held until the end of the run). Mode: splitless. Column: 60 m × 0.25 mm, d_f 0.25 μm HP-INNOWAX. Oven: 30 °C (held for 0.1 min), 2 °C/min to 40 °C (held for 3 min), 12 °C/min to 200 °C (held for 2 min). Mass spectrometer: positive electron impact ionization (70 eV).

analyzed by applying our previously optimized HS-SPME-GC/MS method for baby-foods,[20] validated according to the guidelines laid down by the Brazilian Institute of Metrology, Standardization, and Industrial Quality.[21] This method showed satisfactory results within the linear range 0−100 μg/kg. Limits of detection (LOD) and quantitation (LOQ) were determined for green coffee and coffee brew by analyzing seven replicates of the matrix and calculated as 3- and 10-fold standard deviation, respectively. For green coffee, these limits were 0.2 and 0.8 μg/kg, and for coffee brew, these limits were 3 and 10 μg/kg, respectively.

As roasted ground coffee contains much higher furan levels (up to 6000 μg/kg), it was noted that a reduction of at least 60-fold in the amount of the sample (from 1 to 0.02 g) would be necessary in order to obtain results within the linear range 0−100 μg/kg. However, this reduction could increase the method uncertainty by taking into account the heterogeneity of the samples. Therefore, it was chosen to decrease the amount of the sample from 1 to 0.25 g, adjust the concentration of internal standard to 1200 μg/kg, and increase the range of the calibration curve to 0−9600 μg/kg. For that, the conditions of SPME were optimized in order to avoid the saturation of the fiber and loss of linearity.

This method was then validated by using a sample of roasted coffee containing 1501 μg/kg, as no blank sample is available for this matrix. Good linearity over the range 0−9600 μg/kg was obtained (r^2 = 0.992). A comparison between curves set on standard solutions and on matrix by applying the *F*-test and *t*-test revealed a nonsignificant matrix effect. Recovery, repeatability, and within-laboratory reproducibility were evaluated by spiking the matrix with furan at 480, 1200, and 3600 μg/kg (seven replicates for each concentration level). Mean recoveries ranged from 76% to 101%, and coefficients of variation ranged from 1.7% to 7.1% for repeatability and from 6.2% to 13.8% for within-laboratory reproducibility. A typical chromatogram of a sample of roasted ground coffee is illustrated in Figure 1, showing that a good separation of furan from coextractives was achieved under the chromatographic conditions used.

Chemical Composition and Furan Levels in Green Coffee. As the composition of green coffees depends on several factors, particularly species and cultivars, some of the chemical constituents that may act as potential precursors for furan formation, i.e. sugars, ascorbic acid, and polyunsaturated fatty acids, were determined in the present paper in order to establish possible correlations with furan formed during roasting. The results are shown in Table 1.

Table 1. Concentration of Sugars, Ascorbic Acid, and Fatty Acids in Arabica and Robusta Green Coffees (Wet Base)

component	Arabica	Robusta
	Sugars (g/100 g)	
fructose[a]	nd	nd
glucose	1.8	1.1
sucrose	7.4	5.7
	Ascorbic Acid (mg/100 g)[b]	
	nd	nd
	Fatty Acid Composition (area %)	
C 16:0 (palmitic acid)	31.9	35.5
C 18:0 (stearic acid)	7.6	7.0
C 18:1 (oleic acid)	8.7	11.1
C 18:2 (linoleic acid)	45.0	40.9
C 18:3 (linolenic acid)	3.2	2.9
C 20:0 (arachidic acid)	1.6	0.9
C 22:0 (behenic acid)	0.9	0.5

[a] nd = not detected; LOD = 0.2 g/100 g. [b] nd = not detected; LOD = 0.5 mg/100 g.

In relation to the investigated sugars, only sucrose and glucose were found in quantifiable amounts in green coffee. The concentrations of both sugars were higher in Arabica than in Robusta species. Sucrose was the main carbohydrate in green coffee, with levels approximately 4- and 5-fold higher than glucose levels for Arabica and Robusta, respectively. These results are consistent with data reported in the literature by other authors.[22,23]

Although ascorbic acid was not detected in the green coffee samples of the present study, levels between 3.08 and 3.37 mg/g have been reported in the literature for Arabica and Robusta species.[24]

The lipid content of green coffee samples was 11.4 and 10.8 g/100 g for Arabica and Robusta species, respectively, which is in the range of 7−17 g/100 g reported by Speer and Kölling-Speer.[25] It has been shown that palmitic and linoleic acids are the main fatty acids present in the coffee oil, whereas stearic, oleic, linolenic, and arachidic acids occur in lower proportions.[25] In the analyzed samples, palmitic and linoleic acids ranged from 31.9 to 35.5% and from 40.9 to 45.5% in relative composition, respectively, which is in accordance with the literature. Stearic, oleic, linolenic, arachidic, and behenic acids were also found in lower levels. Arabica contains the highest amounts for most of fatty acids, with the exception of palmitic and oleic acids, for which higher concentrations were observed in Robusta species. Martin et al.[26] have also verified higher levels of oleic acid in Robusta samples.

Furan was not detected in the analyzed green coffee samples. Zoller et al.[8] have also not detected furan in green coffee, while Kuballa et al.[6] reported only trace levels of the contaminant.

Formation of Furan during Roasting. The results of furan levels in roasted coffee are shown in Table 2. While furan was not detected in green coffee, levels between 911 and 5852 μg/kg

Table 2. Furan Levels in Roasted Ground Coffee

species	Agtron disk number	roast degree	furan ± SD (μg/kg)[a]
Arabica	95	light	1373 ± 101
Arabica	95	light	985 ± 105
Arabica	65	medium	3316 ± 29
Arabica	65	medium	3226 ± 355
Arabica	55	medium	3410 ± 230
Arabica	55	medium	3631 ± 68
Arabica	45	dark	3748 ± 84
Arabica	45	dark	4345 ± 297
Arabica	45	dark	3809 ± 42
Arabica	35	dark	3262 ± 256
Robusta	95	light	2332 ± 71
Robusta	95	light	1722 ± 16
Robusta	85	light	2573 ± 100
Robusta	85	light	2315 ± 429
Robusta	65	medium	3505 ± 383
Robusta	55	medium	5468 ± 173
Robusta	45	dark	5169 ± 119
Robusta	45	dark	4859 ± 82
Robusta	45	dark	5697 ± 218
Robusta	45	dark	5580 ± 288

[a] Average of two replicates; SD = standard deviation.

were found in roasted samples. This range is in accordance to data reported in the literature.[6,8,10,14]

Some of the potential precursors of furan were found in significant amounts in green coffee, specially sucrose and linoleic acid, which could lead to the formation of the contaminant during the roasting process. In simple model systems, the relative efficiency of furan formation from degradation of sugars under pyrolytic conditions was D-erythrose > D-ribose > D-sucrose > D-glucose > D-fructose.[11] In relation to fatty acids, it has been observed that only polyunsaturated fatty acids such as linoleic and linolenic acids can generate furan upon heating, and lipids containing three double bonds such as linolenic acid formed more furan than lipids containing two double bonds such as linoleic acid.[12,13] On the other hand, although ascorbic acid and its derivatives have been shown to have the highest potential to form furan in model systems,[11,13] ascorbic acid does not seem an important contributor for furan formation in roasted coffee because it could not be detected in the green coffee samples. Similar conclusions were drawn by Senyuva and Gökmen[27] in a study on furan formation in hazelnuts. Thus, the results of the present work suggest that sucrose, glucose, linoleic, and linolenic acids could act as potential precursors for furan formation in roasted coffee.

Figure 2 shows the average furan levels for the species and roast degrees evaluated. Furan concentrations were significantly higher in Robusta within each roast degree. These results are in discordance to those reported by Guenther et al.[14] that did not observe a difference among coffee samples of Arabica and Robusta species from different origins and roasted at constant times. It should be noted that little information on the influence of species on furan formation in coffee is available in the literature and a larger number of Arabica and Robusta roasted samples should be evaluate in order to draw more reliable conclusions.

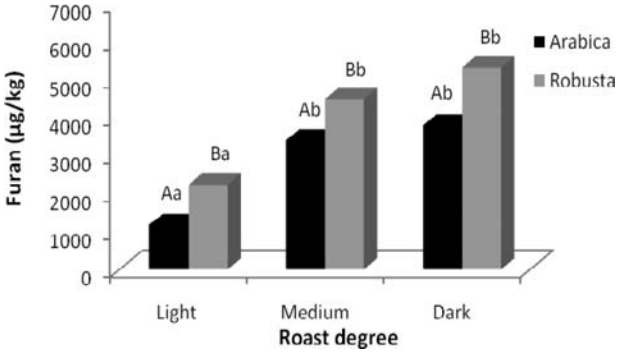

Figure 2. Mean furan levels in roasted coffee according to species and roast degree. Different capital letters indicate statistic difference between species within a same roast degree. Different small letters indicate statistic difference between roast degrees within a same species.

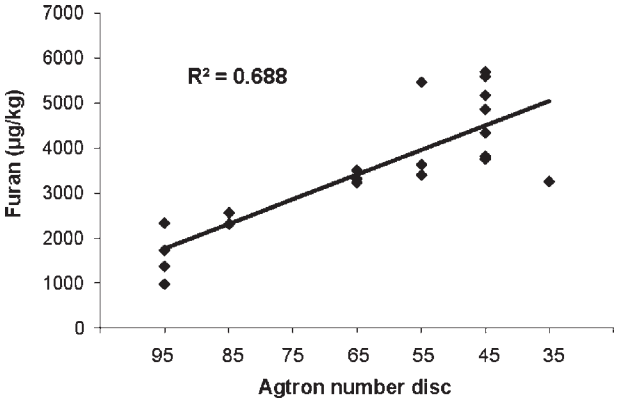

Figure 3. Correlation between furan levels and roast degree for roasted ground coffee.

The higher levels of furan in Robusta samples could not be correlated with any potential precursor measured in this work because the concentrations of glucose, sucrose, linoleic, and linolenic acids were higher in Arabica than in Robusta samples. It is still difficult to deduce which components are the key reactants that could contribute to relatively higher furan levels in some foods. Moreover, it should be noted that other factors might also be involved in the mechanism of furan formation in foods, such as pH. An increase in the levels of furan generated from ascorbic acid and sucrose solutions was observed at a lower pH, whereas from glucose solution and linoleic acid emulsion, the formation of furan was favored at neutral pH.[28,29]

Other potential precursors of furan suggested in the literature are amino acids.[11] Some amino acids such as threonine and alanine were shown to contribute to furan formation in the presence of reducing sugars, while serine and cysteine may generate furan in the absence of reducing sugars. Although these components were not investigated here, data from the literature indicate that most of the amino acids in green coffee occur at higher concentrations in Robusta beans, including threonine and alanine.[23] The possible correlation between the concentration of amino acids and levels of furan in roasted coffee should be further investigated.

In relation to roast degree, the results indicate that furan concentrations significantly increased with the intensity of roasting for both species. Guenther et al.[14] have also observed that darker roast colors had a tendency to result in higher levels of furan in coffee. Figure 3 shows that a significant linear correlation

Table 3. Furan Levels in Coffee Brews (% of Reduction Is Referred to the Ground Coffee)[a]

	filtered nonboiled coffee		filtered boiled coffee	
roasted coffee	furan ± SD (μg/kg)[b]	% reduction	furan ± SD (μg/kg)[b]	% reduction
Arabica, light	30 ± 2	78	24 ± 1	83
Arabica, light	19 ± 1	81	<10	95
Arabica, medium	67 ± 14	80	81 ± 1	76
Arabica, medium	82 ± 1	75	16 ± 1	95
Arabica, medium	129 ± 1	62	19 ± 1	94
Arabica, medium	104 ± 1	71	16 ± 1	96
Arabica, dark	94 ± 1	75	23 ± 8	94
Arabica, dark	149 ± 4	66	58 ± 2	87
Arabica, dark	170 ± 12	55		
Arabica, dark	115 ± 9	65	30 ± 5	91
Robusta, light	55 ± 4	76	48 ± 0	79
Robusta, light	39 ± 4	77	48 ± 2	72
Robusta, light	125 ± 1	51	<10	98
Robusta, light	101 ± 9	56	39 ± 1	83
Robusta, medium	61 ± 2	83	49 ± 1	86
Robusta, medium	171 ± 7	69	12 ± 1	98
Robusta, dark	82 ± 3	84	42 ± 1	92
Robusta, dark	62 ± 9	87	28 ± 2	94
Robusta, dark	112 ± 6	80		
Robusta, dark	279 ± 13	50	21 ± 1	96

[a] LOQ = 10 μg/kg (values below LOQ were considered as $^1/_2$ LOQ). [b] Average of two replicates; SD = standard deviation.

was found between furan levels and roast degree (R^2 = 0.6885, $p < 0.01$).

Furan Levels in Coffee Brew. According to the Brazilian Association of Coffee Industries (ABIC), the consumption of roasted coffee in Brazil was 4.65 kg per capita in 2009, which represents ca. of 78 L of coffee brew per inhabitant.[30] The most consumed type of beverage is the filtered coffee, representing 91% of the total coffee consumption. Other types such as instant coffee, cappuccino, espresso, and decaffeinated coffee accounts for 5.2, 1.9, 1.4, and 0.5%, respectively.[31]

Considering the significant consumption of filtered coffee in Brazil, two different procedures used to prepare this beverage were evaluated in the present work: filtered nonboiled coffee, for which hot water was left to drip onto roasted ground coffee held in a paper filter, and filtered boiled coffee, for which a mixture of water and roasted ground coffee was boiled and then filtered in a paper filter. The furan levels in coffee brews varied from <10 to 288 μg/kg (Table 3), which is in accordance to data reported in the literature.[6,8,10,32,33]

The reduction of furan levels during the preparation of the beverages ranged from 50% to 98% considering the ratio of 50 g of powder and 500 mL of water (Table 3). These results are in agreement with data reported in previous studies, which have shown reductions between 11% and 91% on furan content in filtered coffee.[6,14]

The average furan levels for brewing procedures, species, and roast degree are shown in Figure 4. The brewing process has been considered one of the most important factors for the furan levels found in coffee brew.[6,8] In the present study, with exception of Arabica/light roast degree, most of the beverages made by filtering nonboiled coffee showed significantly higher furan levels than beverages made by filtering boiled coffee. This could be due to a higher furan volatilization when the ground coffee is boiled with the water before filtration, resulting in a higher % of furan reduction in these beverages (Table 3).

The influence of coffee species was not statistically significant for most of the samples, with the exception of beverages of light roast degree/filtered nonboiled procedure, for which Robusta presented significantly higher furan levels than Arabica (Figure 4). According to Van Lancker et al.,[34] the retention of furan in coffee brew was mainly caused by the lipophilic fraction of the matrix, indicating that factors other than the brewing procedure may influence the furan content in the beverages such as the food composition. Although the lipid content of coffee brews was not investigated here, data from the literature indicate that filtered beverages made from Arabica coffee species contain more lipids than those made from Robusta.[35] Taking into account this observation, it could be suggested that the difference on furan levels between coffee species initially found in roasted ground coffee has become not significant in coffee brew due to a higher retention of furan by lipids in Arabica samples.

In relation to the roast degree, different results were observed when considering each brewing procedure. For filtered non-boiled samples, a trend of higher furan levels in beverages made from darker roasted coffee could be verified for both species, although a significant difference between light, medium, and dark degrees have been observed only for Arabica (Figure 4a). On the other hand, no significant difference between roast degree was observed for filtered boiled coffee and no trend of higher furan levels in beverages made from darker roasted coffee could be seen in these samples (Figure 4b). The presented results suggested that a linear positive correlation between furan content in roasted ground coffee and in coffee brew is dependent on the brewing procedure.

In conclusion, the present paper describes the influence of some factors on the formation of furan during roasting of coffee

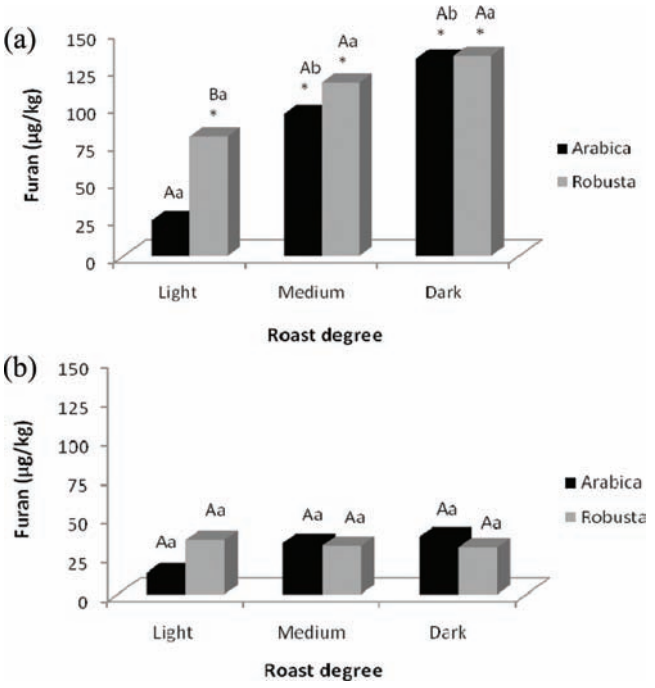

Figure 4. Mean furan levels in coffee brew according to species and roast degree: (a) filtered nonboiled coffee and (b) filtered boiled coffee. Different capital letters indicate statistic difference between species within a same roast degree. Different small letters indicate statistic difference between roast degrees within a same species. * Statistic difference between brewing procedures within a same species and roast degree.

and on its transfer to beverages. In roasted ground coffee, furan levels were affected by species and roast degree, with higher concentrations in Robusta and darker samples. Although some potential precursors of furan were found in significant amounts in green coffee, no correlation could be established considering the differences between species. In coffee brew, the factor that most influenced the furan content was the brewing procedure. Lower levels of furan can be obtained during the preparation of beverages when the ground coffee is boiled with water before filtration.

As coffee brew has been considered the most important contributor to furan exposure in the diet,[32,36] it is very important to know the levels of furan in the final ready-to-drink beverage, the type of preparation, and the brew recipe in order to reliably estimate the daily exposure to furan from coffee and define potential strategies to reduce its intake. Although reductions of up to 98% could be achieved during the brewing process, the remaining levels of furan in the beverages may be still relevant to furan exposure due to the high consumption of coffee.

There is currently no means to reduce furan levels in roasted coffee by changing the heating conditions of roasting without significantly impacting on the organoleptic properties of the product. Moreover, as the exact mechanism of furan formation and the key reactants are not completely understood, no measures can be taken in relation to the reduction of furan precursors as mitigation strategy. Finally, it should be noted that the management of agronomic and industrial parameters, whether it is possible, could not be applied for all types of beverages because it was verified that the correlation between furan levels found in roasted ground coffee and in coffee brew is dependent on the brewing procedure.

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