

## Roasting and Aroma Formation: Effect of Initial Moisture Content and Steam Treatment

JUERG BAGGENSTOSS,<sup>†</sup> LUIGI POISSON,<sup>‡</sup> RUTH KAEGI,<sup>†</sup> RAINER PERREN,<sup>†</sup> AND FELIX ESCHER<sup>\*,†</sup>

Institute of Food Science and Nutrition, Swiss Federal Institute of Technology (ETH) Zurich, and Nestlé Product Technology Centre, Orbe, Switzerland

Initial moisture of green coffee may vary as a function of green coffee processing and storage conditions. The impact of initial moisture and steam treatment on roasting behavior and aroma formation was investigated. Steam treated coffees as well as coffees with initial moisture content of 5.10, 10.04, and 14.70 g water per 100 g wb were roasted. Light and dark roasting trials were carried out using a fluidizing-bed roaster with a batch size of 100 g of green beans. Differences in roast coffee attributes, that is, color, density, and organic roast loss, and odorant concentrations were more marked in light roasted than in dark roasted coffees. The results of roasting steam treated coffee suggest that this step affects roasting behavior primarily by extracting some aroma precursor compounds.

**KEYWORDS:** Coffee; roasting; steam treatment; solid phase microextraction; aroma

### INTRODUCTION

For the development of the characteristic flavor of coffee, roasting is the key step that converts the nearly odorless, slightly pea smelling green coffee beans into roasted coffee. The water content of green coffee is usually around 10 g/100 g wb, but varies depending on the processing and drying methods as well as on storage conditions. Clarke and Macrae (1) state that moisture content in excess of 13 g/100 g wb should be avoided in order to prevent mold growth.

It is known that roasting behavior of green coffee beans depends on water content. Schenker (2) showed that high initial water content leads to higher dehydration rate and faster increase of roast loss. Organic roast loss, however, remained practically unaffected by initial water content. Increase in bean temperature was delayed in coffee beans with high initial water content. Because of these differences in roasting behavior, predrying of green coffee to a moisture content of 5 g/100 g wb was proposed in order to obtain more uniform roast color and reduced density of fast roasted coffee (3).

Roasting of a series of Robusta coffees with moisture contents of 6, 11, and 14 g/100 g wb, respectively, resulted in higher end water content, higher percentage of soluble solids, and less titratable acidity at the highest initial moisture content compared to the lowest one (4). Little et al. (5) roasted unwashed Arabica (Santos) and Robusta coffees with different initial moisture content and found that for partially dehydrated beans and beans stored at normal atmosphere, roast loss was a linear function

of initial water content. The authors stated that the increase of roast loss is not only due to a higher loss of water but also to a higher loss of organic matter. Weight loss in hydrated beans (18 g/100 g wb) was proportionally less severe, and the authors drew the conclusion that conditions for roasting beans with high initial water content would be different from those with low water content.

Steam treating coffee is claimed to diminish undesired substances (e.g., catechol, pyrogallol, and hydroquinone) and to improve flavor quality (6, 7). Contrary to steam roasting, green coffee steam treatment involves pressures of a few bars at most. The effects of steam treatment on green coffee was investigated by several authors. Maier (8, 9) showed that steam treated coffee exhibited lower amounts of volatile saturated acids and mentioned that during steaming of green beans, contents of chlorogenic acids changed: 3-caffeoylquinic acid (3-CQA) and 3,4-dicaffeoylquinic acid (3,4-DCQA) increased, while others decreased. Milo et al. (10) extracted green coffee with hot water and found decreasing concentrations of caffeine (10% of the initial value) and chlorogenic acids (40% of the initial value). Luger and Steinhart (11) analyzed the carbohydrate fraction in steam treated coffee. They found increased amounts of monosaccharides, especially fructose and glucose, and notably decreased amounts of saccharose, while the content of polysaccharides remained unchanged. Similar experiments were carried out in order to determine the impact of steam treatment on the amino acid pattern (12). Free amino acids were reduced to around 50% of the initial value, whereas protein bound amino acids only decreased slightly to about 90% of the initial amount. Theurillat et al. (13) found that upon roasting, steam treated coffee reached target color faster, and hence, the roasting time for the same degree of roast was shorter. The resulting coffee

\* Corresponding author. Fax: +41 44 632 11 23. E-mail: felix.escher@ilw.agrl.ethz.ch.

<sup>†</sup> Swiss Federal Institute of Technology (ETH).

<sup>‡</sup> Nestlé Product Technology Centre.

was sweeter, more acidic, less bitter, and exhibited higher acrylamide content than untreated coffee because of the shorter roasting time.

The present investigation aimed at studying the impact of green coffee moisture content on roasting behavior and aroma development. For this purpose, light and dark roasting was carried out. In addition, the effect of steam treatment on roasting was investigated.

## MATERIALS AND METHODS

**Roasting Process and Process Characterization.** *Raw Material.* Green *Coffea arabica* Tip. variety from Sumatra (Mandheling, S-795, Kartika 1) was supplied by Rast Ltd. (Ebikon, Switzerland).

*Green Coffee Treatment.* Water content of raw coffee was 10.05 g/100 g wb. To obtain a moisture content of 5.10 g/100 g wb, raw coffee was dried at 50 °C for 24 h and at 40 °C for another 26 h. Moistening of coffee was carried out by storing raw coffee over pure water for 20 days, which resulted in a water content of 14.70 g/100 g wb. A 5 L steel pressure chamber (maximum pressure 50 bar) was used for steam treatment of raw coffee beans. Batches of 400 g of green coffee beans were treated with steam for 6 min using a steam pressure of 2 bars. After steam treatment, green coffee was cooled passively for 4 min, and green coffee was dried at 50 °C to 9.32 g/100 g wb moisture content.

*Roasting Trials.* Coffee was roasted in batches of 100 g of green beans using a fluidizing-bed hot-air laboratory roaster (G. W. Barth AG, Freiberg/Neckar, Germany), which was described in detail by Schenker (2) and Geiger et al. (14). An isothermal low-temperature process was applied, with hot air temperature of 227 °C. Roasting time was 210 s for light and 660 s for dark roasts. All roasting trials were carried out in triplicate. Color was measured and moisture content determined using the methods described in Baggenstoss et al. (15). Bean core temperature was recorded during roasting by placing thermocouples (Type K, 0.5 mm, Thermocoax Ltd., Surèsnes, France) into drilled holes in the green coffee beans.

*Density.* For determination of coffee bean density, a displacement method was used as described by Schenker (16). A stainless steel wire basket with and without 30 g coffee beans was immersed into peanut oil, and the weight difference corresponded to the weight of oil displaced by coffee beans. Using a density of 910 kg m<sup>-3</sup> for peanut oil at 25 °C, coffee bean density could be determined. Air bubbles between coffee beans had to be removed by gently moving the basket up and down. Care had to be taken not to overextend weight measuring time, in order to prevent oil from penetrating into pores of coffee beans.

**Aroma Analysis.** *Chemicals.* Stable isotope labeled standards were obtained from Dr. Ehrenstorfer GmbH, Augsburg, Germany ([<sup>2</sup>H<sub>6</sub>]-dimethyl sulfide, [<sup>2</sup>H<sub>5</sub>]-pyridine, and [<sup>2</sup>H<sub>2</sub>]-3-methylbutanal), Witega Laboratorien, Berlin, Germany ([<sup>2</sup>H<sub>3</sub>]-4-vinylguaiacol), AromaLAB, Munich, Germany ([<sup>2</sup>H<sub>2</sub>]-methylpropanal and [<sup>2</sup>H<sub>6</sub>]-3-mercapto-3-methylbutyl formate, [<sup>13</sup>C<sub>4</sub>]-2,3-butanedione, and [<sup>13</sup>C<sub>2</sub>]-2,3-pentanedione), Cambridge Isotope Laboratories Inc., Andover MA, USA ([<sup>2</sup>H<sub>3</sub>]-*N*-methylpyrrole and [<sup>2</sup>H<sub>6</sub>]-dimethyl disulfide), and Toronto Research Chemicals, North York, Canada ([<sup>2</sup>H<sub>2</sub>]-2-furfurylthiol and [<sup>2</sup>H<sub>9-10</sub>]-2,3,5-trimethylpyrazine), [<sup>2</sup>H<sub>2</sub>]-hexanal (17), and [<sup>2</sup>H<sub>6</sub>]-dimethyl trisulfide (18) were synthesized at Nestlé Research Center (Lausanne, Switzerland).

*SPME-GC-MS Analysis and Quantification of Coffee Aroma Compounds.* Quantitative analysis of aroma compounds was carried out using an adapted method as described in ref 15. Freshly roasted coffee was ground using a grain mill (Buehler-Miag 4000, Milano, Italy) at level 3. Then ground coffee was weighed in a 100 mL flask, suspended in boiling water (5% total solids for compounds 1, 4, 5, 9, 15, and 16; 1% total solids for compounds 2, 3, 6–8, and 10–14; see Table 1), and the suspension was stirred for 10 min, while the flask was kept closed. The flask was then cooled under cold water, and the coffee solution was spiked with definite amounts of isotopically labeled standards (Table 1). The coffee solution was subsequently stirred for another 10 min, and 7 mL were transferred to 20 mL headspace vials. The complete sample preparation was carried out in triplicate.

**Table 1.** Analytes and Standards used for the Quantitative Analysis of Aroma Compounds by GC-MS.

analyte (A)	selected ion (m/z) of A	internal standard (IS)	selected ion (m/z) of IS
dimethyl sulfide (1)	47	[ <sup>2</sup> H <sub>6</sub> ]-1	50
dimethyl disulfide (2)	94	[ <sup>2</sup> H <sub>6</sub> ]-2	100
dimethyl trisulfide (3)	126	[ <sup>2</sup> H <sub>6</sub> ]-3	132
3-mercapto-3-methylbutyl formate (4)	102	[ <sup>2</sup> H <sub>6</sub> ]-4	108
2-furfurylthiol (5)	114	[ <sup>2</sup> H <sub>2</sub> ]-5	116
methylpropanal (6)	72	[ <sup>2</sup> H <sub>7</sub> ]-6	79
2-methylbutanal (7)	86	[ <sup>2</sup> H <sub>2</sub> ]-8	88
3-methylbutanal (8)	71	[ <sup>2</sup> H <sub>2</sub> ]-8	73
hexanal (9)	56	[ <sup>2</sup> H <sub>2</sub> ]-9	58
2,3-butanedione (10)	43	[ <sup>13</sup> C <sub>4</sub> ]-10	45
2,3-pentanedione (11)	100	[ <sup>13</sup> C <sub>2</sub> ]-11	102
<i>N</i> -methylpyrrole (12)	81	[ <sup>2</sup> H <sub>3</sub> ]-12	84
pyridine (13)	79	[ <sup>2</sup> H <sub>5</sub> ]-13	84
4-vinylguaiacol (14)	150	[ <sup>2</sup> H <sub>3</sub> ]-14	153
2,3,5-trimethylpyrazine (15)	122	[ <sup>2</sup> H <sub>9/10</sub> ]-15	131 + 132
2-ethyl-3,5-dimethylpyrazine (16)	135	[ <sup>2</sup> H <sub>9/10</sub> ]-15	131 + 132

Coffee aroma compounds were sampled with solid phase microextraction at 40 °C for 10 min using a Supelco 50/30 μm StableFlex DVB/CAR/PDMS fiber (Supelco, Buchs, Switzerland). Injection was done at 240 °C in the splitless mode with a splitless time of 240 s. Compounds 2, 3, 6–8, and 10–14 were separated on a 60 m × 0.25 mm × 0.25 μm ZB-Wax column (Phenomenex, Aschaffenburg, Germany) using a Fisons 8000 Series gas chromatograph (Thermo Electron, Allschwil, Switzerland) with the following temperature program: 40 °C (6 min), 4 °C/min, 120 °C (0 min), 40 °C/min, and 240 °C (5 min). The gas chromatograph was coupled to a quadrupole mass spectrometer SSQ710 (Finnigan MAT, San Jose, California), where mass spectra were recorded in the single ion monitoring (SIM) mode using electron ionization and an ionization potential of 70 eV. Compounds 1, 4, 5, 9, 15, 16 were separated on a 60 m × 0.25 mm × 0.25 μm ZB-1701 column (Phenomenex, Aschaffenburg, Germany) in a 2000 series TRACE GC gas chromatograph (Thermo Quest CE Instruments, Milano, Italy) using the same temperature program as that for the other compounds. The GC was coupled to a TSQ triple quadrupole mass spectrometer (Finnigan MAT, San Jose, California) with Q1 operating in the RF-only mode. Spectra were recorded in single ion monitoring mode. Electron ionization with an ionization potential of 70 eV was applied. All SPME-GC-MS measurements were run in triplicate.

**Statistical Analysis.** Student's *t*-test was applied to the results with a level of significance of 95%.

## RESULTS AND DISCUSSION

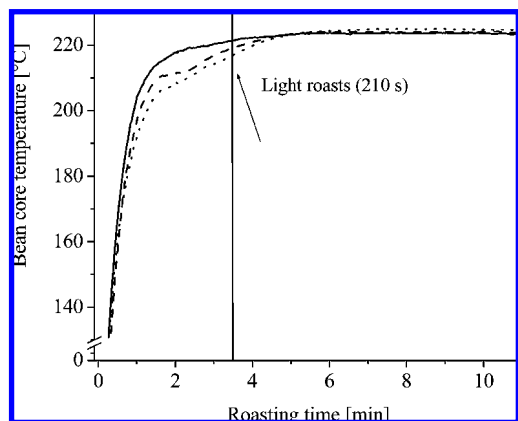
**Influence of Initial Water Content on the Basic Properties of Roasted Coffee.** Table 2 shows water content, roast loss, organic roast loss, color, and density of the roasted coffees. The results are in agreement with those obtained by Schenker (2). In general terms, differences were more marked in light roasts than in dark roasted coffees. Water content, lightness *L*\*, and density were higher in light roasted coffees with higher initial water content. It is obvious that high initial moisture content implied the need for more energy for water evaporation and therefore retarded the temperature increase and hence development of a degree of roast during the first stage of roasting (Figure 1). Organic roast loss was correspondingly smaller in moist coffees. Roast loss, however, was higher in coffees with high initial water content due to higher quantity of evaporated water. However, with the exception of roast loss, these differences disappeared in dark roasted coffees.

**Aroma Development in Coffees with Different Initial Water Contents.** Concentrations of aroma compounds after light and dark roasting are displayed in Tables 3 and 4. As seen in the

**Table 2.** Basic Properties of Light and Dark Roasted Coffees

	green coffee water content [g/100 g wb]	roasted coffee water content [g/100 g wb]	roast loss [g/100 g wb]	organic roast loss [g/100 g wb]	color [ $L^*$ ] <sup>a</sup>	bean density [g/cm <sup>-3</sup> ]
light roasts						
dried	5.10 ± 0.01	2.65 ± 0.10	8.14 ± 0.03	5.76 ± 0.10	27.52 ± 0.11	0.671 ± 0.002
untreated	10.04 ± 0.02	2.82 ± 0.04	12.38 ± 0.03	5.34 ± 0.05	28.62 ± 0.16	0.707 ± 0.002
moistened	14.70 ± 0.03	3.19 ± 0.06	16.04 ± 0.10	4.70 ± 0.12	29.60 ± 0.12	0.751 ± 0.005
steam treated	9.32 ± 0.08	2.67 ± 0.03	12.00 ± 0.02	5.54 ± 0.09	27.64 ± 0.13	0.716 ± 0.004
dark roasts						
dried	5.10 ± 0.01	1.70 ± 0.02	12.37 ± 0.01	9.23 ± 0.02	21.35 ± 0.06	0.608 ± 0.003
untreated	10.04 ± 0.02	1.71 ± 0.01	17.08 ± 0.02	9.39 ± 0.03	21.13 ± 0.16	0.606 ± 0.004
moistened	14.70 ± 0.03	1.70 ± 0.05	21.15 ± 0.10	9.14 ± 0.12	21.29 ± 0.07	0.608 ± 0.001
steam treated	9.32 ± 0.08	1.65 ± 0.02	16.84 ± 0.01	9.80 ± 0.08	20.74 ± 0.15	0.616 ± 0.003

<sup>a</sup> Color is expressed as lightness  $L^*$  in the  $L^*a^*b^*$  color space, where  $L^* = 100$  means white, and  $L^* = 0$  means black.



**Figure 1.** Bean core temperature during roasting of coffee beans with different initial water contents: (—) dried [5.10 g H<sub>2</sub>O/100 g wb], (---) untreated [10.04 g H<sub>2</sub>O/100 g wb], and (···) moistened [14.70 g H<sub>2</sub>O/100 g wb].

preceding section, the desired degrees of roast were faster attained in coffees with low water content. This fact helps to explain most of the concentration differences of the individual aroma components. *N*-methylpyrrole, pyridine, 3-mercapto-3-methylbutyl formate, 2,3,5-trimethylpyrazine and 2-ethyl-3,5-dimethylpyrazine are typical roast products with increasing concentration during the roasting process (19). After light roasting, their concentrations were significantly higher with decreasing initial moisture content. In dark roasts, significant differences were still observable for 2-ethyl-3,5-dimethylpyrazine and 2,3,5-trimethylpyrazine, while for the other compounds, concentration differences leveled off. Similar observations were made in the case of 2-furfurylthiol, but the differences were not significant, due to the relatively high standard deviations caused by the analysis method that was not perfectly suited for compounds exhibiting a strong matrix effect, such as 2-furfurylthiol.

Strecker aldehydes and  $\alpha$ -diketones generally exhibit maximum concentration at medium degree of roast, but at higher temperature formation is counterbalanced by degradation reactions (19–22). Therefore, depending on the onset temperature where degradation of the compounds starts, a coffee with low initial moisture content may exhibit higher (before degradation) or lower (during degradation) concentration than a coffee with high initial water content at same roasting time. After light roasting, the dried coffee exhibited lowest amount of methylpropanal and 3-methylbutanal, and highest amount of 2,3-butanedione and 2,3-pentanedione. There was no significant difference in 2-methylbutanal concentration. In dark roasts, differences in Strecker aldehydes or  $\alpha$ -diketones concentration were small and, in most cases, not significant. Formation of

4-vinylguaiacol did not seem to be much affected by initial water content neither.

A particular behavior was observed in the case of the three investigated sulfides. Dimethyl sulfide and dimethyl disulfide both were at maximum concentration in the coffee with original moisture (10 g/100 g wb) at both roast degrees. In the case of dimethyl disulfide, all moisture contents had a significant influence on concentration, and in the case of dimethyl sulfide, the amount in the moistened coffee was significantly lower than in the others at both roast degrees. A similar, but less pronounced behavior was observed with dimethyl trisulfide. During roasting, dimethyl trisulfide exhibits biphasic behavior: after a sharp increase during the first stage of roasting, degradation takes place, followed by further concentration increase at the end of the roasting process (19). This specific conduct may be the reason for the fact, that medium initial moisture content results in highest concentration.

In conclusion, it may be stated that initial moisture content had an influence particularly on light roasted coffee, while in dark roasted coffees, most differences in odorants concentration leveled off.

#### Impact of Steam Treatment on Coffee Roasting Behavior.

Steam treated raw coffee was dried to a moisture content of 9.32 g water per 100 g wb. Its behavior upon roasting was similar compared to the untreated coffee. Color development was faster, and dark roasting of steam treated coffee resulted in the lowest  $L^*$ -value of all roasting trials (Table 2). However, evolution of several aroma compounds during the roasting of steam treated coffee was different compared to that in untreated coffee (Tables 3 and 4). After light roasting of untreated and steam treated coffees, significant differences in concentration were found for dimethyl sulfide, dimethyl disulfide, 2-furfurylthiol, 2-methylbutanal, *N*-methylpyrrole, pyridine, and 4-vinylguaiacol. Dark roasting led to significant concentration differences in dimethyl sulfide, dimethyl disulfide, dimethyl trisulfide, 2-methylbutanal, *N*-methylpyrrole, pyridine, 4-vinylguaiacol, 2,3,5-trimethylpyrazine, and 2-ethyl-3,5-dimethylpyrazine. Concentration of 2-furfurylthiol also was considerably lower in dark roasted steam treated coffee, but because of high standard deviation during analysis, the difference was not significant. Most of the concentration differences of individual aroma components may be explained by the fact that steam treatment partly extracted precursor compounds. According to Milo et al. (10), a decreased amount of feruloylquinic acid is most probably responsible for the lower amount of 4-vinylguaiacol. The same authors attributed low amounts of Strecker aldehydes in roasted coffee to strong reduction of free amino acids due to hot water extraction of green coffee. Steam treatment is not expected to result in the same degree of amino

**Table 3.** Influence of Initial Moisture Content and Steam Treatment on the Concentration of Selected Aroma Compounds after Light Roasting<sup>a</sup>

aroma compound	aroma concentration [mg/kg dm] at initial moisture content of green coffee beans [g/100 g wb] of			
	5.1	10.0	14.7	9.3 <sup>b</sup>
dimethyl sulfide	6.2a ± 0.3	7.4a ± 0.7	5.0b ± 0.3	4.9b ± 0.4
dimethyl disulfide	0.93a ± 0.04	1.04b ± 0.04	0.61c ± 0.01	1.46d ± 0.08
dimethyl trisulfide	0.034a ± 0.002	0.036a ± 0.001	0.027b ± 0.003	0.037a ± 0.001
3-mercapto-3-methylbutyl formate	0.057a ± 0.004	0.038b ± 0.004	0.023c ± 0.002	0.035b ± 0.001
2-furfurylthiol	0.46a ± 0.11	0.39a ± 0.03	0.27a ± 0.11	0.91b ± 0.15
methylpropanal	25.8a ± 1.4	30.3b ± 0.4	29.7a,b ± 2.0	25.5a,b ± 2.2
2-methylbutanal	21.6a,b ± 0.6	21.9a ± 0.5	22.2a ± 0.8	20.2b ± 0.7
3-methylbutanal	11.9a ± 0.3	13.0b ± 0.3	13.3b ± 0.5	12.7a,b ± 0.6
hexanal	3.57a ± 0.03	3.9a,b ± 0.5	3.3a,b ± 0.2	2.97b ± 0.06
2,3-butanedione	23.7a ± 0.3	22.1b ± 0.6	22.1b ± 0.6	23.2a,b ± 0.2
2,3-pentanedione	14.9a ± 0.3	13.2b ± 0.3	12.8b ± 0.2	13.3b ± 0.4
<i>N</i> -methylpyrrole	1.78a ± 0.06	1.22b ± 0.06	0.85c ± 0.01	0.88c ± 0.04
pyridine	49.0a ± 1.5	30.1b ± 1.5	19.7c ± 0.7	24.8d ± 0.3
4-vinylguaiacol	29.2a ± 1.2	27.8a ± 1.1	29.1a ± 0.8	23.7b ± 0.4
2,3,5-trimethylpyrazine	4.9a ± 0.4	4.7a ± 0.3	3.7b ± 0.1	4.4a,b ± 0.4
2-ethyl-3,5-dimethylpyrazine	1.5a ± 0.1	1.0b ± 0.1	0.69c ± 0.04	1.0b ± 0.1

<sup>a</sup> Different letters indicate statistically significant differences ( $p < 0.05$ ). <sup>b</sup> Steam treated coffee.

**Table 4.** Influence of Initial Moisture Content and Steam Treatment on the Concentration of Selected Aroma Compounds after Dark Roasting<sup>a</sup>

aroma compound	aroma concentration [mg/kg dm] at initial moisture content of green coffee beans [g/100 g wb] of			
	5.1	10.0	14.7	9.3 <sup>b</sup>
dimethyl sulfide	6.0a ± 0.4	6.3a ± 0.6	4.1b ± 0.3	4.5b ± 0.4
dimethyl disulfide	0.98a ± 0.03	1.20b ± 0.06	0.78c ± 0.05	1.86d ± 0.04
dimethyl trisulfide	0.053a,b ± 0.001	0.047c ± 0.002	0.044a,c ± 0.005	0.059b ± 0.004
3-mercapto-3-methylbutyl formate	0.104a ± 0.002	0.10a ± 0.01	0.104a ± 0.005	0.100a ± 0.003
2-furfurylthiol	4.5a ± 0.9	4.3a ± 1.1	3.6a ± 0.6	3.4a ± 0.3
methylpropanal	24.8a ± 1.0	29.6a,b ± 2.4	28.7b ± 0.4	27.1b ± 0.8
2-methylbutanal	19.5a,b ± 0.4	20.2a ± 0.2	21.3a,b ± 1.3	19.6b ± 0.3
3-methylbutanal	10.5a ± 0.1	11.1b ± 0.3	11.3a,b ± 0.4	11.6b ± 0.1
hexanal	1.2a ± 0.2	1.5a ± 0.2	1.31a ± 0.09	1.2a ± 0.1
2,3-butanedione	13.7a ± 0.8	13.2a ± 0.3	13.9a ± 0.5	13.5a ± 0.1
2,3-pentanedione	5.3a,b ± 0.2	5.0a ± 0.2	5.61b ± 0.02	5.3a,b ± 0.3
<i>N</i> -methylpyrrole	3.1a ± 0.1	3.05a ± 0.03	2.95a ± 0.09	2.2b ± 0.1
pyridine	154a ± 7	148a ± 3	144a ± 2	113b ± 2
4-vinylguaiacol	21.1a,b ± 0.1	20.8a ± 0.2	22.4b ± 0.6	18.1c ± 0.3
2,3,5-trimethylpyrazine	5.5a ± 0.3	4.8a ± 0.2	4.1b ± 0.1	4.34c ± 0.03
2-ethyl-3,5-dimethylpyrazine	1.5a ± 0.2	1.11a ± 0.03	0.93a ± 0.06	0.97a ± 0.04

<sup>a</sup> Different letters indicate statistically significant differences ( $p < 0.05$ ). <sup>b</sup> Steam treated coffee.

acid reduction, but still a significantly lower concentration of 2-methylbutanal was found in steam treated coffee compared to that in the untreated coffee.

Formation pathways of pyridine and *N*-methylpyrrole include degradation of trigonelline (23) or pyrolysis of amino acids (24, 25). It was found, however, that steaming of green coffee beans reduces trigonelline content by less than 1% (26); therefore, the lower amounts of pyridine and *N*-methylpyrrole may be explained by partial extraction of free amino acids during steam treatment. For 2,3,5-trimethylpyrazine and 2-ethyl-3,5-dimethylpyrazine, formation pathways using hexose and glycine or alanine, respectively, were proposed (27). Their significantly lower amounts in dark roasted steam treated coffee may therefore be explained by a restricted quantity of free amino acids available for the respective reaction. Considerable differences in dimethyl sulfide, dimethyl disulfide, and dimethyl trisulfide concentrations were found between untreated and steamed coffee. While the amount of dimethyl sulfide was significantly lower in steamed coffee, dimethyl disulfide and dimethyl trisulfide concentrations were significantly higher. One possible reaction pathway of sulfides during roasting is the oxidation and subsequent disproportionation of methanethiol, which is the product of Strecker degradation and  $\beta$ -elimination of methionine (28, 29); however, at high temperatures, other reaction pathways involving methionine and cysteine are also

possible. As dimethyl disulfide and dimethyl trisulfide both exhibit biphasic behavior upon roasting (19), the higher amounts in steam treated coffee may be explained by the faster development of the degree of roast.

The effect of steam treatment on 2-furfurylthiol formation seemed to be complex. Light roasted steam treated coffee exhibited more than 2-fold higher amount of 2-furfurylthiol than untreated coffee, while after dark roasting, 2-furfurylthiol concentration was higher in untreated coffee. Milo et al. (10) found that 2-furfurylthiol concentration doubled upon roasting hot water extracted beans and supposed that this is due to the absence of competing reactions. The results from our study suggest indeed that in the first stages of roasting, a rapid 2-furfurylthiol formation pathway is preferred because of the absence of competing reactions. However, at higher degrees of roast and hence higher product temperature, different formation pathways involving mostly precursors not extracted by water are favored.

Steam treatment mostly influences the roasting behavior of coffee by extracting some precursor compounds. Consequently, concentrations of several odorants were different compared to those in untreated coffee, both in light and dark roasts. The sensory impact of these concentration differences is unclear and needs to be elucidated by sensory tests.



## ACKNOWLEDGMENT

We thank Rast Ltd. (Ebikon, Switzerland) for providing green coffee.

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Received for review February 1, 2008. Revised manuscript received April 25, 2008. Accepted April 27, 2008. We thank G. W. Barth AG (Freiberg/Neckar, Germany) for financial support.

JF8003288