Changes in the Aromatic Profile of Espresso Coffee as a Function of the Grinding Grade and Extraction Time: A Study by the Electronic Nose System

C. Severini,* I. Ricci, M. Marone, A. Derossi, and T. De Pilli
Department of Science of Agricultural, Food and Environment (SAFE), University of Foggia, Via Napoli 25, 71122 Foggia, Italy

ABSTRACT: The changes in chemical attributes and aromatic profile of espresso coffee (EC) were studied taking into account the extraction time and grinding level as independent variables. Particularly, using an electronic nose system, the changes of the global aromatic profile of EC were highlighted. The results shown as the major amounts of organic acids, solids, and caffeine were extracted in the first 8 s of percolation. The grinding grade significantly affected the quality of EC probably as an effect of the particle size distribution and the percolation pathways of water through the coffee cake. The use of an electronic nose system allowed us to discriminate the fractions of the brew as a function of the percolation time and also the regular coffee obtained from different grinding grades. Particularly, the aromatic profile of a regular coffee (25 mL) was significantly affected by the grinding level of the coffee grounds and percolation time, which are two variables under the control of the bar operator.

KEYWORDS: espresso coffee, electronic nose system, aroma profile, extraction time, grinding grade

INTRODUCTION

The Italian espresso coffee (EC) is the most consumed coffee beverage in the world. Particularly because its appreciated sensorial properties, over than 50 million cups are consumed every day.1 EC may be defined as “a brew obtained by percolation of hot water under pressure through compacted cake of roasted ground coffee, where the energy of the water pressure is spent within the cake.”2

As well-known, the quality of EC is affected by several variables, some of which are managed by the industry, such as the coffee varieties, roasting conditions, roasting degree, mixture of roasted coffee varieties, and storage conditions.1,3–7 Other variables are under the control of the barista (i.e., the technician of the bar), such as the temperature and pressure of water, grinding grade, weight of coffee grounds (dose), and pressure on the upper surface of coffee cake (tamping); also, these variables significantly affect the physical, chemical, and sensorial attributes of EC.1–4

Moreover, the extraction time is of crucial importance because the overall quality of EC is the result of the equilibrium of hundreds of chemical compounds.15 In general, a regular coffee of 25 mL is obtained with an extraction rate of 1 mL/s, but several differences are commonly observed. For instance, the so-called ristretto coffee (about 15 mL) and lungo coffee (about 30 mL) are often consumed in Italy and in other countries.14 Under this point of view, for a correct management and an accurate standardization of EC quality, a precise description of the kinetic extraction of all chemical compounds is of great importance, but this aspect has not been subjected to scientific experiments in details; indeed, the majority of the papers available in the literature focused their attention on the extraction and analysis of aromatic compounds, sugars, solids, lipids, proteins, caffeine, etc.13,15,16

Also, even though the EC is considered the most aromatic coffee brew,17–19 very few papers focused their efforts on the changes of volatiles over extraction time, separating the brew in different fractions,16–20 while wide range of literature reports the qualitative and quantitative characterization of volatiles of an EC cup.21,22

For instance, using chromatography/mass spectrometry (GC/MS) and GC/olfactometry (GC/O), over 1000 volatiles and 70 odorants have been identified from EC;23,24 nevertheless, these techniques are expensive and time-consuming.25

On the other hand, sensory analysis has been extensively used to evaluate and discriminate the sensorial attributes of coffee, particularly the aroma and flavor, but some disadvantages of this technique include subjectivity and poor reproducibility.26–28

In the last few years, one of the most promising applications in routine quality control of foods and beverages is the electronic nose that is a new technology that enables the acquisition of the sensory analysis for the detection of the overall aromatic profile of samples. In particular, the electronic nose attempts to emulate the mammalian nose using an array of sensors simulating mammalian olfactory responses to the aroma.29 The sensors respond to a broad range of volatiles that have a high affinity with aldehydes, alcohols, ketones, etc. These compounds are drawn across the sensor array and induce a reversible physical and/or chemical change in the sensing material, which causes a change in electrical properties, such as conductivity. These changes are transducers into electrical signals, which are pre-processed and conditioned before identification by a pattern recognition system.30 Aishima31 and Pornpanomchai et al.,32 using the electronic nose, classified different types of instant coffee on the basis of their aromatic profiles, while other researchers used electronic nose to differentiate commercial coffee brands, different coffee varieties

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or different roasting grades, and the presence of defects on roasted coffee to estimate the shelf life of packaged coffee.\textsuperscript{33–39} Furthermore, the electronic nose system was applied on EC to determine the best time for packaging\textsuperscript{40} of coffee grounds, to discriminate the coffee from different production countries and roasting degrees,\textsuperscript{34} and to classify beans, grounds, and brew of commercial coffee blends.\textsuperscript{41} Particularly, in this work, the authors reported that a correct distinction of the brews was not statistically significant.

On the basis of the above considerations, the purpose of this paper was to study the changes of the EC during extraction to obtain useful information for the better management of the brew quality. More specifically, the main objective was to use the electronic nose system to study the changes of the overall aromatic profile of EC, taking into account the extraction time and the grinding level of coffee powder as independent variables.

\section*{MATERIALS AND METHODS}

\textbf{Raw Materials and EC Preparation.} Roasted coffee beans (medium-dark roasting: \(L^* = 21.50, a^* = 5.92\)) were supplied from ESSSE caffè S.p.A. (Anzola dell’Emilia, Bologna, Italy). The beans were ground by an automatic grinder with flat grinding blades (model Super Jolly coffee grinder for a grocery, Mazzer, Italy) having eight levels of grinding: 1 for the finest, 2 for the coarsest. Water "Leggera" (Gaudianello S.p.A., Italy) used for brew preparation was locally purchased. Table 1 reports the main physical and chemical characteristics of the water as specified on the label, except the pH value, which was experimentally measured. EC samples were prepared using an EC machine mod. V220 (Vibiemme, Italy) with filter holder monodose applied the following experimental conditions: 7.0 g of ground coffee, a 60 mm of holder filter diameter, pressure on the upper surface of ground coffee cake of 1500 g, water temperature of 92 °C, and 9 atm of relative pressure. According to scientific literature, these conditions may be considered as the most common for EC preparation.\textsuperscript{7,8,11–13,42} Instead, the value of pressure was chosen on the basis of preliminary experiments in which different weights were used to press ground coffee.

\textbf{Experimental Design.} EC samples were always prepared within 3 min from the grinding of beans, which was performed at three levels, 6, 6.5, and 7, corresponding to fine, fine–coarse, and coarse coffee grounds, respectively. The choice of these grinding levels was performed on the basis of preliminary experiments, in which the particle size distribution of the ESSSE caffè S.p.A. coffee grounds commonly used in the bars was determined. Once the variability of coffee grounds was defined, we did choose the grinding levels that enabled us to express the differences well in terms of particle size distribution commonly detectable in the bars. Then, the particle size distribution for each grinding level was described shaking 100 g of coffee grounds with four sieves (600, 400, 250, and 180 μm) until a constant weight. Table 2 shows the percentage of distribution of the particle sizes for each grinding level.

\begin{table}[h!]
\centering
\caption{Distribution (\%) of Particle Size in Each Grinding Grade of Coffee Powder (Mean Values ± Standard Deviation)}
\begin{tabular}{|c|c|c|c|}
\hline
particle size (μm) & 6 & 6.5 & 7 \\
\hline
>600 & 0.21 ± 0.11 & 0.68 ± 0.22 & 2.93 ± 0.53 \\
400 < X < 600 & 5.69 ± 1.26 & 13.80 ± 0.82 & 33.87 ± 1.63 \\
250 < X < 400 & 32.00 ± 4.89 & 47.15 ± 14.12 & 35.64 ± 1.88 \\
180 < X < 250 & 52.60 ± 6.12 & 37.18 ± 14.10 & 26.42 ± 1.07 \\
<180 & 9.52 ± 3.21 & 1.19 ± 1.02 & 1.15 ± 0.85 \\
\hline
\end{tabular}
\end{table}

Each EC sample was divided into three fractions (F) collecting the brews obtained in the first 8 s (Ft1), from 9 to 16 s (Ft2), and from 17 to 24 s (Ft3) of extraction. These extraction times were chosen by dividing in three fractions the time necessary to prepare a regular coffee that is 25 s. The extraction times were measured using a digital timer. The regular EC of 25 mL, from each grinding level, was prepared measuring the volume of brew through a graduate cylinder. At least 20 replicates were performed for each espresso, obtaining a total of 240 samples.

\textbf{Physical and Chemical Analyses.} The pH of the samples was measured by a pH-meter model Basic 20 (Crison, Allen) previously calibrated with three buffers at pH 4.00, 7.00, and 9.00. Also, acidity was measured by titration of 25 mL of coffee brew at room temperature with 0.1 N NaOH until pH of 7.00.\textsuperscript{43} The total solids content was measured gravimetrically by drying about 3 mL of EC at 105 °C until a constant weight.

The caffeine content was measured using the method described by Skog et al.,\textsuperscript{35} with some modifications. Each EC brew (fractions and regular coffee) was previously filtered with 0.22 μm nylon filter (Olim Peak, Teknokroma Anlitica, Spain) and directly injected (injection volume = 20 μL) into a high-performance liquid chromatography (HPLC) binary pump (Waters model 1525, Milford, MA) equipped with a detector set at 254 nm (Waters model 2487, Milford, MA). Peak separation was achieved on a C\(_18\) column (Hibar 125–4 with LiChrospher 100, 5 μm) at 25 °C, using a mobile phase (v/v) of water (74%), methanol (25%), and acetic acid (1%) (J.T.Baker) previously seeped through a filter in cellulose acetate of 0.45 μm (VWR International, Radnor, PA) and submitted to an ultrasound pulse (Elmasonic S 60 H, Elma Schmidbauer GmbH, Germany) for 20 min to remove the air. The flow rate of pump was 0.9 mL/min. The concentration was calculated using the equation obtained by the linear regression of external caffeine standards at different concentrations (Sigma-Aldrich, St. Louis, MO), and the results were expressed as milligrams per milliliter.

\textbf{Determination of the Aromatic Profile by the Electronic Nose System.} The aromatic profile was characterized by an electronic nose system aFOX Sensor Array System 2000 (Alpha M.O.S., Toulouse, France) equipped with six metal oxide semiconductor sensors (T30/1, T70/2, P10/1, P10/2, P40/1, and PA/2) and an autosampler model HS 100 (Alpha M.O.S., Toulouse, France). The sensors measure the changes of the electrical resistance generated by the adsorption–desorption of the volatile organic compounds. Dry air with impurities specified as H\(_2\)O < 5 ppm, C\(_{2}\)H\(_6\) < 5 ppm, O\(_3\) + N\(_2\) > 99.95%, and O\(_2\) = 20 ± 1% was used as carrier gas using a flow rate of 150 mL/min. A total of 1 mL of each coffee sample was placed in vials of 10 mL, sealed with a rubber stopper, and maintained in an oven at 87 °C in agitation at 300 rpm for 3 min before the injection of 500 μL. A flow rate of 150 mL/min was used for the analysis. The sensor responses were detected every 1 s for a total time, t, of 300 s (a total of 300 points for each sample). The response of the sensors was
expressed as $R_i/R_0$, where $R_i$ is the resistance of the sensor and the subscripts 0 and $i$ refer to the initial value and each time $i$. After each analysis, the system was purged for 240 s with filtered air before a new injection to allow for re-establishment of the instrument baseline.

**Statistical Analysis.** For each grinding grade, significant differences among physicochemical parameters of the fractions and the regular coffee were determined by one-way analysis of variation (ANOVA). Tukey’s test ($p < 0.05$) was used to highlight significant differences.

Principal component analysis (PCA) was performed on the data of the odor profile to discriminate the samples on the basis of their aromatic profile. The analysis was performed using as experimental data the values of maximum intensity detected by each sensor. Statistical analysis was performed using STATISTICA, version 10 (StatSoft, Inc., Tulsa, OK).

**RESULTS AND DISCUSSION**

Table 3 shows the main chemical attributes of the regular EC samples as well as each fraction of the brew collected as a function of the extraction time. The pH values of the regular coffee were not significantly different ($p > 0.05$), exhibiting values ranging between 4.983 ± 0.419 and 5.177 ± 0.021; these results were in accordance with the data reported from Parenti et al. but slightly lower than the values reported from Andueza et al. and Caporaso et al. who showed average values of ~5.6 and ~5.8, respectively.

Similar results were observed for titratable acidity for which only the samples obtained using a grinding level of 7 showed values significantly lower than the others. Moreover, taking into account the total solid content, no differences were observed ($p > 0.05$), stating that the three grinding grades did not affect this parameter for the regular EC samples. Our results showed values ranging between 44.342 ± 0.745 and 55.115 ± 4.747 mg/mL, which were in accordance with Parenti et al. who showed a total solid content of 59.48 mg/mL. However, a high variance in the total solids content of EC has been reported in the literature.

Caffeine contents of the regular EC between 3.212 ± 0.267 and 4.179 ± 0.209 mg/mL were observed. These values were higher than those reported by Caporaso et al. and Parenti et al. who showed values always lower than 2.44 mg/mL.

Although our results showed some discrepancies when compared to other authors, our findings may be considered within the natural variance of the chemical composition of EC brews. As well-known, the EC may be affected by several variables, such as roasting grade, mixture of roasted coffee varieties, water temperature, etc. In addition, the volume of EC, which considerably affects the chemical composition of brew, is often highly variable among the scientific publications.

However, from Table 3, the analysis of the changes in chemical attributes of the three fractions of EC showed structured variations. The pH values significantly increased as a function of the fraction of brew for each grinding grade. Of course, this result may be caused from the progressive reduction of organic acids still contained in the coffee grounds during the solid—liquid extraction. Moreover, in comparison to the pH values obtained from different grinding grades while keeping the same fraction constant, no significant differences ($p > 0.05$) were observed for the Ft1 samples, while a significant increase ($p < 0.05$) was observed for the second (Ft2) and third (Ft3) fractions of EC. These results were probably caused by a dilution effect because the increase of the grinding grade significantly affected the percolation rates with values of 1.66 ± 0.19, 2.89 ± 0.59, and 6.51 ± 0.26 mL/s when grinding levels of 6, 6.5, and 7 were used, respectively. More specifically, the increase of the percolation rate could be caused by the effect of the different particle size distributions (as reported in Table 2) on the microstructure of the coffee cake. A higher porosity and/or better percolation pathway, which are expected when increasing the grinding grade, could improve the extraction rate. However, because the pH values of the first fraction of EC samples were practically constant, it is possible to suppose that the major amount of organic acids was extracted in the first 8 s of percolation. Similar observations may be performed for titratable acidity, total solids, and caffeine contents, for which a progressive decrease was observed as a function of the coffee fractions and the grinding grade. Particularly, for caffeine content, the HPLC diagram of Ft1, Ft2, and Ft3 samples obtained using a grinding level of 6 is reported in Figure 1, showing the caffeine content decreasing as a function of the extraction time in the range of 5.231 and 0.749 mg/mL.

The study of the aromatic profile of each fraction of the EC and regular coffee obtained using different grinding grades is reported in Figures 2–5.

Figure 2 shows the loading plot of the sensors, which contributes to the discrimination of samples as well as the factor coordinates of the fractions of EC prepared with the three grinding grades. PC1 accounted for 98.77% of the variation of samples, while PC2 accounted for 1.01%, stating that the first two PCs allowed us to explain accurately the variation of the aroma profile of EC samples (99.78%). All of

<table>
<thead>
<tr>
<th>sample</th>
<th>grinding grade</th>
<th>volume of brew (mL)</th>
<th>pH</th>
<th>titratable acidity (mg/L)</th>
<th>total solids (mg/mL)</th>
<th>caffeine (mg/mL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ft1</td>
<td>6</td>
<td>16.239 ± 3.579</td>
<td>5.180 ± 0.017</td>
<td>0.329 ± 0.004</td>
<td>74.615 ± 0.013</td>
<td>4.982 ± 0.624</td>
</tr>
<tr>
<td></td>
<td>6.5</td>
<td>28.858 ± 2.318</td>
<td>5.237 ± 0.047</td>
<td>0.272 ± 0.012</td>
<td>69.699 ± 0.010</td>
<td>4.359 ± 0.919</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>41.847 ± 1.701</td>
<td>5.233 ± 0.031</td>
<td>0.121 ± 0.010</td>
<td>34.632 ± 0.002</td>
<td>2.431 ± 0.338</td>
</tr>
<tr>
<td>Ft2</td>
<td>6</td>
<td>14.661 ± 2.009</td>
<td>5.467 ± 0.068</td>
<td>0.0573 ± 0.010</td>
<td>17.056 ± 0.003</td>
<td>1.288 ± 0.247</td>
</tr>
<tr>
<td></td>
<td>6.5</td>
<td>22.920 ± 3.579</td>
<td>6.023 ± 0.130</td>
<td>0.016 ± 0.004</td>
<td>8.530 ± 0.001</td>
<td>0.833 ± 0.231</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>55.904 ± 1.889</td>
<td>6.790 ± 0.159</td>
<td>0.003 ± 0.001</td>
<td>2.681 ± 0.001</td>
<td>0.305 ± 0.023</td>
</tr>
<tr>
<td>Ft3</td>
<td>6</td>
<td>14.614 ± 1.113</td>
<td>5.893 ± 0.199</td>
<td>0.025 ± 0.014</td>
<td>9.175 ± 0.002</td>
<td>0.645 ± 0.148</td>
</tr>
<tr>
<td></td>
<td>6.5</td>
<td>21.295 ± 2.227</td>
<td>6.510 ± 0.160</td>
<td>0.003 ± 0.001</td>
<td>3.783 ± 0.001</td>
<td>0.290 ± 0.115</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>48.016 ± 1.113</td>
<td>7.213 ± 0.038</td>
<td>0.254 ± 0.008</td>
<td>5.064 ± 0.735</td>
<td>4.179 ± 0.209</td>
</tr>
<tr>
<td>regular coffee</td>
<td>6</td>
<td>4.983 ± 0.419</td>
<td>5.177 ± 0.021</td>
<td>0.241 ± 0.006</td>
<td>55.115 ± 4.747</td>
<td>4.014 ± 0.163</td>
</tr>
<tr>
<td></td>
<td>6.5</td>
<td>5.161 ± 0.021</td>
<td>0.180 ± 0.009</td>
<td>44.342 ± 0.745</td>
<td>3.212 ± 0.267</td>
<td></td>
</tr>
</tbody>
</table>

*Different letters indicate statistically significant differences among grading grade ($p < 0.05$, Tukey’s test).
the sensors have been significant for detecting differences in terms of odor compounds of EC samples. More specifically, the sensors T30/1, P10/2, PA/2, and T70/2 showed the highest contribution in the discrimination of the majority of samples with the exception of the sample 6-Ft1, which was better recognized by the sensors P10/1 and P40/1. Particularly, the sample 6-Ft1 was clearly separated from the other coffee fractions, stating that, during the first 8 s of percolation with the finest coffee grounds, a significantly different aromatic profile was developed. However, the samples 6-Ft2 and 6-Ft3 were also well-discriminated, but their differences were better highlighted from the responses of the other four sensors.
When the three fractions of ECs prepared with the grinding grade 6.5 were considered (6.5-Ft1, 6.5-Ft2, and 6.5-Ft3), a good discrimination was observed in the direction of the sensors T30/1, P10/2, and PA/2, which gave the most important contribution for detecting significant differences in the aroma profile of these samples. Similarly, the three fractions of the samples obtained from the coarse coffee grounds (7-Ft1, 7-Ft2, and 7-Ft3) were well-discriminated from the above three sensors. These results confirmed that there is a significant change in the type and/or amount of volatiles of EC during extraction. Moreover, significant differences were also observed among the three grinding grades used for preparing coffee brews. When the grinding grade was increased for each fraction of EC (Ft1, Ft2, and Ft3), the samples were well-discriminated, proving that the use of different grinding grades may significantly modify the aromatic profile of coffee brew. Again, it is reasonable to suppose that this result was caused by a different level of extraction as a consequence of the variation in the particle size distribution of coffee grounds. Particularly, the particle sizes become smaller as the solid-liquid surface becomes greater, and as previously reported, the percolation rate is lower. Of course, the greater solid-liquid surface could have increased the amount of volatiles extracted from coffee grounds. From Figure 2, it is possible to observe that the sample 6-Ft2 cannot be discriminated from the samples 6.5-Ft1 and 7-Ft1, stating that the coffee brew extracted from 9 to 16 s using the finest coffee grounds showed a similar aromatic profile to the brews obtained during the first 8 s of extraction with the medium—coarse and coarse coffee grounds. According to our results, Clarke and Andueza et al. reported that the coffee brews prepared with coarse coffee grounds showed the lowest aromatic profile. Bhurmiratana et al. demonstrated that the grinding of roasted coffee beans increased the surface area and, consequently, influenced the release of aromatic compounds. Again, these results support the idea that different aromatic profiles of EC may be obtained when different grinding grades are used and/or when the extraction time is not constant.

With the aim to better compare the difference in aromatic profiles among the fractions of EC and regular coffee, Figures 3 and 4 show the results of principal component analysis (PCA) for samples prepared with grinding grades of 6 and 6.5, respectively. In all cases, PC1 accounted for more than 97% of the variance of the samples, while PC2 explained a maximum of 1.93%. Considering the samples prepared with a grinding grade of 6, a clear discrimination of each of the three fractions was observed (Figure 3). Again, these differences could be a result of a dilution effect because of the progressive reduction of the chemical substances and volatiles still contained in the coffee grounds, going forward with the extraction time of coffee brew. However, the regular coffee of 25 mL seems to have an aromatic profile comparable to the second fraction of the brew collected from 9 to 16 s of extraction. This is in accordance with the above results; particularly, by considering the flow rate of 1.66 mL/s, ~15 s is the time necessary to obtain a regular coffee of 25 mL, which is in the range of time for obtaining an EC cup with all Ft1 and part of Ft2 samples. Probably, the dilution effect produced by the addition of Ft2 to Ft1 led the regular EC to have an aromatic profile similar to the Ft2 sample only. Similarly, Nicoli et al. and Severini et al. observed a progressive reduction of chemical and aromatic concentrations in the consecutive fractions of EC and moka coffee.

When grinding grades of 6.5 and 7 were used for EC preparation, a good discrimination was again observed among the three different fractions of the brew. Nevertheless, by considering PC1 axis, where the maximum variance explained resides, regular coffee appeared to be practically overlapped with the Ft1 sample when using a grinding grade of 6.5 (Figure 4), while the regular coffee was slightly separated when a grinding grade of 7 was used (data not shown). Again, considering the volume of brew of 28.858 ± 2.318 and 41.847 ± 1.701 mL (Table 3) measured for grinding grades 6.5-Ft1 and 7-Ft1, respectively, it is reasonable to suppose that these fractions showed similar and lower concentrations of odor compounds, respectively, when compared to the regular coffee (25 mL). Some studies supported our results, showing that the fine grade produced a low volume of coffee brew with respect to a coarse grinding level. In addition, Clarke and Macrae reported that the brews obtained with fine-ground coffee exhibited the highest extraction of soluble solids and volatile compounds, while Andueza et al. found that the particle size is inversely related to the extraction of organic acids and the sensorial aromatic perception.

In Figure 5, the results of PCA obtained by analyzing the regular coffee only achieved from different grinding levels are shown. In this case, both the PCs had a significant contribution in the discrimination of samples, with PC1 accounting for 73.24% and PC2 accounting for 22.96%. The three types of regular coffee were well-distinguished, proving that different aromatic profiles were obtained by preparing a cup of coffee of 25 mL using coffee powder with different grinding levels; nevertheless, in comparison to the difference observed among

<table>
<thead>
<tr>
<th>grinding grade</th>
<th>sample</th>
<th>T30/1</th>
<th>P10/1</th>
<th>P10/2</th>
<th>P40/1</th>
<th>T70/2</th>
<th>PA/2</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>Ft1</td>
<td>0.561 ± 0.011</td>
<td>0.404 ± 0.014</td>
<td>0.553 ± 0.013</td>
<td>0.348 ± 0.013</td>
<td>0.563 ± 0.016</td>
<td>0.685 ± 0.016</td>
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<tr>
<td></td>
<td>Ft2</td>
<td>0.377 ± 0.022</td>
<td>0.262 ± 0.013</td>
<td>0.398 ± 0.018</td>
<td>0.224 ± 0.011</td>
<td>0.321 ± 0.026</td>
<td>0.436 ± 0.029</td>
</tr>
<tr>
<td></td>
<td>Ft3</td>
<td>0.246 ± 0.018</td>
<td>0.209 ± 0.008</td>
<td>0.312 ± 0.013</td>
<td>0.183 ± 0.006</td>
<td>0.187 ± 0.017</td>
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<tr>
<td>6.5</td>
<td>Ft1</td>
<td>0.430 ± 0.015</td>
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<td>0.428 ± 0.010</td>
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<tr>
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<td>Ft2</td>
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<td>0.235 ± 0.007</td>
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<td>0.130 ± 0.009</td>
<td>0.189 ± 0.009</td>
</tr>
<tr>
<td></td>
<td>Ft3</td>
<td>0.099 ± 0.006</td>
<td>0.156 ± 0.004</td>
<td>0.194 ± 0.005</td>
<td>0.142 ± 0.003</td>
<td>0.073 ± 0.004</td>
<td>0.121 ± 0.007</td>
</tr>
<tr>
<td>7</td>
<td>Ft1</td>
<td>0.381 ± 0.014</td>
<td>0.261 ± 0.010</td>
<td>0.383 ± 0.019</td>
<td>0.226 ± 0.009</td>
<td>0.327 ± 0.016</td>
<td>0.416 ± 0.023</td>
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<td></td>
<td>Ft2</td>
<td>0.151 ± 0.015</td>
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<td>0.200 ± 0.010</td>
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<td>0.115 ± 0.012</td>
<td>0.148 ± 0.012</td>
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<td>Ft3</td>
<td>0.084 ± 0.009</td>
<td>0.154 ± 0.005</td>
<td>0.170 ± 0.006</td>
<td>0.141 ± 0.004</td>
<td>0.066 ± 0.006</td>
<td>0.093 ± 0.006</td>
</tr>
<tr>
<td>6</td>
<td>regular coffee</td>
<td>0.453 ± 0.013</td>
<td>0.285 ± 0.007</td>
<td>0.401 ± 0.009</td>
<td>0.244 ± 0.006</td>
<td>0.424 ± 0.017</td>
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<td>0.237 ± 0.005</td>
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</tr>
<tr>
<td>7</td>
<td>0.410 ± 0.007</td>
<td>0.281 ± 0.005</td>
<td>0.402 ± 0.007</td>
<td>0.243 ± 0.004</td>
<td>0.364 ± 0.009</td>
<td>0.452 ± 0.009</td>
<td></td>
</tr>
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</table>

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each fraction, the three types of regular coffee appeared to be
nearest. According to the previous results, the regular coffee
prepared with fine−coarse and coarse coffee grounds contain
the entire Ft1 sample and only a small part of it, respectively,
while using the fine coffee grounds, the regular coffee contains
both fractions Ft1 and Ft2. Under this consideration, it can be
stated that the regular coffee collected the majority of odor
compounds.
Table 4 shows the maximum value of the responses of each
sensor to the volatiles of EC samples. A reduction of the
response of all sensors as a function of the fractions of EC brew
was observed for each grinding grade. As reported from several
authors, the reduction of the intensity of the response of the
sensors may be related to the concentration of aromatic
compounds.\(^{57,50}\) Similarly, the reduction observed in Table 4
for EC samples may be related to a decrease of the volatile
concentration in the brew because of the dilution effect
discussed above. The maximum response observed for the Ft1
samples confirmed the hypothesis that the maximum extraction
of odor molecules occurs during the first few seconds of the
percolation process. For all grinding levels, the reduction of
sensor intensity was more pronounced from Ft1 to Ft2, while
the gap between Ft2 and Ft3 appeared practically negligible.
For the regular EC (25 mL), only slight variations in the
response of each sensor were observed, confirming the low
differences in terms of the aromatic profile, as highlighted in
Figure 5.
In conclusion, the chemical attributes and aromatic profiles
of EC were proven to be significantly affected by the extraction
time and grinding grade of coffee powder. Particularly, the
majority of organic acids, solids, and caffeine contained in the
coffee grounds was extracted during the first 8 s of percolation.
Also, using the electronic nose system, it was possible to prove
the overall aromatic profile of EC samples; indeed, through
PCA, a high discrimination was obtained among the brew
fractions and grinding levels. This result highlights the
importance of making more efforts on the control of these
two variables in the bar with the aim to ensure a constant
aromatic quality of EC served every day.

**AUTHOR INFORMATION**

**Corresponding Author**
*Telephone: +39-0881-589222. E-mail: carla.severini@unifg.it.*

**Notes**
The authors declare no competing financial interest.

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