

Degradation of benzopyrene and acrylamide in roasted coffee beans by corona discharge plasma jet (CDPJ) and its effects on biochemical and sensory properties

Taehoon Lee^a, Hyesung Park^a, Pradeep Puligundla^a, Gwi-Hee Koh^b, Jungro Yoon^{b,*}, Chulkyoon Mok^{a,*}

^a Department of Food Science & Biotechnology, Gachon University, 1342 Seongnam-daero, Sujeong-gu, Seongnam-si, Gyeonggi-do, 13120, Republic of Korea

^b Department of Food Processing and Distribution, Gangneung-Wonju National University, Gangneung 25457, Republic of Korea

ARTICLE INFO

Keywords:

Benzopyrene
Acrylamide
Degradation
Roasted coffee
Corona discharge plasma
E-tongue
E-nose

ABSTRACT

This study was aimed to reduce the concentrations of benzopyrene (BaP) and acrylamide (ACR) in roasted coffee beans by corona discharge plasma jet (CDPJ). The initial concentrations of BaP and ACR in roasted beans were decreased by 53.6% and 32.0%, respectively, following CDPJ (powered by 20 kV DC/1.5 A) treatment for 60 min. The levels of total solid, total acid, chlorogenic acid, caffeine, trigonelline, and pH were insignificantly changed upon CDPJ treatment compared to controls. However, the concentration of total phenolic content and Agtron color values were altered significantly. The treatment of beans did not alter descriptive sensory properties of the corresponding coffee brews, except aroma and aftertaste characteristics. As the treatment time increased from 15 to 60 min, scores for aroma profiles in PCA plot were shifted from right to left, although overlapping was observed between 15- and 30-min-treated samples. Additionally, none of the treated samples were discriminated from the control by electronic tongue.

1. Introduction

Benzo[a]pyrene (BaP) and acrylamide (ACR) are toxic neoformed compounds (NFCs), often found to coexist in many foods processed at high temperature. These are generally formed during processing due to complex reactions between components. BaP is generated by incomplete combustion of organic substances at temperatures between 300 and 600 °C (Lee, Puligundla, & Mok, 2019). ACR is known to be formed by a Maillard type reaction between reducing sugars and specific amino acids (asparagine and methionine) (Mottram, Wedzicha, & Dodson, 2002). They are known to exhibit diverse toxicity, including genotoxicity, neurotoxicity, reproductive toxicity, and potential carcinogenicity (Zhao et al., 2017). Heat treatment of foods, such as roasting, frying, and grilling, has been shown to induce BaP and ACR formation, and hence these toxins are generally found in roasted seeds and smoked or grilled meats.

The roasting of coffee beans is responsible for their characteristic flavor and final quality. However, this process leads to the formation of undesirable compounds, such as ACR, furan, and polyaromatic hydrocarbons (PAHs) including BaP (Arisseto, Vicente, Soares Ueno, Verdiani Tfouni, & De Figueiredo Toledo, 2011; De Kruijff, Schouten, & Van der

Stegen, 1987; Tfouni et al., 2012, 2013). Several studies demonstrated that coffee is a significant dietary source of ACR, especially in those countries with a high coffee consumption (Mojska & Gielecinska, 2013). Dry coffee has been shown to contain ACR at an average level of 522 µg/kg or ppb (Raffan & Halford, 2019).

Non-thermal or cold plasma can be used for toxin degradation in foods. In a recent study, an atmospheric cold plasma, namely corona discharge plasma jet (CDPJ), has successfully been used for the degradation of BaP in roasted sesame and perilla seeds; degradation levels in the range of 32.96 to 45.90% were observed following treatment for 30 min (Lee et al., 2019). In the present study, CDPJ was used for the degradation of BaP and ACR in roasted coffee beans. In addition, the effects of the treatment on the biochemical and sensory properties of coffee beans were investigated.

2. Materials and methods

2.1. Coffee beans

Arabica green coffee beans (Ethiopia Yirgacheffe G2) were purchased from Global Soft Commodities GSC International Coffee® (Seoul,

* Corresponding authors.

E-mail addresses: yoong@gnu.ac.kr (J. Yoon), mokck@gachon.ac.kr (C. Mok).

<https://doi.org/10.1016/j.foodchem.2020.127117>

Received 4 February 2020; Received in revised form 1 May 2020; Accepted 20 May 2020

Available online 21 May 2020

0308-8146/ © 2020 Elsevier Ltd. All rights reserved.

Korea).

2.2. Roasting

The roasting of coffee beans to a very dark roast degree (Agtron No. 26.2) was carried out using an 800 g capacity drum roaster (Namgaiver, Namyangju, Korea). Preheating temperature of the roaster was 190 °C, final temperature was 235 °C, and roasting time was 11 min 50 s.

2.3. Corona discharge plasma production

Corona discharge plasma jet (CDPJ) used for the degradation of BaP and ACR in this study was generated as described in our previous studies (Lee et al., 2019; Puligundla, Kim, & Mok, 2017). In brief, CDPJ was generated under atmospheric pressure conditions using a 1.5 A current (input) at 58 kHz operating frequency. Under high voltage (20 kV DC output voltage), a streamer-type discharge in air was observed between tungsten electrodes. In order to create plasma jet, a centrifugal air blower (Ventur Tekniska, Goteborg, Sweden) was used. The rotational speed of the impeller of the blower was 3312 rpm, and 2.5 m/s air velocity was observed at the tip of the electrodes.

2.4. Treatment with CDPJ

For each treatment, roasted coffee beans (5 g) taken in a Petri plate were exposed to CDPJ. The plasma treatment times were 0, 15, 30, 45, and 60 min. A sample-to-electrode distance of 25 mm was maintained during the treatment.

2.5. Color measurement

Color changes were monitored by measuring the change in reflected blue light with an Agtron colorimeter (CM-100, Lighttells Corp. Ltd., Zhubei city, Taiwan).

2.6. ACR quantification

The concentration of ACR in roasted coffee beans was estimated by HPLC method. Test solution was prepared as described previously (Chung, Park, & Choi, 2007). Briefly, 1 g of homogenized sample was taken into a 50- mL polypropylene conical tube, and 9 mL of triple distilled water was added. After initial mixing, placed on a shaker and shaken for 20 min at 180–200 rpm. After extraction, centrifuged for 30 min at 9000 rpm. The obtained supernatant was centrifuged again at 7000 rpm for 10 min. The resultant supernatant was used as test sample. Then, the Oasis® HLB SPE cartridge (Waters Corporation, Milford, MA, USA) was activated by adding 3.5 mL of methanol (99.5%) and 3.5 mL of triple distilled water. Thereafter, 1.5 mL of test sample and 0.5 mL of triple distilled water were added to the cartridge. Then, the cartridge was eluted using 1.5 mL of triple distilled water and eluate (1.5 mL) was collected in a centrifuge tube.

Later, the Bond Elut-Accucat® cartridges (Varian Inc., Harbor City, CA, USA) were conditioned with 2.5 mL of methanol and 2.5 mL of triple distilled water before loading with 0.5 mL of eluate. The eluate was allowed to pass-through, and the remaining 1 mL eluate was loaded into the cartridge for analysis.

Analyses were performed using an ultra-high performance liquid chromatography (UHPLC) system (Dionex Ultimate 3000 UPLC, Thermo Scientific, San Jose, CA, USA) equipped with a C₁₈ column (250 mm × 4.6 mm, 5 µm) at a column temperature of 35 °C, as described in a previous study (Wang, Feng, Guo, Shuang, & Choi, 2013). Mobile phase comprised of solvents A and B. Solvent A was the mixture of acetonitrile (10% v/v) and water (90% v/v) containing formic acid (0.10% v/v). Solvent B was pure acetonitrile. An ultraviolet (UV) detector was used at 210 nm.

2.7. BaP quantification

BaP concentration in roasted coffee beans was quantified using a HPLC method with fluorescence detection, as described previously (Lee et al., 2019).

2.8. Coffee extract or brew preparation

Each coffee brew was prepared using the AeroPress coffee maker (Aerobie, Inc., Palo Alto, CA, USA) by pouring 150 mL of hot water (93 °C) over 8.25 g of ground coffee beans and allowed to stand for 5 min before pressing.

2.8.1. Total solid content

Total solid content of coffee brews was determined by weighing the samples dried at 105 °C for 16 h.

2.8.2. Caffeine, chlorogenic acid (5 CQA), and trigonelline

The concentrations of caffeine, chlorogenic acid, and trigonelline in coffee extract were determined using liquid chromatography coupled to mass spectrometry (LC-MS) as described in a previous study (Flambeau & Yoon, 2018). In brief, analyses were performed using a liquid chromatograph system (Agilent 1100 series) equipped with an autosampler/injector and a diode-array detector (DAD) at a column temperature of 35 °C; and this system was coupled to an Agilent 1100 mass spectrometer (LC/MSD Ion Trap VL). A reverse phase column (ZORBAX Eclipse Plus, XDB-C₁₈, 4.6 mm × 150, 5 µm, Agilent Tech., Lexington, MA, USA) was used. Mobile phase was comprised of solvent A and B. Solvent A was methanol containing acetic acid (0.1% v/v). Solvent B was triple distilled water containing acetic acid (0.1% v/v). Detection wavelengths used for caffeine, 5-CQA, and trigonelline were 278 nm, 325 nm, and 268 nm, respectively.

2.8.3. Total phenolic content

Total phenolic content was determined using Folin-Ciocalteu reagent as described previously by Cosoreci, Moldovan, Raba, Popa, and Dumbravă (2014). Standard solutions of gallic acid (0.005–0.08 mg/mL) in distilled water were used for calibration.

Two and a half milliliters of FC reagent were added to each 0.5 mL coffee brew sample and to each of the standard solutions. After 10 min, 2 mL of 7.5% Na₂CO₃ solution were added and then incubated for 2 h. Polyphenol content was calculated as gallic acid equivalent (w/v) using a UV-visible spectrophotometer (T60 U, PG Instruments Ltd., Lutterworth, UK) at 750 nm. Distilled water was used as blank.

2.8.4. Titratable acidity and pH

The acidity of coffee brew was determined according to the experimental procedure described by Santos, Lopo, Rangel, and Lopes (2016). Five milliliters of the brew were diluted to 100 mL using distilled water and titrated with 0.1 N NaOH solution to the phenolphthalein end point (pH 8.2) under magnetic stirring. The acidity was expressed as percentage citric acid (w/v).

The pH of coffee brews was determined using a microprocessor-based pH meter (pH 210, Hanna Instruments, Woonsocket, RI, USA). Measurements were performed in triplicate.

2.9. Analysis of aroma profile

Aroma profiles of coffee brews were obtained using Heracles II electronic nose system (Alpha MOS, Toulouse, France), as described previously (Flambeau, Lee, & Yoon, 2017). This device was equipped with a HS-100 auto-sampler, two capillary columns in parallel (MXT-5; polar and MXT-1701; slightly polar), each connected to a flame ionization detector (FID).

Before running the sample analysis, 20 µL of Kovats standard (a mixture of C₆–C₁₆ alkanes) were injected into the electronic nose (e-

nose) and analyzed under the same chromatographic conditions as the samples.

Five milliliters of each brew were immediately transferred into 20 mL vials and capped to keep the fresh aroma. The headspace was generated by an auto-sampler at 60 °C for 15 min with agitation at 500 rpm. Five milliliters from the headspace were then injected into the injector at 200 °C with a speed of 250 μ L/s. The valve, trap, and desorption temperatures were set at 250 °C, 40 °C, and 250 °C, respectively. The column temperature was increased from 40 °C to 270 °C by 3 °C/s in a split-less mode, whereas the acquisition time was 120 s and detector temperature was 270 °C. For each column, a chromatogram indicating intensity of each aroma compound against its retention time for each sample was recorded and the average peak areas were calculated by AlphaSoft software (Alpha MOS, Toulouse, France) for data analysis.

2.10. Analysis of taste profile

Taste profiles of coffee brews were obtained using Astree II electronic tongue (Alpha MOS, Toulouse, France) equipped with seven cross-selective sensors, as described previously (Flambeau et al., 2017). Prior to analysis, 0.01 M aqueous solutions of HCl, monosodium glutamate (MSG), and NaCl were used to calibrate and diagnose the sensors and system.

Three brews per sample were cooled at ambient temperature and filtered using Whatman No. 1 filter paper. Twenty-five mL per brew were then transferred into beakers and placed onto the autosampler tray with two beakers containing distilled water before each sample for cleaning the sensors between sample measurements. The acquisition time was set to be 120 s. The potential difference between each sensor and the reference electrode with respect to acquisition time was then collected by AlphaSoft software (Alpha MOS, Toulouse, France).

2.11. Sensory analysis

Sensory analysis was performed according to the Specialty Coffee Association of America (SCAA) protocols (SCAA, 2015). Briefly, samples from the five treatment conditions were subjected to sensory evaluation by a panel of twelve experts. Each sample was prepared using 18 g of roasted and ground coffee in 300 mL of hot water. The evaluation was conducted three times on three consecutive days. Aroma was evaluated by sniffing the brew three minutes after its preparation and stirring. Other primary sensory attributes including acidity, flavor, body, and aftertaste were evaluated by tasting the brew by spraying it in the mouth to maximize retro-nasal vapors. The quality and intensity of each attribute was evaluated simultaneously by using a scale varying from 1 to 10 (Worst to Best). Cupper's points [scale: -5 (Very Poor) to +5 (Outstanding)] represents the overall liking for the harmonious integration of the total sensory impact of the five primary sensory attributes. Overall score was the sum of five primary sensory scores and cupper's points and added an additional 50 points to adjust the final score to a 100-point basis.

2.12. Data analysis

All treatments were performed in triplicate, and results are presented as mean $\pm$ standard deviation. Data were statistically analyzed using SAS statistical software package (version 9.2, SAS Institute Inc., Cary, NC, USA). Differences among groups were analyzed by one-way analysis of variance (ANOVA), followed by Duncan's multiple range test at $\alpha = 0.05$.

PCA score plot was constructed using the most discriminating peaks (those that showed discrimination power $\geq 90\%$; identified using the Alpha MOS's AroChemBase library) selected as important odorants that contribute to the discrimination. Discrimination (or separation) was achieved by comparing the distances and pattern discrimination indices

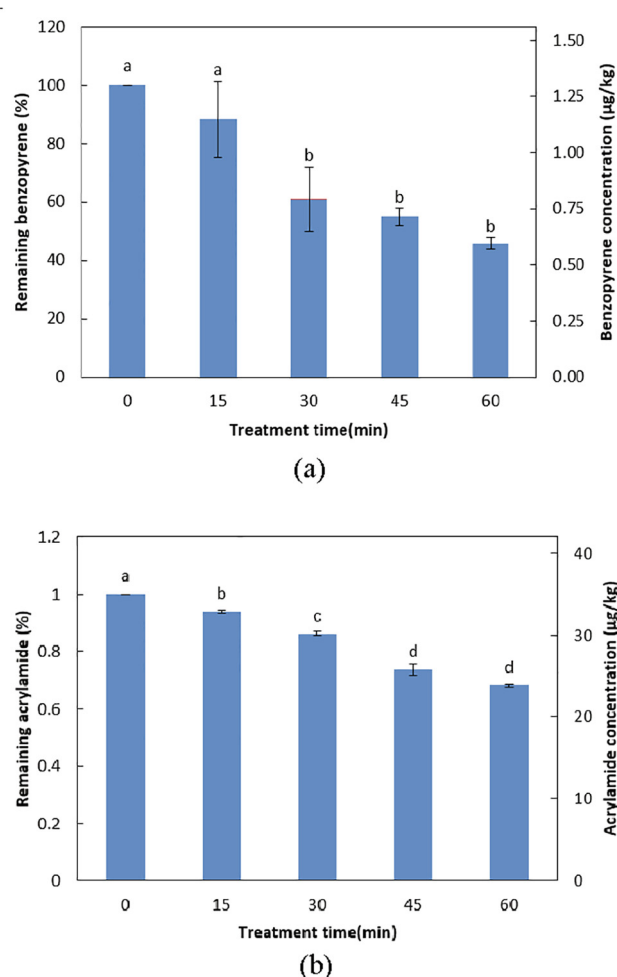


Fig. 1. Residual concentrations of benzopyrene (a) and acrylamide (b) in roasted coffee beans following CDPJ treatment.

between sample groups on PCA score plot.

3. Results and discussion

3.1. Degradation of BaP

Time-dependent reduction in the levels of BaP was observed upon CDPJ treatment. The initial concentration of BaP in roasted coffee beans was found to be 1.27 ± 0.12 μ g/kg. Following CDPJ treatment for 60 min, BaP concentration was reduced significantly ($p < 0.05$) by $> 50\%$ of initial concentration (Fig. 1a). Similar results were observed in a previous study for CDPJ-induced BaP degradation in roasted oil seeds (Lee et al., 2019).

3.2. Degradation of ACR

The concentrations of ACR were also decreased in the beans following CDPJ treatment in a time-dependent manner. In 0–60 min treatment time, initial concentrations (35.4 ± 1.41 μ g/kg) were reduced by about 30% (Fig. 1b). Upon treatment with the CDPJ, relatively low levels of degradation were noted for ACR when compared with BaP degradation.

Different processing strategies have been recommended for ACR mitigation in food products (Matthäus & Haase, 2016). For instance, the addition of the enzyme asparaginase during dough preparation has been shown to reduce ACR content in cracker products (Vass, Amrein, Schonbachler, Escher, & Amado, 2004). In addition, the use of sodium

Table 1
Changes in biochemical properties of roasted coffee beans upon CDPJ treatment.

Treatment time (min)	Total solid content (w/v %)	pH	Titrateable acidity (g/L)	Agtron number	Caffeine (mg/L)	Chorogenic acid (mg/L)	Trigonelline (mg/L)	Total phenolic content (g/L)
0	1.10 ± 0.06 ^a	5.87 ± 0.023 ^a	0.297 ± 0.023 ^a	26.2 ± 0.35 ^b	559 ± 9 ^{ab}	62 ± 1 ^a	219 ± 4 ^{ab}	1.37 ± 0.02 ^a
15	1.20 ± 0.08 ^a	5.87 ± 0.013 ^a	0.286 ± 0.012 ^a	26.1 ± 0.43 ^b	560 ± 6 ^{ab}	63 ± 1 ^a	223 ± 4 ^{ab}	1.40 ± 0.02 ^a
30	1.20 ± 0.05 ^a	5.87 ± 0.007 ^a	0.281 ± 0.000 ^a	25.4 ± 0.59 ^b	562 ± 7 ^{ab}	64 ± 1 ^a	227 ± 2 ^a	1.39 ± 0.02 ^a
45	1.10 ± 0.08 ^a	5.87 ± 0.007 ^a	0.286 ± 0.012 ^a	26.1 ± 0.58 ^b	571 ± 3 ^a	63 ± 1 ^a	221 ± 1 ^{ab}	1.32 ± 0.03 ^b
60	1.10 ± 0.03 ^a	5.89 ± 0.004 ^a	0.281 ± 0.000 ^a	27.7 ± 0.48 ^a	548 ± 13 ^b	62 ± 3 ^a	216 ± 8 ^b	1.29 ± 0.02 ^c

Values are given as mean ± SD (n = 3). Distinct letters within the same column indicate significant differences (p < 0.05).

Table 2
Descriptive sensory attributes of brews of untreated and CDPJ-treated roasted coffee beans.

Treatment							
time (min)	Aroma	Acidity	Flavor	Body	Aftertaste	Cupper's point	Overall
0	4.33 ± 1.15 ^b	3.75 ± 1.05 ^a	4.21 ± 2.33 ^a	5.00 ± 1.65 ^a	4.00 ± 2.52 ^b	−0.50 ± 2.73 ^a	60.58 ± 6.68 ^a
15	5.91 ± 1.92 ^a	4.41 ± 1.44 ^a	3.83 ± 1.46 ^a	4.25 ± 1.62 ^a	4.08 ± 1.37 ^b	0.91 ± 2.15 ^a	63.41 ± 4.43 ^a
30	5.83 ± 1.58 ^a	4.08 ± 1.50 ^a	3.83 ± 1.40 ^a	4.66 ± 1.30 ^a	4.83 ± 1.52 ^a	0.66 ± 1.69 ^a	63.91 ± 4.41 ^a
45	5.11 ± 2.01 ^{ab}	4.50 ± 1.53 ^a	4.00 ± 1.53 ^a	5.08 ± 1.67 ^a	4.42 ± 2.75 ^{ab}	0.50 ± 2.19 ^a	63.51 ± 6.37 ^a
60	4.08 ± 1.62 ^b	3.83 ± 1.89 ^a	4.21 ± 1.95 ^a	4.91 ± 2.46 ^a	5.51 ± 2.06 ^a	−0.42 ± 3.26 ^a	61.92 ± 6.55 ^a

Values are given as mean ± SD (n = 12). Distinct letters within the same column indicate significant differences (p < 0.05).

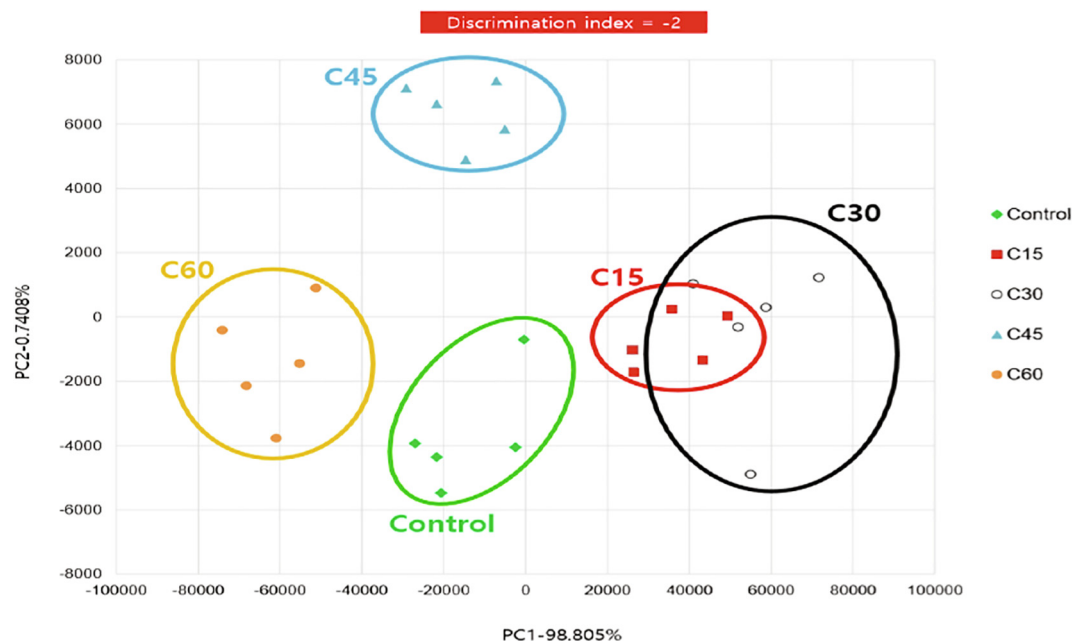


Fig. 2. Scatter plot of principal components showing the electronic-nose (e-nose) discrimination of aroma profiles of untreated and CDPJ-treated roasted coffee beans. Details of PC1 and PC2 coordinate values of samples are given in Table A2 (see supplementary file).

hydrogencarbonate instead of ammonium hydrogencarbonate as baking agent and the replacement of reducing sugars by sucrose have been shown to reduce ACR content substantially in wheat cracker. The use of asparaginase and the addition of glycine (which competes with the precursor asparagine in the Maillard reaction) have been suggested for the mitigation of ACR in bakery products (Capuano et al., 2009).

3.3. Biochemical properties

The total solid content of roasted coffee beans did not alter significantly (p > 0.05) by CDPJ treatment compared to untreated control (Table 1). The average total solid contents in the extracts of untreated and CDPJ-treated roasted coffee beans were in the range of 1.10–1.20%. On the other hand, compared to untreated control, the total phenolic content of the beans was significantly (p < 0.05)

decreased following CDPJ treatment for 45 or 60 min. The average total phenolic contents in the extracts of untreated and CDPJ-treated roasted coffee beans ranged from 1.29 to 1.40 mg/L. Since Folin-Ciocalteu test measures not only phenolic compounds but also reducing agent (Amorati & Valgimigli, 2015), the results reflect the effect of corona discharge on the reducing agent in general.

Titrateable acidity and pH values of the beans remained unaltered (p > 0.05) by CDPJ treatment for up to 60 min when compared to untreated control. The average titrateable acidity and pH values of extracts of untreated and CDPJ-treated roasted coffee beans were in the ranges of 0.281–0.297 mg/L and 5.87–5.89 mg/L, respectively (Table 1).

The color of the roasted coffee in terms of Agtron color value was 26.2. Agtron color values did not change significantly during CDPJ treatment period up to 45 min, however, further increase led to a

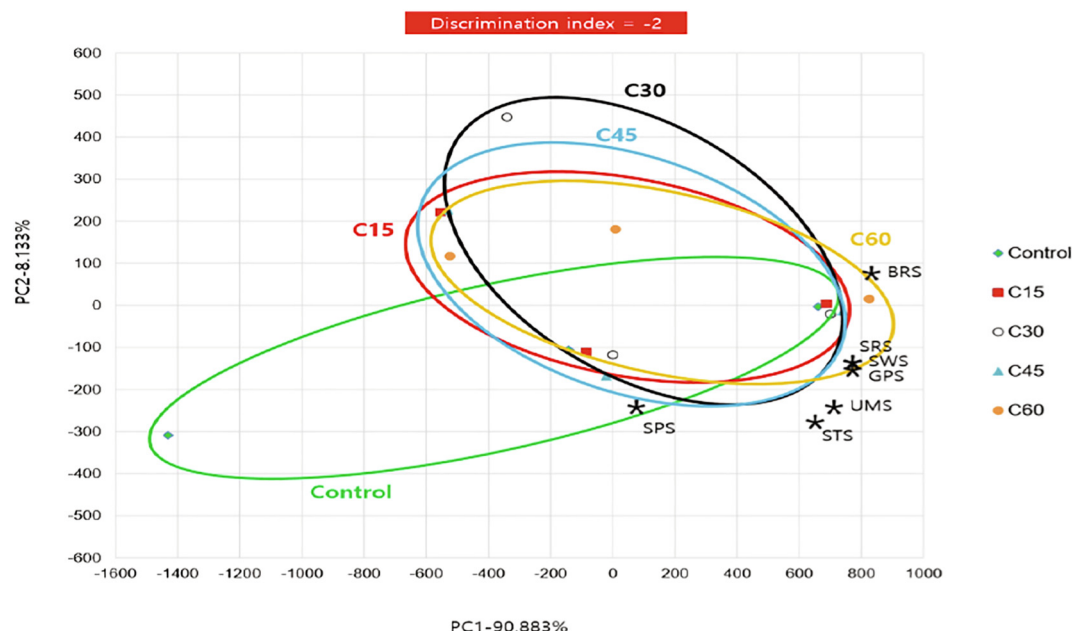


Fig. 3. Principal component analysis score and factor loading showing the electronic-tongue (e-tongue) discrimination of taste profiles of untreated and CDPJ-treated roasted coffee beans and positions of 7 sensors: SRS (sourness), GPS (metallic), STS (saltiness), UMS (umami), SPS (spiciness), SWS (sweetness) and BRS (bitterness). Details of PC1 and PC2 coordinate values of samples are given in Table A3 (see supplementary file).

significant increase implying the color became lighter with treatment time (Table 1).

Caffeine concentrations in the beans treated by CDPJ were not significantly different from that of untreated control ($p > 0.05$). The average caffeine concentrations in the extracts of untreated and CDPJ-treated roasted coffee beans ranged from 548 to 571 mg/L. Concentrations of chlorogenic acid did not alter significantly ($p > 0.05$) by CDPJ treatments up to 60 min when compared with untreated controls. The average chlorogenic acid concentrations in the extracts of untreated and CDPJ-treated roasted coffee beans were in 62–64 mg/L range.

The levels of trigonelline in the beans upon CDPJ treatment were not significantly different from that of untreated control ($p > 0.05$). The average trigonelline concentrations in the extracts of untreated and CDPJ-treated roasted coffee beans were in 216–227 mg/L range.

The LOD and LOQ values obtained for the tested components are given as Supplementary Data (excel file).

3.4. Descriptive sensory analysis

For sensory analysis of coffee, cupping or the cup test is a standard method (Ribeiro et al., 2017). It is a systematic method to assess the aroma and taste of coffee. Compared to brews of untreated roasted coffee beans, acidity, body, cupper's point, and flavor characteristics of brews of CDPJ-treated roasted coffee beans were not significantly different ($p > 0.05$) (Table 2). However, aroma and aftertaste characteristics were altered significantly ($p < 0.05$) upon CDPJ treatment. The treatment (up to 45 min) positively impacted aroma characteristics; thereafter diminished. On the other hand, aftertaste characteristic steadily improved with increasing treatment time up to 60 min. Overall, CDPJ treatment did not negatively affect sensory characteristics of roasted coffee.

3.5. Discrimination of aroma profile

The intrinsic aroma characteristics of untreated and CDPJ-treated roasted coffee bean samples were determined based on their correlation with the selected odorants which is a reflection of higher intensities of

those compounds in each particular sample than other samples. The intensities of the most discriminating aroma compounds against their retention time are indicated on a Heracles II e-nose FID chromatogram.

Discrimination of aroma characteristics was achieved by constructing principal component analysis (PCA) score using selected peaks (those with discriminating power $\geq 90\%$) which were considered to be the most important odorants. Discrimination power explains the contribution of each peak in differentiating the samples. Selected odorants were identified using information stored in the AroChemBase library of the e-nose (Table A1; see supplementary file).

Discrimination of aroma profiles of the samples is presented on the PCA score plot (Fig. 2). On the plot, samples were well-separated into distinct groups representing their treatment times except that an overlap in aroma profiles between coffee samples treated for 15 min (C15) and samples treated for 30 min (C30) was observed. This separation occurred along the first principal component (PC1), which accounted for 98.8% of the information on the variation between samples. On the other hand, the second principal component (PC2) explains only 0.7%, indicating separation of the samples based on aroma profile is heavily dependent on PC1. The treatment (up to 30 min) changed the sample location to the right on the PC1. However, further treatment (C45) shifted the location back to the position close to the control (in PC1 coordinate value) and ultimately to the left-hand side of the control (C60). It implies that the effect of longer CDPJ treatment (> 30 min) on aroma profile could be opposite to that of short treatment. This is in good agreement with the result of sensory evaluation, especially aroma quality, wherein the treatment up to 30 min increased the score of aroma characteristics significantly and further treatment offset the effect (Table 2).

3.6. Taste discrimination

All sensor responses generated for each taste (sweetness, saltiness, bitterness, sourness, umami, metallic, and spiciness) and for each sample were combined and converted into sensory scores that are used to describe the sample's unique taste (Ramamoorthy, Mohamed, & Devi, 2014). Principal component analysis score and factor loading plot revealed that the taste profiles of untreated and CDPJ-treated roasted

coffee bean samples were not distinguishable and spread widely, indicating that the differences in taste created by treatment were not significantly larger than the difference due to replication (Fig. 3). A clear overlapping of taste profiles of control group samples with CDPJ treatment group samples was observed. All the samples were not differentiated by 7 sensors including SRS (sourness), which is consistent with the fact that noticeable change in acidity was not observed in sensory evaluation (Table 2). The PCA result by electronic tongue was very contrasting with that by electronic nose which was clearly distinguished by treatment.

4. Conclusions

The initial concentrations of BaP and ACR in dark-roasted coffee beans were found to be 1.27 µg/kg and 35.4 µg/kg, respectively. The levels of BaP and ACR in the beans were decreased by CDPJ treatment; BaP by 53.6% and ACR by 32.0% following the treatment for 60 min. Discrimination of aroma profiles on PCA plots indicated that groups (untreated and CDPJ-treated) were well-separated although an overlap in aroma profiles between coffee samples treated for 15 min and samples treated for 30 min. Discrimination of taste profiles on PCA plots indicated that the groups are closely associated with each other. Sensory characteristics of roasted coffee beans were not negatively affected by CDPJ treatment.

CRediT authorship contribution statement

Taeheon Lee: Methodology, Investigation. **Hyesung Park:** Methodology, Investigation. **Pradeep Puligundla:** Writing - original draft, Writing - review & editing. **Gwi-Hee Koh:** Methodology, Investigation. **Jungro Yoon:** Conceptualization, Methodology, Writing - review & editing. **Chulkyoon Mok:** Conceptualization, Methodology.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

This study was supported by Gachon University research fund of 2018 (GCU-2018-0675) and the Ottogi Foundation, Korea.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.foodchem.2020.127117>.

References

- Amorati, R., & Valgimigli, L. (2015). Advantages and limitations of common testing methods for antioxidants. *Free Radical Research*, 49(5), 633–649. <https://doi.org/10.3109/10715762.2014.996146>.
- Arisseto, A. P., Vicente, E., Soares Ueno, M., Verdiani Tfouni, S. A., & De Figueiredo Toledo, M. C. (2011). Furan levels in coffee as influenced by species, roast degree, and brewing procedures. *Journal of Agricultural and Food Chemistry*, 59(7), 3118–3124. <https://doi.org/10.1021/jf104868g>.
- Capuano, E., Ferrigno, A., Acampa, I., Serpen, A., Açar, Ö.Ç., Gökmen, V., & Fogliano, V. (2009). Effect of flour type on Maillard reaction and acrylamide formation during toasting of bread crisp model systems and mitigation strategies. *Food Research International*, 42(9), 1295–1302. <https://doi.org/10.1016/j.foodres.2009.03.018>.
- Chung, H. W., Park, S. K., & Choi, D. (2007). Determination of acrylamide in food products. *Analytical Science & Technology*, 20(2), 164–169.
- Cosoreci, A., Moldovan, C., Raba, D. N., Popa, M. V., & Dumbrăvă, D. G. (2014). Evaluation of antioxidant capacity and total polyphenol content of some coffee. *Journal of Agroalimentary Processes and Technologies*, 20(2), 161–164.
- De Kruif, N., Schouten, T., & Van der Stegen, G. H. (1987). Rapid determination of benzo[a] pyrene in roasted coffee and coffee brew by high-performance liquid chromatography with fluorescence detection. *Journal of Agricultural and Food Chemistry*, 35(4), 545–549.
- Flambeau, K. J., & Yoon, J. (2018). Characterization of raw and roasted fully washed specialty Bourbon cultivar of *Coffea arabica* from major coffee growing areas in Rwanda. *Food Engineering Progress*, 22(2), 89–99. <https://doi.org/10.13050/foodengprog.2018.22.2.89>.
- Flambeau, K. J., Lee, W. J., & Yoon, J. (2017). Discrimination and geographical origin prediction of washed specialty Bourbon coffee from different coffee growing areas in Rwanda by using electronic nose and electronic tongue. *Food Science and Biotechnology*, 26(5), 1245–1254. <https://doi.org/10.1007/s10068-017-0168-1>.
- Lee, T., Puligundla, P., & Mok, C. (2019). Degradation of benzo[a]pyrene in roasted oil seeds by corona discharge plasma jet. *Food Engineering Progress*, 23(3), 171–177. <https://doi.org/10.13050/foodengprog.2019.23.3.171>.
- Matthäus, B., & Haase, N. U. (2016). Acrylamide in ready-to-eat foods. *Food Hygiene and Toxicology in Ready-to-Eat Foods*, 353–382. <https://doi.org/10.1016/b978-0-12-801916-0.00020-0>.
- Mojska, H., & Gielecinska, I. (2013). Studies of acrylamide level in coffee and coffee substitutes: Influence of raw material and manufacturing conditions. *Roczniki Państwowego Zakładu Higieny*, 64(3), 173–181.
- Mottram, D. S., Wedzicha, B. L., & Dodson, A. T. (2002). Acrylamide is formed in the Maillard reaction. *Nature*, 419, 448–449. <https://doi.org/10.1038/419448a>.
- Puligundla, P., Kim, J. W., & Mok, C. (2017). Effect of corona discharge plasma jet treatment on decontamination and sprouting of rapeseed (*Brassica napus* L.) seeds. *Food Control*, 71, 376–382. <https://doi.org/10.1016/j.foodcont.2016.07.021>.
- Raffan, S., & Halford, N. G. (2019). Acrylamide in food: Progress in and prospects for genetic and agronomic solutions. *Annals of Applied Biology*, 175(3), 259–281. <https://doi.org/10.1111/aab.12536>.
- Ramamoorthy, H. V., Mohamed, S. N., & Devi, D. S. (2014). E-nose and e-tongue: Applications and advances in sensor technology. *Journal of NanoScience and NanoTechnology*, 2, 370–376.
- Ribeiro, L. S., Ribeiro, D. E., Evangelista, S. R., Miguel, M. G. D. C. P., Pinheiro, A. C. M., Borém, F. M., & Schwan, R. F. (2017). Controlled fermentation of semi-dry coffee (*Coffea arabica*) using starter cultures: A sensory perspective. *LWT-Food Science and Technology*, 82, 32–38. <https://doi.org/10.1016/j.lwt.2017.04.008>.
- Santos, J. R., Lopo, M., Rangel, A. O., & Lopes, J. A. (2016). Exploiting near infrared spectroscopy as an analytical tool for on-line monitoring of acidity during coffee roasting. *Food Control*, 60, 408–415. <https://doi.org/10.1016/j.foodcont.2015.08.007>.
- SCAA. (2015). <http://www.scaa.org/PDF/resources/cupping-protocols.pdf>.
- Tfouni, S. A., Serrate, C. S., Carreiro, L. B., Camargo, M. C., Teles, C. R., Cipolli, K. M., & Furlani, R. P. (2012). Effect of roasting on chlorogenic acids, caffeine and polycyclic aromatic hydrocarbons levels in two *Coffea* cultivars: *Coffea arabica* cv. Catuai Amarelo IAC-62 and *Coffea canephora* cv. Apoatã IAC-2258. *International Journal of Food Science & Technology*, 47(2), 406–415. <https://doi.org/10.1111/j.1365-2621.2011.02854.x>.
- Tfouni, S. A., Serrate, C. S., Leme, F. M., Camargo, M. C., Teles, C. R., Cipolli, K. M., & Furlani, R. P. (2013). Polycyclic aromatic hydrocarbons in coffee brew: Influence of roasting and brewing procedures in two *Coffea* cultivars. *LWT-Food Science and Technology*, 50(2), 526–530. <https://doi.org/10.1016/j.lwt.2012.08.015>.
- Vass, M., Amrein, T. M., Schonbachler, B., Escher, F., & Amado, R. (2004). Ways to reduce the acrylamide formation in cracker products. *Czech Journal of Food Sciences*, 22(Spl. Issue), 19–21.
- Wang, H., Feng, F., Guo, Y., Shuang, S., & Choi, M. M. (2013). HPLC-UV quantitative analysis of acrylamide in baked and deep-fried Chinese foods. *Journal of Food Composition and Analysis*, 31(1), 7–11. <https://doi.org/10.1016/j.jfca.2013.02.006>.
- Zhao, M., Wang, P., Li, D., Shang, J., Hu, X., & Chen, F. (2017). Protection against neo-formed contaminants (NFCs)-induced toxicity by phytochemicals. *Food and Chemical Toxicology*, 108, 392–406. <https://doi.org/10.1016/j.fct.2017.01.023>.