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Puffing, a novel coffee bean processing technique for the enhancement of extract yield and antioxidant capacity

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ABSTRACT

Puffing of coffee beans, which induces heat- and pressure-derived physicochemical changes, was applied as an alternative to roasting. Roasted or puffed coffee beans with equivalent lightness values were compared. The moisture content was higher while the crude fat and protein compositions were lower in puffed beans than in roasted beans. The pH was lower and the acid content was higher in puffed beans than in roasted beans. The roasted beans exhibited greater specific volumes, while the puffed beans displayed greater extraction yields. The trigonelline and total phenolic contents were greater in puffed beans than in roasted beans resulting in an enhanced antioxidant capacity. Sensory evaluation of roasted and puffed coffee bean brews revealed that puffing did not affect the flavor or overall acceptance. The current study provides evidence that puffing is an alternative to roasting coffee beans with various benefits.

1. Introduction

Coffee, an extracted beverage of roasted green beans (the seeds of coffee trees), is characterized by harmonious flavors and tastes of bitterness, sourness, nuttiness, and astringency, and its consumption is continuously growing worldwide (Butt & Sultan, 2011). It has been reported that coffee contains caffeine, chlorogenic acid, trigonelline, and sugars, which affect its flavor or 'aroma' (Franca, Mendonça, & Oliveira, 2005). The compositional characteristics of green coffee beans are primarily determined by the coffee species, of which the three major species are *Coffea arabica* (Arabica), *Coffea canephora* (Robusta), and *Coffea liberica* (Liberian). Of these, Arabica cultivars grown in Colombia, Ethiopia, Tanzania, Kenya, and Brazil account for 75% of coffee production (Butt & Sultan, 2011). With its lower bitterness and milder aroma, Arabica coffee is generally higher in quality and price than the other two species (Ky et al., 2001). Robusta, predominantly cultivated in Vietnam, occupies another 22–23% of the coffee market. Liberian specialties are produced in Vietnam, India, Thailand, Brazil, and the Ivory Coast, and account for 2–3% of coffee consumption (Kim et al., 2007).

In addition to the compositional characteristics of the coffee species, roasting - the initial processing of the green beans - is also considered to be a major factor determining coffee quality. During heat-applied roasting, physical and chemical changes in the coffee beans confer aroma and taste to the product. Time and temperature are the main factors affecting the quality of roasted beans; as these increase, the sourness decreases and bitterness reciprocally increases. The roasting process is known to initiate chemical reactions including, but not limited to, the Maillard and Strecker reactions, producing brown pigments from monosaccharides. Roasting also affects the quality of coffee by promoting the degradation of proteins, polysaccharides, trigonelline (an alkaloid), and chlorogenic acid (an organic acid) (Franca et al., 2005).

Puffing is the process of suddenly reducing pressure at high pressure and temperature, thus reducing the moisture and increasing the specific volume of a food matrix. Puffing is generally categorized into either the atmospheric-pressure method or the pressure-drop method (Kim et al., 2008). Sand puffing, air puffing, oil puffing, and roller puffing are typical examples of the former, whereas gun puffing is an example of the latter (Chandrasekhar & Chattopadhyay, 1989). During the puffing process, the food matrix increases with the expansion of volume, resulting in a porous texture. In addition to physical alterations, puffing also causes chemical changes: proteins are denatured, resulting in the inactivation of enzymes; starches are gelatinized; and sugars undergo the Maillard reaction (An et al., 2011).

Since Arabica cultivar is commercially favored in spite of higher price, process developments for lower-grade cultivars were attempted for the improvement. In the current study, the puffing method was applied to coffee production with the relatively low-grade Robusta cultivar for the purpose of comparative analysis with the conventional roasting process.

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Table 1
Lightness (L values) and proximate compositions of ground green (raw), roasted, and puffed beans. R9, R11, and R13 represent coffee beans roasted for 9, 11, and 13 min, respectively. P7, P8, P9, and P10 represent beans puffed at 7, 8, 9, and 10 kg_f/cm^2, respectively.

Processing	L value	Proximate compositions (%, w/w)			
		Moisture	Ash	Crude fat	Crude protein
Green	57.72 ± 0.7[a*]	11.8 ± 0.4[a]	3.2 ± 0.1[e]	7.2 ± 0.6 c[d]	15.6 ± 0.6[d]
R9	24.17 ± 0.1[d]	2.6 ± 0.1[d]	3.9 ± 0.1[d]	8.2 ± 1.8 c[d]	17.4 ± 1.8[bc]
R11	11.00 ± 0.3[f]	2.4 ± 0.3[d]	4.9 ± 0.1[ab]	10.2 ± 1.2[b]	18.1 ± 0.6[ab]
R13	4.23 ± 0.1 g	2.0 ± 0.1[e]	5.0 ± 0.2[a]	13.4 ± 0.2[a]	18.4 ± 0.4[a]
P7	26.82 ± 0.2[b]	4.9 ± 0.0[bc]	4.7 ± 0.0[b]	6.2 ± 0.2[e]	16.2 ± 0.3[d]
P8	25.16 ± 0.3[c]	5.2 ± 0.1[b]	4.3 ± 0.3[c]	7.3 ± 0.8[de]	15.9 ± 0.0[d]
P9	13.46 ± 0.4[e]	5.0 ± 0.0[bc]	4.1 ± 0.3[c]	8.3 ± 1.8 c[d]	16.6 ± 0.4 c[d]
P10	10.75 ± 0.3[f]	4.8 ± 0.1[c]	3.7 ± 0.1[d]	9.5 ± 0.5[bc]	16.2 ± 0.8[d]

* Values with the same superscript in the same column are not significantly different at $p < 0.05$.

Table 2
pH and acidity contents of hot water extracts of ground green (raw), roasted, and puffed beans. R9, R11, and R13 represent coffee beans roasted for 9, 11, and 13 min, respectively. P7, P8, P9, and P10 represent beans puffed at 7, 8, 9, and 10 kg_f/cm^2, respectively.

Processing	pH	Acid content (mL)*
Green	6.30 ± 0.01[a**]	0.63 ± 0.03[bc]
R9	5.25 ± 0.22 c[d]	0.56 ± 0.05[d]
R11	5.36 ± 0.20[c]	0.51 ± 0.03[e]
R13	5.53 ± 0.18[b]	0.43 ± 0.02[f]
P7	5.11 ± 0.22[d]	0.61 ± 0.03[c]
P8	5.11 ± 0.23[d]	0.65 ± 0.03[b]
P9	4.94 ± 0.24[e]	0.70 ± 0.04[a]
P10	4.91 ± 0.22[e]	0.71 ± 0.03[a]

* Acid content was titrated in a 10X diluted solution with 0.1 M NaOH and expressed as the equivalent volume.

** Values with the same superscript in the same column are not significantly different at $p < 0.05$.

2. Materials and methods

2.1. Chemicals

HPLC-grade acetonitrile and water were purchased from Fisher Scientific (Pittsburgh, PA, USA). Caffeine, trigonelline hydrochloride, chlorogenic acid, Folin-Ciocalteu's phenol reagent, 2,2′-azino-bis (3-ethylbenzthiazoline-6-sulfonic acid) diammonium salt (ABTS), 2, 2′-azobis (2-amidino-propane) dihydrochloride (AAPH), 1,1-diphenyl-2-picrylhydrazyl (DPPH), gallic acid, catechin, and ascorbic acid were purchased from Sigma-Aldrich Co. (St. Louis, MO, USA).

2.2. Thermal treatments and extraction of coffee

Green Robusta coffee beans (*Coffea canephora*, Vietnamese Robusta) were purchased from a local market in Suwon, Korea. Roasting and puffing were conducted as described for cacao beans in a previous report (Hu, Kim, & Baik, 2016). In brief, approximately 50 g of coffee beans were roasted at 235 °C for 9, 11, or 13 min in a sample roaster type RE1 (Probat-Werke, Reinbek, Germany). The roasted beans were designated according to roasting time as R9, R11, and R13, respectively. Alternatively, puffing was performed at 7, 8, 9, and 10 kg_f/cm^2 (P7, P8, P9, and P10, respectively) for approximately 200 g of coffee beans with a traditional gun puffing machine. Following roasting and puffing, all samples were cooled to room temperature and ground in a grinder (Model 600N, Tiamo Feima grinder, Taipei, Taiwan) and screened through a 16-mesh sieve. Aliquots were stored at −20 °C for further physicochemical analyzes. For all analyses except the sensory test, extracts were prepared by solid–liquid extraction. Briefly, 1 g of each ground coffee sample was extracted with 100 mL distilled water at 90 °C by standing at room temperature for 20 min, followed by filtration through Whatman No. 2 filter paper.

2.3. Lightness and proximate analysis

The lightness (L value) of the ground beans prepared by the aforementioned methods was assessed with a colorimeter (Model Color TC 801, Color Techno System Co., Ltd, Tokyo, Japan). The moisture, ash, crude fat, and protein contents were determined by official AOAC methods (AOAC, 1995). Briefly, the moisture content was measured by weight loss following oven drying at 105 °C for 3 h. The ash content was calculated from the weight of the sample after it was burned at 600 °C overnight. The crude fat content was determined by the Soxhlet extraction method. The nitrogen (N_2) content was determined by the Kjeldahl method, and the crude protein content was calculated as the nitrogen content multiplied by 6.25. The pH of each coffee extract was measured with a pH meter (Model Orion 710 A+, Thermo Fisher Scientific, Beverly, MA, USA). The acid contents of 10X diluted coffee extracts in distilled water were titrated with 0.1 M NaOH in the presence of phenolphthalein as an indicator.

2.4. Extraction yield and specific volume

For the measurement of extraction yield, 10 mL of filtered extract was transferred to a tared aluminum dish, dried at 105 °C to a constant weight, cooled in a desiccator, and weighed. The extraction yield was expressed as a percentage, as follows:

$$\text{Extraction yield (\%)} = \frac{\text{weight of solid in extract (g)}}{\text{weight of sample (g)}} \times 100 \quad (1)$$

The specific volume, a measurement of increased volumes in puffed food materials (Xie, Huff, Hsieh, & Mustapha, 2008), was quantified as the volume of non-ground coffee sample in a graduated cylinder (100 mL) divided by weight. The specific formula follows:

$$\text{Specific volume (cc/g)} = \frac{\text{volume of graduated cylinder (cc)}}{\text{weight of sample (g)}} \quad (2)$$

2.5. Caffeine, chlorogenic acid and trigonelline analyses

The caffeine, chlorogenic acid, and trigonelline in each coffee extract were qualitatively and quantitatively analyzed with an HPLC system (LC-20AD, Shimadzu, Kyoto, Japan) equipped with a YMC-PACK ODS C18 column (5 × 4.6 × 250 mm, YMC-Gel Company, Tokyo, Japan) and a photodiode array detector (SPD-20A, Shimadzu, Kyoto, Japan). Coffee extracts were 20X diluted in distilled water, filtered through a 0.45-μm membrane filter, and injected at a volume of 20 μL with the flow rate set at 1.0 mL/min. The binary gradient elution system consisted of 0.1% formic acid in double-distilled water (solvent A) and acetonitrile (solvent B), with separation achieved through the following gradient (A/B): 92/8 at 0 min, 89/11 at 4 min, 87/13 at 20 min, 80/20 at 27.5 min, 40/60 at 50 min, 92/8 at 52 min, and 92/8 at 60 min.