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Qualitative properties of roasting defect beans and development of its classification methods by hyperspectral imaging technology

Jeong-Seok Cho [a], Hyung-Jin Bae [b], Byoung-Kwan Cho [b], Kwang-Deog Moon [a,*]

[a] Department of Food Science and Technology, Kyungpook National University, 80 Daehak-ro, Daegu 702-701, South Korea
[b] Department of Biosystems Machinery Engineering, College of Agricultural and Life Science, Chungnam National University, 99 Daehak-ro, Yuseong-gu, Daejeon 305-764, South Korea

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ABSTRACT

Qualitative properties of roasting defect coffee beans and their classification methods were studied using hyperspectral imaging (HSI). The roasting defect beans were divided into 5 groups: medium roasting (Cont), under developed (RD-1), over roasting (RD-2), interior under developed (RD-3), and interior scorching (RD-4). The following qualitative properties were assayed: browning index (BI), moisture content (MC), chlorogenic acid (CA), trigonelline (TG), and caffeine (CF) content. Their HSI spectra (1000–1700 nm) were also analysed to develop the classification methods of roasting defect beans. RD-2 showed the highest BI and the lowest MC, CA, and TG content. The accuracy of classification model of partial least-squares discriminant was 86.2%. The most powerful wavelength to classify the defective beans was approximately 1420 nm (related to O—H bond). The HSI reflectance values at 1420 nm showed similar tendency with MC, enabling the use of this technology to classify the roasting defect beans.

1. Introduction

Coffee is the most popular beverage in the world due to its unique flavour and functional properties. In recent years, the coffee cup quality has been closely related to the term "specialty coffee" which involves a number of components and production systems to produce high quality coffee (Piccino, Boulanger, Descroix, & Shum Cheong Sing, 2014). Roasting is an essential step for enhancing aroma, flavour, and colour of the coffee beans to produce high quality beverages (Somporn, Kamtuo, Theerakulpisut, & Siriamornpun, 2011). Furthermore, the roasting process is able to influence the contents of phenolic compounds and bioactive capacity linked with melanoidin formation (Fernando & Manuel, 2010). Melanoidins are defined as brown-coloured products of the Maillard reaction, formed during the roasting process (Ludwig et al., 2012). Many studies were performed regarding the relationship between roasting degree and qualitative properties (Lee, Kim, Kim, Lee, & Yeum, 2013), chlorogenic acid levels (Mills, Oruna-Concha, Mottram, Gibson, & Spencer, 2013), and bioactive capacity (Vignoli, Bassoli, & Benassi, 2011) of coffee beans.

The coffee roasting degree is controlled by roasting time and temperature (Vignoli, Viegas, Bassoli, & Benassi, 2014). Conventional roasting process is usually performed at temperatures ranging from 200 °C to 300 °C for 12–20 min (Mendes, Menezes, Aparecida, & Silva, 2001). Roasting defect beans are the result of operating errors, such as over roasting, that actually damages the bean by effects like scorching, baking, or bean cracks (Boot, 2005). There are some types of roasting defect beans as follows: under developed defect beans have lower roasting degrees than normal roasted beans; over roasting defect beans have higher roasting degrees than normal roasted beans; interior under developed defect beans have lower roasting degrees only inside or center cut than outside of beans; interior scorching defect beans mean that center cut is more roasted than outside of beans. These roasting defect beans indicate problems in the roasting process, resulting in changes in functional and qualitative properties of the beans (Yang et al., 2016). Moreover, it can change the roasting degrees of coffee beans produced by same condition due to its specific roasting degrees. Therefore, it is very important to classify the roasting defect beans among standard roasting beans for producing high quality coffee beans roasted under same conditions. It also can meet the various preferences in accordance with various roasting degrees, required by consumers.

Hyperspectral imaging (HSI), a technique combining the principles of spectroscopy and imaging, has been applied to detect many defects in food products (López-Maestresalas et al., 2016). Moreover, it can be valuable for investigating the local distribution of components, and for monitoring particular chemicals using near-infrared rays (Huang, Min, Duan, Wu, & Li, 2014). Several studies

* Corresponding author.
E-mail address: kdmoon@knu.ac.kr (K.-D. Moon).

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in recent years have investigated the identification of qualitative properties and classification methods in various beans using HSI technology (Calvini, Ulrici, & Amigo, 2015; Kaliramesh et al., 2013; Chelladurai, Karuppiah, Jayas, Fields, & White, 2014). In the coffee industry, there are few studies focussing only on green bean defects. Calvini et al. (2015) introduced classifying the coffee species using HSI technology. Achata, Esquerre, Donnell, and Gowen (2015) studied the relationship between moisture contents and HSI reflectance parameters of instant coffee powder. However, there is no study for identifying coffee roasting degree related to roasting defect beans. Therefore, it is necessary to investigate roasting defect beans using HSI technology to produce high-quality roasted coffee beans and beverage.

The aims of this study were: (i) identifying the qualitative properties of various roasting defect beans, and (ii) development of their classification method using HSI technology by comparing their quality parameters.

2. Materials and methods

2.1. Coffee samples

Arabica green coffee beans were cultivated in India and a crop year was in 2014. They were then roasted in batch sizes of 1.5 kg using a drum roaster (Easyster, Korea). Five roasting conditions were used to induction of different type defect, as shown in Table 1. To analyse the qualitative properties of coffee beans, roasted samples were ground using a coffee grinder (Vario-W, Baratza, Taiwan), then passed through a sieve of 0.92 mm aperture. Ground coffee (8.25 g) was extracted with 150 mL of hot water (92 °C), and filtered using filter paper (No. 4, Whatman, Tokyo, Japan). The filtrates (coffee brew) were used for browning index (BI) and high performance liquid chromatography (HPLC) experiments.

2.2. Qualitative properties of roasting defect beans

2.2.1. Measurement of moisture content (MC)

MC of the roasting defect coffee beans were analysed using infrared moisture analyser (FD-720, Kett, Tokyo, Japan). Two grams of coffee powder was placed on an aluminium dish, and the instrument calculated moisture content of the coffee powder automatically, by increasing the temperature to 105 °C. The moisture contents were expressed as percentages (%).

2.2.2. Measurement of browning index (BI)

BI was determined using a previously described procedure (Ludwig et al., 2012) with some modifications. Two hundred microliters of coffee brew was diluted up to 2 mL with distilled water. BI was assayed by measuring the absorbance at 420 nm, using a UV–vis spectrophotometer (Evolution 201, Thermo Fisher Scientific Inc., Madison, WI, USA).

2.2.3. Measurement of chlorogenic acid (CA), trigonelline (TG), and caffeine (CF) content

The CA, TG, and CF contents were measured using HPLC, with some modifications in a previously described method (Kim & Park, 2006). Briefly, the coffee extracts were filtered through a 0.45-μm membrane filter, and the filtrates were analysed by HPLC (Prominence, Shimadzu, Kyoto, Japan), with a diode array detector and C_{18} (4.6 mm × 150 mm × 5 μm) column. The mobile phase comprised of 10 mM HCl and methanol (9:1) at a flow rate of 1 mL/min. The column temperature was 40 °C, and the injection volume was 10 μL. The wavelengths for detection were 327 mm (CA), 267 nm (TG), and 275 nm (CF).

2.3. Hyperspectral imaging (HSI) technology

2.3.1. Hyperspectral imaging data acquisition

A shortwave infrared (SWIR) HSI system was used to acquire the hyperspectral images of roasting defect coffee beans. The system comprised of a line scan image spectrograph (SWIR, Headwall Photonics, Fitchburg MA, USA) with a spectral range of 1000–1700 nm, a high performance camera (MCT, Headwall Photonics, Fitchburg, MA, USA), tungsten halogen lamp (100 W), and Microsoft Windows operating system to control and operate the HSI system. The HSI spectra of total 200 samples (40 samples of each group) of roasting defect beans were analysed.

2.3.2. Data analysis

The hyperspectral images of roasting defect coffee beans were composed of background and samples. To remove the background, the region of interest (ROI) method was applied. The mean spectra of the sample portions were pre-treated by the standard normal variate (SNV) method to minimize the scattering noise (Barnes, Dhanoa, & Lister, 1989). The reflectance values from HSI data were classified using partial least-squares discriminant analysis (PLSDA). The PLSDA model was developed with the calibration data to reduce the overfitting using 70% of total samples, and 30% of total samples were used to validate the developed model. A beta coefficient was also calculated from the PLSDA model to predict the wavelengths affecting the classification of various roasting defect beans. All HSI data analyses were carried out using the MATLAB software (ver. 7.0.4, Mathworks Inc., Natick, MA, USA) with PLS toolbox.

2.4. Statistical analysis

All the chemical analyses were conducted in triplicates, and the results were subjected to analysis of variance using the SPSS statistical package (ver. 14.0, SPSS Inc., Chicago, IL, USA). Duncan's multiple range tests were used for comparing the significant differences between samples ($P < 0.05$). Values are expressed as means ± standard deviations.

Table 1
Roasting conditions for coffee beans.

Groups[1]	Starting temperature	Development temperature[2]	Development time[3]	Total roasting time
Cont	210 °C	210 °C	1 min 20 s	10 min 20 s
RD-1	210 °C	210 °C	40 s	9 min 40 s
RD-2	210 °C	210 °C	3 min 30 s	12 min 30 s
RD-3	193 °C	193 °C	1 min 20 s	10 min 30 s
RD-4	210 °C	160 °C	4 min 40 s	13 min 40 s

[1] Cont, medium roasting; RD-1, under developed; RD-2, over roasting; RD-3, interior under developed; RD-4, interior scorching.
[2] Temperature at first crack (popping).
[3] Time from first crack (popping) to the end of roasting.