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Using hyperspectral imaging to characterize consistency of coffee brands and their respective roasting classes

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ABSTRACT

The uniqueness and consistency of commercial food and beverage brands are critically important for their marketability. Thus, it is important to develop quality control tools and measures, so that both companies and consumers can monitor whether a given food product or beverage meets certain quality expectations and/or is consistent when purchased at different times or at different locations. In this study, we characterized the consistency (levels of extractable protein and reducing sugars) of 15 brands of roasted coffee beans, which were obtained from a supermarket at two dates about six months apart. Coffee brands varied markedly in extractable protein and reducing sugar contents between dates, and also within and among roasting classes (light, medium, medium-dark, and dark roasts). We acquired hyperspectral imaging data (selected bands out of 220 narrow spectral bands from 408 nm to 1008 nm) from ground samples of the roasted coffee beans, and reflectance-based classification of roasting classes was associated with fairly low accuracy. We provide evidence that the combination of hyperspectral imaging and a general quality indicator (such as extractable protein content) can be used to monitor brand consistency and quality control. We demonstrated that a non-destructive method, potentially real-time and automated, and quantitative method can be used to monitor the consistency of a highly complex beverage product. We believe the results from this study of brand consistency are not only of relevance to the coffee industry but to a wide range of commercial food and beverage brands.

1. Introduction

Radiometric data, such as reflectance or vibrational profiles, are used as explanatory variables in two types of classifications: 1) Estimation or prediction of the concentration of particular compounds or physical traits along continuous scales. Such classifications include levels of purity of pharmaceutical samples (Amigo and Ravn, 2009; Gowen et al., 2008, 2011; Ravn et al., 2008), and food products (Huang et al., 2014; Lefcout and Kim, 2006; Park et al., 2006; Vargas et al., 2005). 2) To classify food objects with or without particular defects (Gaston et al., 2011; Heitschmidt et al., 2004; Nansen et al., 2014; Singh et al., 2009, 2010; Wang et al., 2010, 2011; Zhang et al., 2015) or food into specific classes (Barbin et al., 2012; Blasco et al., 2003; Cubero et al., 2011; Kamruzzaman et al., 2012). There are several important and comprehensive reviews of applications of hyperspectral imaging in studies of both food quality and food safety (Elmasry et al., 2012; Feng and Sun, 2012; Huang et al., 2014). Thus, there is a widespread appreciation for the potential of automated machine vision systems in food safety and quality control of food and beverage products.

Coffee is one of the most popular beverages in the world (Duarte et al., 2005) with consumption per capita of 4 kg in the US and 5 kg per capita in Europe (http://www.worldmapper.org/posters/worldmapper_1038_coffee_consumption_ver2.pdf). Moreover, it has been estimated that American consumers spend about $21 per week on coffee (http://www.statista.com/topics/1248/coffee-

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market/). Due to national and regional variations in growing conditions and cultivation of *arabica* and *robusta* coffee varieties, there is a considerable diversity in potential sources of green coffee beans. Hyperspectral imaging has been used to discriminate 33 samples of green beans of *arabica* and *robusta* with over 97% classification accuracy (Calvini et al., 2015). In addition, RGB imaging (Red, Green and Blue color) of 120 green bean samples from four color classes (whitish, green, cane green, and bluish-green) were classified with over 99% accuracy (de Oliveira et al., 2016). These studies underscore the potential for reflectance-based classification and quality assessment of coffee samples.

As part of the roasting process, green coffee beans are heated to specific temperatures for varying durations depending on the roast level. The organic compounds that result from roasting of coffee beans have been studied for over 50 years (Rhoades, 1960), and more than 850 substances have been identified from volatile fractions of roasted coffee (Franca et al., 2009; Rocha et al., 2004; Yeretzian et al., 2014). The chemical changes during the roasting process are associated with Maillard and Strecker reactions, amino acid and protein degradations, and changes to profiles of polysaccharides and trigonelline and chlorogenic acids (De Maria et al., 1996; Duarte et al., 2005; Montavon et al., 2003; van Boekel, 2006). Yeretzian et al. (2014) studied the chemical changes during 0–30 min after roasting, and it highlighted the complexity of the chemical and biochemical reactions associated with roasting of coffee beans.

Roasted coffee beans are commercialized under general roasting classes, such as light, medium, medium-dark, and dark roasts. Many supermarkets offer large bins with a wide variety of bulk roasted coffee brands within each of these roasting classes. As described by Franca et al. (2009), industry evaluation of both green and roasted coffee beans is based on reflectance and/or visual inspection. For instance, the National Coffee Association of the USA (http://www.ncausa.org/About-Coffee/Coffee-Roasts-Guide) refers to: 1) light roasts as "light brown in color", 2) medium roasts as "medium brown in color", 3) medium dark roasts as "dark in color", and 4) dark roasts as "shiny black beans".

The main purpose of this study was to investigate the consistency of samples a highly complex and valuable beverage, coffee, which is commercialized under a wide variety of brands and roasting classes. In particular, we intended to demonstrate the potential of classification of hyperspectral imaging data as a non-destructive, potentially real-time and automated (quantitative) analytical method to determine the consistency of ground coffee. We conducted extractable protein and reducing sugar content analyses of 15 coffee brands, which were acquired at two time points (30 samples). These two chemical traits were chosen as consistency indicators, as they provide broad and fairly non-specific information about the composition of food and beverages. In addition, we acquired hyperspectral imaging data (220 narrow spectral bands from 408 nm to 1008 nm) from all combinations of coffee brand and date of sampling. The specific objectives were: 1) determine the consistency of extractable protein and reducing sugar contents in commercial coffee brands at two time points, 2) compare extractable protein and reducing sugar contents across roasting classes (light, medium, medium-dark, and dark roasts), 3) use hyperspectral imaging data to classify coffee samples into existing roasting classes, and 4) provide evidence that commercial coffee brands can be classified accurately based on hyperspectral imaging data, if a quantifiable variable, such as extractable protein content, is used to divide coffee brands into discrete classes. Due to the importance of consistency of commercial brands, we believe this study is of considerable relevance to a wide range of food and beverage products.

2. Materials and methods

2.1. Coffee samples

On April 7th and October 29th, 2015, we collected samples from 15 commercial brands of coffee from a supermarket in Davis, California (30 samples in total). On both dates, we sampled the same coffees, and they represented the following roasting classes: "light roast" (1 brand), "medium roast" (7 brands), "medium-dark roast" (4 brands), and "dark roast" (3 brands). Although we did not have any means to quantify the relative differences among the blends/roasts, we used this information as a potential classifier of the coffee samples, as roasting class is important in the commercialization of brands of roasted coffee. Subsamples of 10 g roasted coffee beans were ground for 2 min with a coffee grinder (Mr Coffee, www.walmart.com), which was cleaned thoroughly between samples. Immediately after grinding, coffee samples were transferred to sealed bags and placed in a −8 °C freezer. Ground coffee samples were thawed for approximately 20 min before being subjected to hyperspectral imaging and then transferred back to a −8 °C freezer. Hyperspectral imaging was completed in about 60 min. The ground coffee samples were kept in the freezer until being subjected to analyses of extractable protein and reducing sugar content.

2.2. Measurement of extractable protein and reducing sugar content

To obtain quantitative data on the consistency, we quantified the total extractable protein and reducing sugar contents of all coffee samples. It is important to highlight that these two indicators are unlikely valid indicators of the actual quality of the coffee samples, but they provide fairly broad and non-specific information and were therefore considered valid indicators of consistency of the coffee samples. It is also important to highlight that analytical chemistry can be time consuming, expensive, and require special equipment and highly trained personnel. Thus, it is highly desirable to rely on analytical methods that are both well-described, easy and inexpensive. Even if such analytical methods are not directly linked to quality of a food or beverage product, they may be highly preferable due time constraints in large scale manufacturing, repeatability, and cost concerns. Ground roasted coffee was extracted using a hydrothermal method described previously (Conde and Mussatto, 2016). For each coffee sample, 2 g of ground roasted coffee beans were combined with 40 mL of DI water in a pressure tube (Ace Glass, Vineland, NJ). Mixtures were heated at 121 °C for 20 min in an autoclave. Mixtures were then transferred to centrifuge tubes and separated via centrifugation at 2500 × g for 10 min. Supernatants were filtered through PTFE syringe filters (0.2 μm pore size, Thermo Fisher Scientific, Waltham, MA) and stored at −20 °C until further use. The protein content in extracts was determined using the Bradford technique (Bradford, 1976). Reducing sugar content in extracts was measured using a reducing sugar assay described previously (Allison et al., 2016). Bovine serum albumin (BSA) (Thermo Fisher Scientific) and glucose were used as standards for the Bradford and reducing sugar assays, respectively. Triplicate extractable protein and reducing sugar content measurements were made on each extract. The measured extractable protein and reducing sugar concentrations in each extract were used in conjunction with the dry weight of the extracted coffee sample and the total extract volume to calculate the mass of extractable compounds per unit of dry roasted coffee mass.

Using PC-SAS 9.3 (SAS Institute, NC), we conducted pairwise *t*-test (proc ttest) of extractable protein and reducing sugar contents