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Statistical pattern recognition classification with computer vision images for assessing the furan content of fried dough pieces

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ABSTRACT

This research tested furan classification models in fried matrices based on the pattern recognition of images. Samples were fried at 150, 160, 170, 180, and 190 °C for 5, 7, 9, 11, 13, and 30 min. Furan was measured by GC–MS. Corresponding images were acquired and processed to extract 2175 chromatic and textural features. Principal component analysis was used to reduce features to 8–12 principal components. In parallel, sequential forward selection coupled with linear discriminant analysis (LDA) was the best strategy to select only 5–7 features. LDA was the best classifier with 91.39–97.60% recognizing above 113 μg/kg and 69.54–83.80% to classify images from class 1 (0–38 μg/kg) from class 2 (39–113 μg/kg). Also, support vector machine recognized 87.71–96.74% of class 3 (114–398 μg/kg) from class 4 (399–646 μg/kg). The technique may be used to detect high amount of furan in fried starchy matrices.

1. Introduction

Cooking, baking, toasting, roasting, and frying are common thermal treatments used to make tasty and nutritive foods. These treatments involve chemical changes that are promoted by reactions, such as protein denaturation, sugar caramelization, and non-enzymatic browning (NEB), that are crucial for the development of positive sensorial attributes, such as flavor, color, and texture (Wang, Zhou, Ma, Zhou, & Jiang, 2013; Martins, Jongen, & van Boekel, 2000). Unfortunately, NEB also promotes the formation of neocontaminants, such acrylamide, 5-hydroxymethylfurfural, and furan, negatively affecting the chemical safety of foods.

Furan (C_4H_4O) is a small lipophilic organic compound (MW = 68 g mol^{-1}) (Hasnip, Crews, & Castle, 2006) and a possible human carcinogen that is found in several foods processed at high temperatures, such as coffee and baby foods (Crews & Castle, 2007; Mariotti et al., 2012). For this reason, efforts have focused on understanding the mechanism of furan formation. Thermal degradation and the rearrangement of sugars were suggested as the primary sources of furan in food (Morehouse, Nyman, McNeal, Dinovi, & Perfetti, 2008). However, amino acids, polyunsaturated fatty acids, and ascorbic acid have also been implicated as critical precursors (Van Lancker, Adams, Owczarek, De Meulenaer, & De Kimpe, 2009; Vranova & Ciesarova, 2009).

Since there is no intake limit of furan, dietary exposure to furan from common foods has been previously reported. The Food and Drugs Administration of the United States of America (FDA) has estimated the average intake for United States consumers to be 0.2 μg/kg bw/d, detecting that furan in slow moisture foods ranged from <0.2 ppb (ppb) to over 170 ppb. Complementary antecedents regarding dietary exposure to furan showed the high impact of starchy foods, as presented by Mariotti et al. (2012), who reported furan exposure for different age groups in Chile, where school children (10–13 years old) were exposed to the highest levels of furan (~500 ng $kgbw^{-1}$ day^{-1}) compared to nine-month-old babies (~250 ng $kgbw^{-1}$ day^{-1}), adults (~70 ng $kgbw^{-1}$ day^{-1}), and the elderly (~100 ng $kgbw^{-1}$ day^{-1}). One of the causes of high furan exposure of school children was the high intake of frying starchy foods in their regular diets.

Sadly, misinformation, a nonexistent regulatory framework, and the high costs of the regular industrial estimation of furan content can impact incipient furan assessment in the food industry. The traditional method of determining the furan content, which is based on gas chromatography–mass spectrometry, is quite expensive and time-consuming. Moreover, equipment cost, specific reagents, and technical knowledge restrict this methodology to research centers and analytical laboratories, as furan testing is unaffordable in industry. It is paramount to develop

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non-destructive methods that are easy-to-implement in an industrial setting.

Computer vision (CV), has been applied to food quality evaluation in the last ten years; however, studies that use CV have concentrated on using or developing tailored methods based on visual features that are able to complete a specific task, such as to identify color or shapes (Mery, Pedreschi, & Soto, 2013). Accordingly, CV has been one of the most useful methodologies to evaluate the external quality of agriculture products and processing foods. The analysis of an image of a food product by computers allows for the control of processes and study of phenomena in foods (Leiva-Valenzuela & Aguilera, 2013).

Although CV techniques have been used many times in starchy food quality operations (Pedreschi, Bunger, Skurtys, Allen, & Rojas, 2012), there have been few applications in food safety systems to identify and quantify toxic compounds in easy, fast, and connected ways. Pedreschi, Kaack, and Granby (2006) implemented a CV system to evaluate the color of fried potato slices using color images to describe the NEB. CV has also been used to study the kinetics of acrylamide formation and its correlation with surface color in fried potatoes (Pedreschi, Bustos et al., 2007; Pedreschi, León et al., 2007; Pedreschi, Moyano, Kaack, & Granby, 2005). More recently, good correlations were found between the acrylamide content of fried potatoes and their color (Serpen & Gökmmen, 2009). These studies reinforce the idea that the color of foods, specifically the surface color of potato chips, is highly correlated with the acrylamide content. Interestingly, some authors have acquired potato chip reflectance images by near-infrared spectroscopy (NIR) to simultaneously estimate the content of fat, dry matter, and acrylamide in fried potato chips (Pedreschi, Segtnan, & Knutsen, 2010). Although the prediction error was fairly high, this study demonstrates the potential of using visible and near-infrared spectroscopy as screening techniques for evaluating the acrylamide content in potato chips. Since acrylamide was the first new contaminant from NEB described since 2002 in potato chips, most studies have focused on this toxic food compound.

From the point of view of CV, cooking or frying processes have been studied only according to their chromatic features, such the average intensity values of a transformed matrix CIE $L^*a^*b^*$ from red (R), green (G) and blue (B), which correlate well with the color changes that occurred. However, there are no studies able that established a relation between new contaminants and image texture changes.

Models to classify fried starchy foods according to their furan content are still nonexistent. This paper describes a first approach of this type of classification. Based on scientific evidence, it is possible to develop classification models that are based on statistical pattern recognition in fried starchy doughs according to the color and texture features of images acquired by a simple CV system. Thus, after more detailed investigations, online sorter systems should be able be used to assess the furan content that contributes to the reducing the dietary exposure of furan by integrating segregation plans before food is sold.

2. Materials and methods

A diagram of the assessment of the furan content by CV is presented in Fig. 1a. Basically, traditional Chilean fried bread (*sopaipillas*) was prepared by frying in 30 time–temperature combinations. After thermal processing, pieces were imaged, segmented, and enhanced. The chromatic and textural features were extracted, and their furan content was chemically determined to calibrate and test the ability of the models to assess furan by non-destructive CV.

2.1. Dough pieces formulation and frying

Dough formulations were prepared based on the criterion that all samples should have the same moisture content of 40 ± 0.6% before being fried, and according to the protocol described by Mariotti-Celis, Zúñiga, Cortés, and Pedreschi (2016). The dough was cut into 40-mm diameter circular pieces and the exact thickness of the resultant dough slices ranged from 2 to 2.3 mm.

The prepared wheat flour dough samples were fried at all possible combinations of the following time–temperature conditions: 5, 7, 9, 11, or 13 min and oil temperatures of 150, 160, 170, 180, or 190 °C. The samples were fried in a 20-L deep-fryer, following the procedure described by Mariotti-Celis et al. (2016). A total of 10 samples of 3.7 ± 0.03 g were placed in a basket and held in position with a wire grid to prevent floating during frying process. After that, the samples were drained over a wire screen for 5 min (Moyano & Pedreschi, 2006) and then refrigerated for 30 min. The analysis were done in triplicate.

2.2. Furan determination

The chemical reagents for furan analyses were as follows: (i) furan (Dr. Ehrenstorfer Company, Augsburg, Germany), (ii) *D*4-furan (100 μg mL^{-1}, Dr. Ehrenstorfer Company, Augsburg, Germany), (iii) methanol (HPLC-grade, Rathburn, Walkerburn, Scotland), and (iv) sodium chloride (>99%, Merck, Darmstadt, Germany). The working standards of furan and *D*4-furan (1.5 μg mL^{-1}) were prepared with 10 mL of HPLC-grade water and 150 μL of a standard solution of furan and D_4-furan.

Furan in fried samples was quantified according to the methodology described by Mariotti-Celis et al. (2016). Automated headspace sampling (Agilent Technologies, Model CTC Combi PAL) followed by gas chromatography–mass spectrometry (GC–MS) (Agilent Technologies, Model 7890A/7050, Santa Clara, Calif., U.S.A.) analysis was performed to detect furan and *D*4-furan in scan mode. Furan was quantified by using a standard addition curve.

2.3. Image processing

2.3.1. Image acquisition

Sample images were acquired using a laboratory CV system (Mery et al., 2013) under standardized conditions. Then, the images were processed using Matlab R2014a and the image processing toolbox (The Mathworks, Inc., Natick, MA, USA). First, single color images were decomposed into different color space images (León, Mery, Pedreschi, & León, 2006): (i) gray (g); (ii) red (R), green (G), and blue (B); (iii) L^* a^* b^* CIELAB coordinates (L^* indicates diffuse white or lightness, a^* indicates the position between red and green, and b^* from yellow and green); and (iv) HSV (angle Hue, Saturation and Value).

2.3.2. Segmentation

Channels a^* and b^* were used to increase the difference between the sample and background and then to segment the region of interest inside the unitary image of interest while considering the histogram threshold criteria (Otsu, 1979). Morphologic operations were implemented for the specific elimination of isolated groups of pixels. Binary masks allowed for the identification of the specific fried sample in the original image so that it could be extracted for further image processing. From each segmented image, ten intensity images were obtained for analysis, and thus, a total of 3600 images were analyzed.