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A portable computer-vision-based expert system for saffron color quality characterization

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ABSTRACT

In this work, attempts were made in order to develop and evaluate a Computer Vision System (CVS) for non-destructive characterization of saffron (*Crocus sativus* L.). Thirty-three saffron samples from different geographical regions were tested. Fourteen color features were extracted using image analysis. Principal Component Analysis (PCA) was used for saffron sample clustering and for selection of color features. Partial Least Squares (PLS), Multiple Linear Regression (MLR) and Multilayer Perceptron (MLP) neural networks were utilized to establish relationships between color features and coloring strength of saffron based on ISO 3632 standard. Experimental results showed that the optimal PCA was obtained by the first 2 PCs and with 95% total variance between the samples tested. Performance of MLP models for saffron color characterization were better than others, with high correlation coefficients of the cross validation (R^2 and RMSE values equal to 99% and 4.5, respectively) and high classification success rate of 96.67%.

1. Introduction

Saffron color is an important attribute that is widely used to evaluate its quality and is a key factor in the market acceptance of this product (Rios et al., 1996; Pham et al., 2000; Abdullaev, 2002). With respect to saffron chemistry, the compounds responsible for its color attributes are crocins ($C_{44}H_{64}O_{24}$) (Lozano et al., 2000). Saffron color quality can be influenced by the geographical location of production, harvesting conditions, drying procedures, storage conditions and blending with other non-colored parts of the plant, generally stalks as well as other adulterant materials (Bolandi and Ghoddusi, 2006; Del Campo et al., 2010a; Maghsoodi et al., 2012). For saffron color quality evaluation, as explained in a previous study (Kiani et al., 2016a), conventional quality analysis techniques such as chromatography, spectroscopy and chemical analysis suffer from several drawbacks including high cost and their off-line nature. Other techniques such as electronic nose (e-nose) and electronic tongue (e-tongue) cannot track the color features of food materials such as saffron. Therefore, it was decided to develop and evaluate a computer vision system complemented with suitable multivariate data analysis for saffron color quality assessment to be coupled with other artificial senses such as e-nose and e-tongue as a fusion technique (Kiani et al., 2016b,c). In general, computer vision system (CVS) is well known as the integrated use of devices for non-contact optical sensing, computing and decision making to receive and interpret real images automatically (a digital camera, standard lighting system, and software for image processing and analysis) (Wu and Sun, 2013; Kiani and Minaei, 2016). Quantitative color information is extracted from digital images using image processing techniques and analyzed for rapid, on-line and non-destructive color measurement. Many studies have demonstrated the capability and potential usage of CVS for authentication of foods, fruits, and vegetables by using visual attributes such as shape, size, color, and texture. As an example, this system has been applied for the analysis of bananas (Mendoza and Aguilera, 2004), beef (Larrain et al., 2008), fish (Yagiz et al., 2009; Bahrami et al., 2015), orange juice (Fernandez-Vazquez et al., 2011), potato chips (Pedreschi et al., 2011), honey (Shafiee et al., 2014), coffee beans (Oliveira et al., 2016), and many other products as reported by Sliwinska et al. (2014), and Chen et al. (2015). No previous study on the use of CVS has been reported for the characterization of saffron color quality. Thus, the main aim of this work was to develop and evaluate an expert system based on CVS for color-based saffron quality characterization (prediction of the amount of saffron color strength and therefore its quality grade based on ISO 3632 (ISO/TS 3632, 2010)).

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2. Materials and methods

2.1. Saffron samples and chemical

Thirty-three saffron samples of three years of production from prominent saffron producing regions of Iran were procured directly from producers with a guarantee of origin and freedom from adulteration. These included Kashmar (S1), Taybad (S2 & S24), Shahrekord (S3, S4 & S14), Qhayen (S5, S6, S10, S27 & S32), Kermanshah-Kangavar (S7, S12 & S26), Esfahan-Tiran (S8, S9 & S22), Esfahan-Golpaygan (S11 & S18-S21), Sabzevar (S13 & S30), Tabriz-Varzeghan (S15 & S33), Neyshabur (S16 & S25), Estahban (S17), Ardabil-Namin (S23), Boonal (S28), Torbat Heydariyeh (S29), and Bakharz (S31) regions. The samples had been dried at room temperature in ventilated conditions and were refrigerated at 4 °C before the experiments. One gram of the dried stigmas of each sample was taken for image analysis. Pure crocins were purchased from Sigma–Aldrich Chemie GmbH (17304-1G, with 99% purity).

2.2. UV–vis spectrophotometry measurement and analysis

Spectral characteristics of aqueous saffron extract were monitored by scanning from 200 to 700 nm using a Cary 6o UV- Vis spectrophotometer (Agilent Technologies, Inc. USA) with Cary WinUV software. Saffron samples were ground to make a fine powder before the experiment. One gram of saffron was dissolved in 100 mL distilled water using magnetic shaker at 50 °C for 1 h. Two hundred micro liters (200 μL) of this sample was taken and the final volume made to 4000 μL (0.5 g/L). This sample was then diluted 10 times and submitted to the spectrophotometer analyzer. The UV maximum absorbance for the prepared sample in the 1 cm quartz cell and maximum wavelength (about 440 nm) indicates the color strength using Eq. (1) corresponding to the amount of crocins compounds. Also, a crocins calibration curve was developed using spectroscopic analysis of ten different concentrations of pure crocines solutions (5–50 mg/L) (17304-1G) to determine the amount of crocins compounds. This method is recommended by the International Standardization Organization (ISO) for saffron quality characterization (ISO/TS 3632, 2010).

$$E_{1cm}^{1\%}440nm = \frac{A*100}{m}\cdot\frac{100}{100-h} \quad (1)$$

Where $E_{1cm}^{1\%}440nm$ Color strength, A: the absorbance at 440 nm (maximum absorbance of crocins), m: mass of the saffron sample, in grams, and h: moisture and volatile content of the sample, expressed as a mass fraction.

Moisture and volatile matter contents were identified by using powdered saffron stigmas. After weighing, the powdered samples were placed uncovered in an oven set at 75 °C for 48 h. The moisture and volatile matter contents are expressed as a percentage of the initial sample using the following relationship: (initial mass- constant mass)/ initial mass)* 100. Standard ISO3632 specifies the saffron color quality in four classes based on $E_{1cm}^{1\%}440nm$ value. The higher number of $E_{1cm}^{1\%}440nm$ indicates the higher color quality of saffron and vice versa. It has been presented from quality grade (QG) 1–4 as given in Table 1.

Table 1
Color quality of saffron based on ISO 3632.

	QG			
	QG 1	QG 2	QG 3	QG 4
$E_{1cm}^{1\%}440nm$	190 & Higher	150–190	100–150	80–100

2.3. CVS structure

The computer vision system consists of four main parts as follows:

- A dark chamber having internal surfaces covered with dark sheets to prevent reflection and eliminate interference from outside light.
- A CCD camera (Model HV-8081A, HIVISION) with 1/3" image sensor, 640 × 480 resolution, and equipped with manual gain control. The camera was installed in the chamber 16 cm above the sample plane.
- An appropriate lighting system with LED lamps and optical filter (30 LED lamps in a 47-cm long strip, 12 cm above the sample plane which, after filtering, give good illumination and homogenous light intensity over the sample).
- A laptop computer equipped with MATLAB 7.14.0 software (The Math Works Inc., Natick, MA, USA, R2012a). A program written in MATLAB software was developed to acquire, analyze and process the captured images.

The saffron sample was located against the center of the background (Fig. 1). Images were taken with the maximum resolution of the camera, and were saved in RGB format.

2.4. Image processing

The image processing operation includes two steps, namely, pre-processing and processing.

Pre-processing: The image pre-processing steps are presented in Fig. 2. After image acquisition and storage (Fig. 2a), image cropping was performed to extract image sample from each image (Fig. 2b), smoothing method (10*10 neighborhood averaging) was applied to remove voids (Fig. 2c) and the resulting image was used for color feature extraction.

Processing: The RGB values of the processed cropped images were calculated by averaging RGB values of all pixels. Linear color transformations of RGB color space were performed to obtain three other color spaces, namely, HSV, YIQ, and YCbCr. Digital images with RGB format are affected by several parameters such as lighting and digital camera parameters and direct conversion from RGB to the CIE L*a*b* color space is not possible (Oliveira et al., 2016). Thus, it was decided to develop a color space transformation model based on Leon et al. (2006) for RGB conversion to CIE L*a*b*. Methods of color space conversion to HSV, YIQ, YCbCr and CIE L*a*b* are described comprehensively in the literature (Sangwine and Horne, 1998). Finally, 14 color features (Table 2) were organized in a 14*495 rectangular matrix as a raw database (14 features *33 saffron types * 5 image samples of each type and 3 repetitions (after each captured sample was shaken)).

2.5. Data analysis

The color features were fed to pattern recognition algorithm to identify the color differences of the saffron samples. Principal component analysis (PCA) as unsupervised and partial least squares (PLS), multiple linear regression (MLR) and multilayer perceptron (MLP) neural networks as supervised methods were utilized for this purpose. PCA is a data projection method that is helpful in sample clustering, feature selection and dimensionality reduction (Haddi et al., 2011; Li et al., 2012). PLS, a fixed linear regression technique, is the "gold standard" in chemometrics due to its ability to handle collinear data and to reduce the number of required calibration samples (Patel, 2014). MLR was utilized in compare with PLS model. These two models were utilized for calculating the values of the regression coefficients of the color features and minimizing the sum of squared deviations (between the predicted $E_{1cm}^{1\%}440nm$ and the actual measured $E_{1cm}^{1\%}440nm$). More details about these techniques are discussed by Scott et al. (2007). Also, the MLP model with input, output, and hidden layers was utilized for