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Fusion of dielectric spectroscopy and computer vision for quality characterization of olive oil during storage

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ABSTRACT

Oxidation level and quality characteristics of olive oil require monitoring during storage to ensure that their amounts are maintained in the lawful thresholds. It is especially important for licensing their commercialization as high-value virgin olive oils. The present research proposes a novel approach based on the fusion of dielectric spectroscopy and computer vision for the characterization of olive oil quality indices during storage in order to reduce the time of analysis, reagent consumption, manpower and high-cost equipment. Colour features in RGB, HSV and $L^*a^*b^*$ spaces were extracted as well as dielectric features in the frequency range of 40 kHz to 20 MHz for each olive oil sample. After data pre-processing, classification and prediction models were developed and compared. Several machine learning techniques were investigated for storage time classification and quality indices prediction including artificial neural network (ANN), support vector machine (SVM), Bayesian network (BN) and multiple linear regression (MLR). The best result in the classification of olive oils during the storage period was obtained by BN technique with 100% accuracy. Among predictive models, the SVM with RBF kernel had the best results (R = 0.969, 0.988 and 0.976) for prediction of peroxide value (PV), UV absorbance at 232 nm (K_{232}) and chlorophyll, respectively. Also, the SVM with normalized polynomial kernel had the best results (R = 0.989, 0.976, 0.969 and 0.969) for prediction of p-Anisidine value (AV), total oxidation value (TOTOX), UV absorbance at 268 nm (K_{268}) and carotenoid, respectively. The ANN with 40-2-1 topology gave the best result (R = 0.977) for modelling free acidity (FA). Results of this research can be utilized for developing an efficient and reliable system for olive oil quality evaluation and monitoring by industry.

1. Introduction

Lipid oxidation is one of the main aspects that leads to destruction during the storage and processing of oils, edible fats and fat-containing products (Keramat et al., 2016). Quality parameters of impacting suitability for consumption such as colour, flavour, aroma and nutritive value change in the oxidation process of fats and oils (Nogala-Kalucka et al., 2005).

In recent years olive oil usage has been increasing because of its positive health effects that are related to its balanced unsaturated fatty acid content, high oxidative stability and the existence of other functional compounds such as phenolics, tocopherols and chlorophyll (Temime et al., 2008). Olive oil in spite of high stability is also prone to suffer from oxidative processes such as enzymatic oxidation (that occurs during the technological extraction process when the oil is in the fruit), photo-oxidation (that occurs while the oil is exposed to light) and auto-oxidation (that occurs while the oil is in contact with oxygen during processing and storage) (Lerma-García et al., 2009; Uncu and Ozen, 2015). Allylic hydroperoxides are primary products in lipid oxidation, in which the double bonds remain but in the fatty acid have altered the position and/or configuration from their original form (Mahesar et al., 2010).

The large increase in the need for high-quality olive oil during the recent years is not only related to its characteristics and sensory attributes but also to its potential health benefits (Cayuela Sánchez et al., 2013). For quality assessment and grade differentiation, reducing the possibility of incorrect or abusive labelling of virgin olive oil (VOO) has presented 26 physicochemical and organoleptic parameters (Garcia et al., 2013; Lerma-García et al., 2009). In addition to olive cultivar, harvesting, edapho-climatic conditions and technological procedures, physicochemical characteristics of olive oil is also significantly affected by the type of packing material, storage conditions, temperature, exposition to air and/or to light (Abbadi et al., 2014; Caponio et al., 2013; Rodrigues et al., 2016; Valli et al., 2015). Indeed, the amount of olive

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oils quality parameters, such as UV absorbance at 232 nm (K_{232}) and 268 nm (K_{268}), free acidity (FA) and peroxide value (PV), p-Anisidine value (AV) and colour pigments (chlorophyll and carotenoid) may significantly change during storage (Abbadi et al., 2014; Afaneh et al., 2013; Jabeur et al., 2015; Rodrigues et al., 2016). The reference official chemical and sensory methods utilized for these measurements are costly, destructive, time-consuming, labour-intensive, and need considerable amounts of solvent and reagents (Bendini et al., 2007).

The idea of developing the production process in its technical and economic viewpoints, as well as improving the quality standards for VOO, is continuously stimulating the look for new technologies, with great interest in the olive oil industry to monitor their physicochemical quality characteristics making use of simple, green, user-friendly and cost-effective analytical devices that could offer fast analysis as complementary or alternative methods to the time-consuming classical analytical reference techniques. Currently, methods such as fluorescence spectroscopy, gas chromatography-mass spectrometry (GC–MS), high performance liquid chromatography (HPLC), near infrared transmission spectroscopy (NITS) and Fourier transform infrared spectroscopy (FTIR) have been developed to measure oil quality parameters during oxidation (Guzmán et al., 2015; Pizarro et al., 2013; Talpur et al., 2015; Tasioula-margari and Okogeri, 2001; Wójcicki et al., 2015). However, these methods need costly instrumentation, a laboratory environment, high-skill users as well as spectral pretreatment to develop complex models. Researchers have proposed other methods such as electronic tongue and electronic nose for checking olive oil physicochemical quality along the commercialization line and storage (Cosio et al., 2007; Lerma-García et al., 2009; Rodrigues et al., 2016; Xu et al., 2016).

In image analysis for food products, colour is an important attribute and robust descriptor that often simplifies object extraction and detection from an image, and it is the first factor that influences the consumer to choose or reject foodstuff. Colour of food and agricultural products is influenced by the internal biochemical, microbial, physical and chemical changes which often result from growth, ripeness, and postharvest handling and processing stages, thus, colour assessment has been utilized for the indirect estimation of internal quality characteristics, such as freshness, maturity, variety and desirability (Wu and Sun, 2013; Zhang et al., 2014). Chlorophyll and carotenoids are responsible for the characteristics green and yellow colour respectively in olive oil. Also, chlorophyll compounds because of their antioxidant nature in the dark and their pro-oxidative activity in the light carry out a crucial task in the oxidative stability of VOO. Carotenoids can behave as primary antioxidants through trapping free radicals or they can behave as secondary antioxidants by quenching singlet oxygen (Fakourelis et al., 1987; Keramat et al., 2016). Therefore in addition to aroma and taste, colour is a major quality attribute in olive oil that darkens during storage and needs to be evaluated in a robust quality authentication system.

At present, computer vision system through monitoring of food appearance has become the key issue in the food industry because it is a consistent, effective and low-cost alternative to the destructive methods. This method is a reliable, safe and rapid technique which needs no sample withdrawing and can be employed as an on-line computation tools for the colour analyses in quality assessments of olive oil (Aghbashlo et al., 2014). Thus, investigating the olive oil colour change during storage as well as the development of a colour change function would be beneficial for monitoring quality characteristics of olive oil.

In recent years, computer vision technology has been considered for objectively measuring the colour and other quality features of foods (Cubero et al., 2011; Gomes and Leta, 2012; Jackman et al., 2011; Sanaeifar et al., 2016; Wu and Sun, 2013). In the case of olive oil, Marchal et al. (2013) suggested a system based on computer vision to carry out a rapid classification of the impurity content of olive oil samples at three different levels. For this purpose, the authors examined three different parameter vectors obtained from the histogram of the channels of the RGB, CIELAB and HSV colour spaces, and four different feature extraction methods. In another research, a new methodology was investigated based on digital images and supervised pattern recognition methods for the classification of extra virgin olive oil (EVOO) samples with regard to brand and detection of adulteration with soybean oil (de Melo Milanez and Pontes, 2015). Kadiroğlu and Korel (2015) assess the influence of aroma and colour of Turkish commercial EVOO samples received with the electronic nose (zNose™) and computer vision system analysed with chemometric methods on the classification of olive oils according to the geographical origins and crop years of olive oils.

The dielectric properties of foods and agricultural products have become other valuable parameters in food engineering and technology (Içier and Baysal, 2004). These properties are related to moisture content, density, temperature, chemical composition, structure and the frequency of the applied alternating electric field (Nelson and Trabelsi, 2012). Dielectric spectroscopy provides the dielectric information of a medium as a function of frequency (Naderi-Boldaji et al., 2015). This technique has been studied and utilized widely in evaluation and monitoring quality of different agricultural products and investigated the correlation between dielectric properties and many attributes of materials (Nelson et al., 2007; Skierucha et al., 2012; Sosa-Morales et al., 2010).

Lizhi et al. (2008) investigated the effects of frequency, temperature, moisture and composition on dielectric properties of edible oils and fatty acids. In this work, the samples were obtained from different oils (safflower, sunflower, olive oils, sesame, corn, soybean and canola) with different fatty acids concentrations and they used a liquid test fixture and an LCR meter (Agilent Technologies) for data recording. The dielectric parameters were measured at frequencies between 100 Hz and 1 MHz. Authors realized that this technique could be employed in predicting the main fatty acid components and the percentage of oleic and linoleic acid of oils. The same authors carried out a similar study in order to detect adulterated olive oil samples with different concentrations of cheaper vegetable oils (Lizhi et al., 2010). Furthermore, this technique has been considered for monitoring qualitative characteristics and detecting adulteration of vegetable oils (Cataldo et al., 2012, 2010) and for determining the water content of olive oil samples (Ragni et al., 2012, 2013). Dielectric technique was also proved to be a valuable tool in determining heat abuse for frying fats and oils (Corach et al., 2014; El-Shami et al., 1992; Inoue et al., 2002; Paul and Mittal, 1996).

This study aimed to develop a low-cost, simple, rapid and non-destructive system based on fusion of dielectric spectroscopy and computer vision for characterization of virgin olive oil quality indices during storage such as UV absorbance at 232 nm (K_{232}) and 268 nm (K_{268}), free acidity (FA) and peroxide value (PV), p-Anisidine value (AV), total oxidation value (TOTOX) and colour pigments (chlorophyll and carotenoid). To achieve this goal, several techniques including artificial neural network, support vector machine, Bayesian network and multiple linear regression were studied to provide the most robust model.

2. Materials and methods

2.1. Sample preparation

The VOO was supplied by Etka oil company (Rudbar, Iran). The oils were stored at the temperature of 8 °C until the test time. In order to do the measurements under the accelerated storage condition, VOO was poured into glass bottles and kept open in the oven at 60 ± 1 °C. During 24 days, samples were taken out of the oven at 3-day intervals. Therefore 9 steps of quality measurement were carried out by measuring the chemical indices of lipid oxidation. These 9 stages constituted different classes of oil quality in this study. So, the VOO storage