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Determining quality and maturity of pomegranates using multispectral imaging

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Abstract In this paper, we investigated the use of multispectral imaging technique to quantify pomegranate fruit quality. Three quality factors including total soluble solids (TSS), pH and firmness were studied at four different maturity stages of 88, 109, 124 and 143 days after full bloom (DAFB) and were correlated with the spectral information extracted from images taken at four wavelength spectra. TSS, pH and firmness of the same samples were recorded using nondestructive methods and then modeled with their corresponding spectral data using partial least squire regression (PLSR). The correlation coefficient (r), RMSEC and RPD for the calibration models was found to be: $r = 0.97$, RMSEC = 0.21 °Brix and RPD = 6.7 °Brix for TSS; $r = 0.93$, RMSEC = 0.035 and RPD = 5.01 for pH; $r = 0.95$, RMSEC = 0.65 N and RPD = 5.65 N for firmness. Also these parameters for the validation models were as follows: $r = 0.97$, RMSEP = 0.22 °Brix and RPD = 5.77 °Brix for TSS; $r = 0.94$, RMSEP = 0.038 and RPD = 4.98 for pH; $r = 0.94$, RMSEP = 0.68 N and RPD = 5.33 N for firmness. The results demonstrated the capability of multispectral imaging and chemometrics as useful techniques to nondestructively monitoring pomegranate main quality attributes.

1. Introduction

Pomegranate is one of important fruits consumed as fresh fruit as well as in processed form such as juice and jams all over the world. Determining optimum ripening stage of pomegranate is important to its use and is related to "technological maturity". Technological maturity mainly corresponds to a number of coordinated physiological and biochemical properties such as firmness, total soluble solids (TSS) and pH (Moing et al., 1998; Opara, 2000; Nunes et al., 2009). Various methods have been used to determine the maturity stages of pomegranate but

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most techniques are destructive in nature, time consuming and inapplicable to grading and sorting (Salah and Dilshad, 2002; Al-Said et al., 2009; Zarei et al., 2011; Fawole and Opara, 2013a,b). Therefore, any technology that can classify the fruits non-destructively based on their physiological parameters and nutritional values is of importance and can assure better fruit quality and consistency which in turn increases the consumer acceptance and satisfaction. Many research works have been conducted worldwide to develop nondestructive methods to determine overall quality of pomegranate fruit. Machine vision, NMR, dielectric spectroscopy, and X-ray computed tomography are some of the most recent nondestructive techniques used for quality evaluation of Pomegranate (Blasco et al., 2009; Zhang and McCarthy, 2013; Castro-Giraldez et al., 2013; Magwaza and Opara, 2014).

In light of providing a more consistent and objective evaluation of fruit quality, optical measurement techniques, such as machine vision and Near Infrared (NIR) spectroscopy, are considered as the most potential methods and complementary to the human inspection on the automatic fruit sorting line. Machine vision has been used successfully in categorizing fruits in terms of size, color and other appearance indices. However, its capacity for determination of internal quality parameters is still limited and often not reliable (Lu, 2003; Leemans and Destain, 2004). On the other hand, NIR spectroscopy has been used to evaluate nondestructively the internal quality parameters of many agricultural products (Ying et al., 2005; Guthrie et al., 2006; Shao et al., 2007; Fan et al., 2009). However, since spectroscopy generally measures an aggregate amount of light reflected or transmitted from a specific area of a sample (point measurement), it does not contain spatial information about the product under study.

As an extension of both spectroscopy and imaging techniques, hyperspectral and multispectral imaging techniques have been emerged to integrate both techniques in one system to provide spectral and spatial backgrounds simultaneously. Multispectral imaging, which was originally developed for space-based imaging, may capture light from wavelengths outside of the visible spectral range, such as infrared. It can, therefore, provide more information than what human eye can capture. Multispectral imaging can be used to address features such as ripening (Lu, 2004) and external defects (Diaz et al., 2000, 2004; Kleynen et al., 2003; Leemans and Destain, 2004; Mehl et al., 2004; Unay and Gosselin, 2006) with higher sensitivity in comparison with the ordinary RGB imaging (Aleixos et al., 2002, 2007; Leemans et al., 2002; Kleynen et al., 2003). However, despite an extensive research on multispectral imaging of fruits, yet very limited published results on the multispectral imaging of pomegranate fruit and pomegranate arils are available.

The multispectral imaging is believed to perform as a useful new technique for fruit internal quality evaluation and assessment of postharvest storability. These operations are of interest to growers, breeders and postharvest technologists particularly when implemented non-destructively. Hence, this study was undertaken to acquire the multispectral image of pomegranate fruits at different maturity stages (four distinct maturity stages between 88 and 143 days after full bloom (DAFB)) to model fruits' quality parameters (firmness, TSS and pH) from their multispectral data. The aim was achieved by fulfilling the following specific objectives:

(i) To select the optimal wavelengths that provide the highest correlation between the spectral data and the three studied quality parameters.
(ii) To develop partial least square (PLS) models to quantitatively predict firmness, TSS, and pH in pomegranate fruit, and to examine the prediction accuracy of these models.

2. Material and methods

2.1. Materials

A total of 400 samples for this study were all complete and undamaged pomegranate fruits. The fruits were of *ASHRAF* variety and handpicked from a pomegranate orchard in Shahidabad Village, Behshahr County, Mazandaran Province, Iran (36°41′32″N 53°33′09″E). Harvesting and handpicking started on 31 August 2014, when it was possible to squeeze juice from fruit arils, and ended in October 2014 at fruits' commercially full ripe stage. The 400 sample pomegranates were divided into four groups of 100 samples, each representing maturity levels of 1–4 corresponding to 88, 109, 124 and 143 days after full bloom (DAFB), respectively (Fig. 1). Features of samples at these maturity stages are shown in Table 1. The tested fruits in each maturity stage were randomly divided into two subgroups for training and testing. The first subgroup of 70 samples was used as a training set for developing partial least square (PLS) model. The remaining subgroup of 30 fruits was used for model validation and to verify the prediction power of the models.

2.2. Wavelengths selection

Selecting vital few wavelengths that are most influential on the quality evaluation of the product is often of interest to researchers. They are also interested in eliminating wavelengths having no discrimination power. The selected wavelengths result in data dimensionality reduction while the most important information is preserved in a lower dimensional data space. The responses of the fruits to spectral analysis are considered in determining the selected wavelengths. The main aim of this research also was to select the most suitable wavelength bands based on which we develop a calibration model for predicting quality parameters of pomegranate fruit. Therefore, before acquisition of multispectral images, the whole spectra (400–1100 nm at intervals of 1 nm) of fruit samples were acquired using a dual-channel spectrometer AvaSpec-2048TEC (Avantes Company, Russia) equipped with AvaSoft7 software for Windows, a cooled, one nanometer resolution and sensitivity of 2000 count per 1 mJ entrance irradiation. Then, four most suitable wavelength bands that discriminate studied maturity stages were selected by means of principal component analysis, similar to the approached followed by Miller et al. (1998) and Mehl et al. (2002). PCA is an effective method for data dimensionality reduction and feature extraction. Since each PC is a linear sum of intensity at individual wavelengths multiplied by corresponding spectral weighing coefficients, the wavelengths with weighing coefficients at peaks and valleys represent the dominant wavelengths. The selected wavelengths were as follows: 680, 800, 900, and