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Astringency assessment of persimmon by hyperspectral imaging

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ABSTRACT

One of the current challenges of persimmon postharvest research is the development of non-destructive methods that allow determination of the internal properties of the fruit, such as maturity, flesh firmness and astringency. This study evaluates the usefulness of hyperspectral imaging in the 460–1020 nm range as a non-destructive tool to achieve these aims in Persimmon cv. 'Rojo Brillante' which is an astringent cultivar. Fruit were harvested at three different stages of commercial maturity and exposed to different treatments of CO_2 (95% CO_2 – 20 °C – from 0 to 24 h) in order to obtain fruit with different levels of astringency. Partial Least Square (PLS) based methods were used to classify persimmon fruits by maturity and to predict flesh firmness from the average spectrum of each fruit. The results showed a 97.9% rate of correct maturity classification and an R^2_P of 0.80 for firmness prediction with only five selected wavelengths. For astringency assessment, as our results showed that the soluble tannins that remain after CO_2 treatments are distributed irregularly inside the flesh, a model based on PLS was built using the spectrum of every pixel in the fruit. The model obtained an R^2_P of 0.91 which allowed the creation of the predicted distribution maps of the tannins in the flesh of the fruit, thereby pointing to hyperspectral systems as a promising technology to assess the effectiveness of the deastringency treatments that are usually applied before commercialising persimmons from astringent cultivars.

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1. Introduction

Astringency removal is required prior to commercialising astringent persimmon cultivars. The astringency of persimmon fruit is due to the high soluble tannin content in the flesh. Traditionally, the astringent cultivars have been consumed after fruit has been submitted to an over-ripening treatment with exogenous ethylene; under these conditions astringency removal is accompanied by a drastic loss of flesh firmness which hampers postharvest handling of the fruit. For this reason, postharvest treatments which allow astringency removal while preserving high flesh firmness have been developed in recent years. Among them, the most widely used technique in commercial settings is based on exposing fruits to high CO_2 concentrations (95%–98%) for 24 h–36 h. This method promotes anaerobic respiration in the fruit, giving rise to an accumulation of acetaldehyde, which reacts with the soluble tannins (ST). Tannins become insoluble at the end of the treatment and astringency is no longer detected (Matsuo and Ito, 1982; Matsuo et al., 1991).

The optimum duration of the CO_2 treatment depends on the cultivar but also on the stage of fruit maturity (Besada et al., 2010). If the treatment is too short, it may result in fruit with residual astringency, and if extended excessively it may lead to losses of fruit quality (Novillo et al., 2014). Therefore, the optimum treatment conditions must be determined for the different cultivars, but the stage of fruit maturity must also be taken into account. Therefore, the knowledge of the fruit condition at harvest according to its stages of maturity is a prerequisite to apply the adequate CO_2 treatment.

After application of the CO_2 treatment it is necessary to evaluate its effectiveness to avoid residual astringency that could negatively affect the future buying intentions of consumers. Currently, the effectiveness of deastringency treatment can be assessed by measuring the content of ST that remains in the flesh, although this is a slow and destructive analytical method, and thus commercially

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unfeasible. Another method to determine the level of astringency of persimmon fruit is based on the reaction of ST (responsible for astringency) with $FeCl_3$, which leads to a blue staining; the intensity of the staining observed after a slice of the flesh is impregnated with $FeCl_3$ depends on its level of ST. Although this method is faster and easier than the analytical determination of ST, it is also destructive and subjective and therefore it is necessary to search for new rapid, reliable, non-contact and non-destructive techniques.

Among them, computer vision represents a fast, accurate, and proved alternative for monitoring fruit quality (Cubero et al., 2011). However, this kind of sensors is limited to analysing the external properties of the fruit like colour, size or the presence of external defects, not being capable of detecting internal compounds like ST, responsible of the astringency. Therefore, other methods capable of analyse internal compounds are necessary. Spectroscopy is a non-destructive, inexpensive, rapid and reliable technique that has traditionally been used in food chemistry for qualitative and quantitative determination of different compounds in fruit samples, especially near infrared (NIR) spectroscopy (Nicolaï et al., 2007, 2014; Magwaza et al., 2012; Lopez et al., 2013). This technique has been utilised for the quantitative determination of soluble solids content (SSC), firmness, acidity, dry matter, chemical substances such as glucose, sucrose, citric acid, malic acid, starch or cellulose in different fruits (Schmilovitch et al., 2000; Nagle et al., 2010; Theanjumpol et al., 2013), and even to determine a maturity index (Jha et al., 2013), internal quality index (Cortés et al., 2016) or different appropriate indices for quality analysis (Attila and János, 2011).

However, a major disadvantage of spectroscopy is that only can measure in a single point of the sample. On the other hand, hyperspectral imaging is a non-destructive optical technology that integrates the advantages of spectroscopy and conventional imaging to obtain both spatial and spectral information simultaneously. It allows the visualisation of internal compounds of the fruit distributed into the image which is not possible with conventional spectroscopy (Gowen et al., 2007; Lorente et al., 2012; Gómez-Sanchis et al., 2013) as in the case of the ST of the persimmon, leading to a non-valid probe measurement and forcing to take measurements in many places of the fruit surface (Noypitak et al., 2015). Thus, using hyperspectral imaging Mendoza et al. (2011) developed a method for the in-line prediction of firmness and SSC achieving coefficient of correlation between 0.83 and 0.95 for prediction of firmness and between 0.67 and 0.87 for prediction of SSC in different apple cultivars. Later they compared several spectral sensors to predict these properties (Mendoza et al., 2012). Cen et al. (2014) investigated the detection of internal chilling injuries in pickling cucumbers using hyperspectral reflectance (500–675 nm) and transmittance (675–1000 nm) achieving 100% of correct detection using SVM with the fruit travelling at 100 mm/s, which gives an idea of the potential of this technology for non-destructive in-line quality control.

Ripeness has been one of the main features studied with this technology. Lleó et al. (2011) used hyperspectral imaging (400–1000 nm) to predict the maturity of ‘Rich lady’ peaches by computing different indices extracted from band ratios and combinations. The application of these indices to create maps from the classification of individual pixels showed that the ripening was not uniform throughout the entire fruit. Furthermore, the ripening of intact bell peppers was studied by Schmilovitch et al. (2014) using hyperspectral imaging (550–850 nm). They were able to relate some internal compounds like SSC, total chlorophyll, carotenoid and ascorbic acid content with the spectral data by means of a PLS regression, in all cases achieving an R^2 higher than 0.90 except for ascorbic acid (0.72). The chemometric models they established were used to estimate internal components in each pixel of the fruit image, thus allowing mapping of the quality parameters in the intact peppers.

Apart from maturity, other properties can also be assessed. Yang et al. (2015) measured anthocyanin content in lychee pericarp in the 350–1050 nm range. They created several models achieving an R^2 of 0.92 using all wavelengths. The model was later applied to entire fruits to create distribution maps with which to visualize the changes in anthocyanin content during storage time. Liu et al. (2015) used multispectral images to predict lycopene and phenolic compounds content in intact tomatoes. The comparison of methods based on PLS, least squares-support vector machines (LS-SVM) and back propagation neural networks (BPNN) showed BPNN to be the one that performed best, with an R^2 of 0.96. By applying the model to each pixel of the tomato they were able to create prediction maps of the intact tomatoes.

In persimmon fruit the use of this non-destructive technology to assess different quality parameters is beginning to be studied. Hence, Wei et al. (2014) used hyperspectral imaging to study the relationship between firmness and fruit maturity. Mohammadi et al. (2015) also used image analysis techniques to evaluate the index of external colour of the fruits in order to classify them into three stages of commercial maturity. Nevertheless, more studies are necessary in this regard, particularly with fruit that will be commercialized with a firm texture. Furthermore, to our knowledge, the potential of hyperspectral technology to detect the level of astringency in persimmon has not been evaluated to date. Only some works have been carried out to detect phenolic compounds related to astringency (Nogales-Bueno et al., 2014), focused especially on wine quality (Aleixandre-Tudó et al., 2015; Boulet et al., 2016). And only one work has been found related to astringengy in persimmon using NIR spectroscopy in the range of 660–960 nm (Noypitak et al., 2015).

The aim of this work is to advance in the development of a non-destructive tool to assess the astringency of persimmon fruits that have been gone under deastringency treatment, since at present there are no methods or previous research focused on this aim for this type of fruit, being still a demand from the industry.

2. Materials and methods

2.1. Image acquisition and calibration

The hyperspectral imaging system capable of acquiring images in the spectral range 400–1100 nm was composed of an industrial camera (CoolSNAP ES, Photometrics, AZ, USA), and two liquid crystal tunable filters (LCTF) (Varispec VIS-07 and NIR-07, Cambridge Research & Instrumentation, Inc., MA, USA) and a lens capable of covering the whole spectral range without losing the focus (Xenoplan 1.4/23, Schneider Optics, Hauppauge, NY, USA). The system was configured to capture images of 1392 × 1040 pixels with a spatial resolution of 0.14 mm/pixel and a spectral resolution of 10 nm. To optimise the dynamic range of the camera, prevent saturated images and correct the spectral sensitivity of the different elements of the system, a calibration of the integration time of each band was performed by capturing the averaged reflectance of a white reference target (Spectralon 99%, Labsphere, Inc, NH, USA) corresponding to 90% of the dynamic range of the camera. The scene was illuminated by 12 halogen spotlights of 37 W each (Eurostar IR Halogen MR16. Ushio America, Inc., CA, USA) powered by direct current (12 V), which lit the scene indirectly by means of diffuse reflection inside a hemispherical dome where whole fruits were introduced manually (Fig. 1). The inner surface of the aluminium dome was painted in white and given a rough texture using a synthetic polish sprayer in order to reduce directional reflections that could cause bright spots, thus

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