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A new internal quality index for mango and its prediction by external visible and near-infrared reflection spectroscopy

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ABSTRACT

A non-destructive method based on external visible and near-infrared reflection spectroscopy for determining the internal quality of intact mango cv. 'Osteen' was investigated. An internal quality index, well correlated with the ripening index of the samples, was developed based on the combination of a biochemical property (total soluble solids) and physical properties (firmness and flesh colour) of mango samples. The diffuse reflectance spectra of the samples were recorded and used to predict the internal quality and the ripening index. These spectra were obtained using different spectroscopic external measurement sensors involving a spectrometer, capable of measuring in different spectral ranges (600–1100 nm and 900–1750 nm), and also a spectrocolorimeter that measured in the visible range (400–700 nm). Three regression models were developed by partial least squares to establish the relationship between spectra and indices. Good results in the prediction of internal quality of the samples were obtained using the full spectral range (R_p^2 = 0.833–0.879, RMSEP = 0.403–0.507 and RPD = 2.341–2.826) and some selected wavelengths (R_p^2 = 0.815–0.896, RMSEP = 0.403–0.537 and RPD = 2.060–2.905). The results obtained from this study revealed that external visible and near-infrared reflection spectroscopy can be used as a non-destructive method to determine the internal quality of mango cv. 'Osteen'.

1. Introduction

Spain is the main European producer of subtropical fruits, with approximately 1400 ha dedicated to mango (Galán and Farré, 2005). In particular, the south-west region has a large potential for the production of tropical and subtropical fruit, with a favourable year-round climate and infrequent frosts.

Mango fruit is sold in the market in quality categories. In the past, skin colour, fruit size and shape, freedom from defects and the absence of decay were the most common quality determinants, but nowadays other organoleptic characteristics related with internal and nutritional quality play an important role in the consumer's decision, as opposed to just appearance. The quality of mangoes changes almost daily and it is essential to correlate all the major quality parameters with one another in order to reveal the overall quality of the fruit (Jha et al., 2011).

In a climacteric fruit, such as mango, the fruit is not considered to be of desired eating quality at the time it initially becomes mature. It requires a ripening period before it achieves the taste and texture desired at the time of consumption. The ripening process is regulated by genetic and biochemical events that result in biochemical changes such as the biosynthesis of carotenoids (Mercadante and Rodriguez-Amaya, 1998), loss of ascorbic acid (Hernández et al., 2006), increase in total soluble solids (Padda et al., 2011); physical changes such as weight, size, shape, firmness and colour (Ornelas-Paz et al., 2008; Kienzle et al., 2011); and changes in aroma, nutritional content and flavour of the fruit (Giovannoni, 2004). Traditional determination of the internal quality of mango requires a destructive methodology using specialised equipment, procedures and trained personnel, which results in high analysis costs and does not allow the whole production to be analysed (Torres et al., 2013). Nevertheless, new technologies to monitor fruit quality changes during the postharvest handling chain are rapidly being introduced, especially those based on non-destructive assessment methods, recently reviewed by Jha et al. (2010) and Nicolaï et al. (2014). These fast and non-

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destructive methods can help to provide decisive parameters with which to obtain better quality mango products and to promote consumption of mangoes with better health benefits (Ibarra-Garza et al., 2015).

Several non-destructive technologies have been widely explored to predict the quality and maturity of mango, such as nuclear magnetic resonance (NMR) (Gil et al., 2000), impact response (Padda et al., 2011; Wanitchang et al., 2011), electronic nose (Lebrun et al., 2008; Zakaria et al., 2012), hyperspectral analysis (Vélez-Rivera et al., 2014a), and near-infrared spectroscopy (Saranwong et al., 2004). Conversely, some authors, such as Jha et al. (2005), have included in their studies the full visible spectrum using spectroscopy in intact mangoes, although studies using colour coordinates are more common, such as Jha et al. (2007), Subedi et al. (2007) or Rungpichayapichet et al. (2015).

Schmilovitch et al. (2000) studied the feasibility of near-infrared spectroscopy (NIRS) to determine the total soluble solids, firmness and acidity of mangoes cv. 'Tommy Atkins' in relation to the maturity stage. Nagle et al. (2010) developed a method to measure total soluble solids, total acidity and dry matter in mango cv. 'Chok Anan' on the trees using NIRS. Theanjumpol et al. (2013) studied the possibility of predicting six main chemical substances found in mango fruit cv. 'Keitt' and cv. 'Nam Dok Mai Si Thong', which are important in Thailand, such as glucose, sucrose, citric acid, malic acid, starch and cellulose. They used VIS-NIR spectrometry but decided not to use the visible information to avoid the influence of colour pigments. Jha et al. (2013) studied the properties of different mangoes that are important for the Indian production using NIRS in the 1200–2200 nm range to measure properties that make it possible to predict the maturity stage. They were able to predict the sweetness of the mangoes from measurements of total soluble solids and pH (Jha et al., 2012) or to determine a maturity index based on the estimations of total soluble solids, dry matter and total acidity that was compared with destructive analysis and sensory panels, and corrected using a constant that depended on the cultivar (Jha et al., 2014). Watanawan et al. (2014) studied the 700–1100 nm region in an attempt to correlate total soluble solids, total acidity and dry matter of mango cv. 'Namdokmai' with maturity in order to predict the optimum harvesting time. They found good correlations among NIRS values and firmness and dry matter content at harvest, and predicted TSS with very high accuracy, although they consider that their study needs to be revised in order to reduce the heterogeneity in fruit maturity and increase the outturn quality.

The main problem of using NIRS to assess fruit quality is the robustness of the calibration model (Rungpichayapichet et al., 2016). Additionally, fruit cultivar, size, and harvest season also play an important role in the robustness of NIRS models (Bobelyn et al., 2010). In this study, a non-destructive method based on visible and near-infrared spectroscopy was investigated to determine the internal quality of mango cv. 'Osteen' during ripening because this is the main variety of mango grown in Spain. This variety could be included in the group of late-ripening mangoes, with higher weights and prices than other varieties of the same fruit. For this reason, this variety is considered to be optimal for export owing to its late maturing characteristics and final relatively low weight loss (Siller-Cepeda et al., 2009).

Hence, the aims of this research were (a) to determine an internal quality index for mangoes, based on their main biochemical (total soluble solids) and physical properties (firmness and flesh colour), avoiding the titratable acidity analysis, because it is a laborious and slow analysis that generates waste, (b) to apply it to mango cv. 'Osteen', and (c) to develop statistical models based on Partial Least Squares (PLS) to predict the internal quality of the samples through the analysis of external VIS-NIR spectral data.

2. Materials and methods

2.1. Experimental procedure

A batch of 140 unripe mangoes (*Mangifera indica* L., cv 'Osteen') were obtained from plantations in Málaga (Spain). The fruit selected were free of external damage or diseases, showing a uniform shape and size. All mangoes were washed and dried to

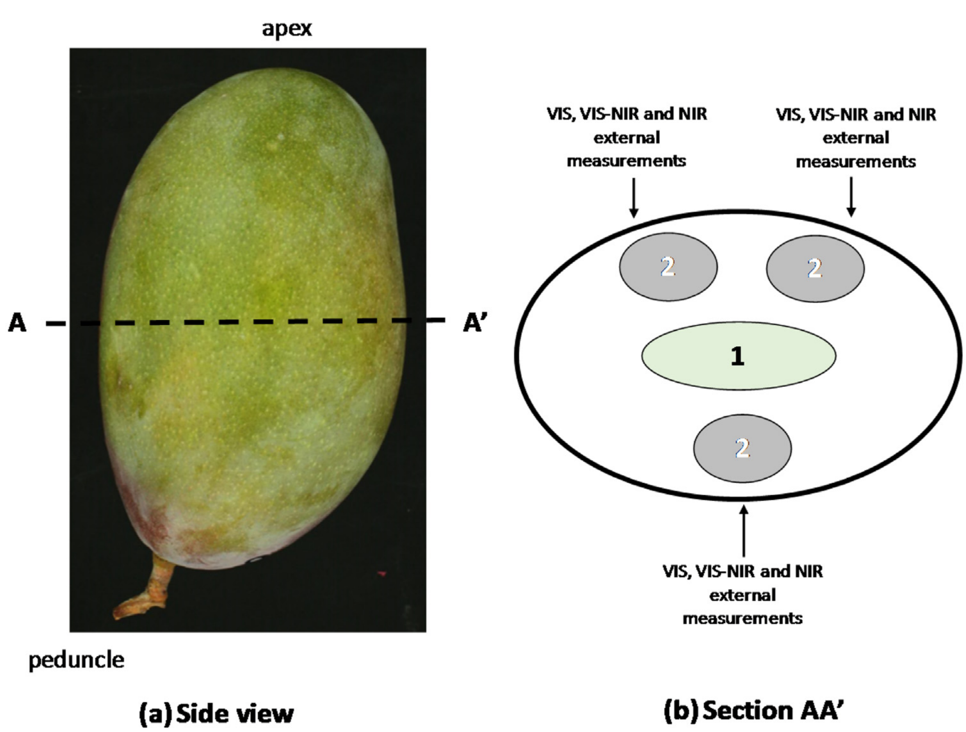

Fig. 1. External reflection spectroscopy measurements in fruit slice AA' (1: seed; 2: penetrometer firmness and flesh colour measurement locations).