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Original Research Article

Non-destructive determination of β-carotene content in mango by near-infrared spectroscopy compared with colorimetric measurements

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ABSTRACT

Non-destructive applications for the detection of food quality, especially internal properties, are highly relevant for process control in the food industry. In this respect, colour measurement and near-infrared spectroscopy (NIRS) were evaluated and compared for their ability to predict β-carotene content in mango cv. 'Nam Dokmai'. Colorimetric analysis of peel and flesh colour as well as NIR measurements in the short- (700–1100 nm) and long-wave regions (1000–2500 nm) were analysed for prediction ability. It was found that β-carotene content could be estimated by multiple linear regression (MLR) models developed from b^* and hue angle (h°) values of the flesh with good results for coefficient of determination (R^2) and standard errors of cross validation (*SECV*) of 0.941 and 10.2 retinol equivalents (*RE*) 100 g^{-1} edible part (EP), respectively, while peel colour showed poor results. However, flesh colour measurement is a destructive method. NIRS calibration showed good results with $R^2 > 0.800$ and standard error of prediction (*SEP*) 11.642–20.2 *RE* 100 g^{-1} EP. Long-wave NIR provided better prediction ability than short-wave. From these results, NIRS can be recommended for non-destructive and reliable determination of β-carotene content in mango. The results have implications for quality control in the industrial handling and processing of fruits.

1. Introduction

Mango is a major global fruit crop that is widely grown in tropical and subtropical regions around the world. Increasing demand has stimulated production to rise about 17% from 2008 to 2012, with the major producers in terms of volume being India, China and Thailand, respectively (FAOSTAT, 2014). Mango is a good source of vitamins, minerals and other bioactive compounds (Liu et al., 2013; Ma et al., 2011; Masibo and He, 2009; Schieber et al., 2000). In mango, the colour of both the fruit peel and the fruit flesh is governed by concentrations of chlorophyll and carotenoid pigments. During ripening, colour of the flesh (and in some cultivars peel as well) shifts from green to yellow-orange, due to chlorophyll degradation in conjunction with carotenoid biosynthesis (Gouado et al., 2007; Vásquez-Caicedo et al., 2006). There are 17 major carotenoids found in mango, amongst them β-cryptoxanthin, zeaxanthin, luteoxanthin isomers, violaxanthin, neoxanthin and β-carotene, with the last being the most prevalent (Mercadante et al., 1997; Ornelas-Paz et al., 2007). Carotenoid content is affected by various factors, such as ripening stage, cultivar and processing method (Gouado et al., 2007; Mahayothee et al., 2007). Mercadante and Rodriguez-Amaya (1998) reported that total carotenoid content increased about threefold during ripening and other research stated that carotenoid accessibility was greater in ripe fruits than in unripe ones (Ornelas-Paz et al., 2008). Therefore, ripened mango is a good source of provitamin A and can be a nutritional source for malnourished people and also for customers who are interested in functional foods (West and Darnton-Hill, 2008).

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The standard approach to evaluate β-carotene content is via chromatographic quantification, such as high pressure liquid chromatography (HPLC). This method is a destructive technique which is time-consuming and costly with highly technical sampling requirements. Due to instability of the pigments, loss of analytes during extraction is a further disadvantage (Ruiz et al., 2008). Therefore, non-destructive methods for determining β-carotene content are imperative to monitor individual samples. The relationship between total carotenoid content and fruit colour has been evaluated in some studies. Arias et al. (2000) found a good correlation between carotenoids and fruit colour parameters (a^*/b^* ratio) in tomato which could be used to predict lycopene content. Ruiz et al. (2005) found that hue angle (h°) of peel was the most appropriate parameter for estimating the total carotenoid content in apricots. For orange juice, provitamin A content could be calculated as a function of L^*, a^* and b^* values (Meléndez-Martínez et al., 2003). For mango, Ornelas-Paz et al. (2008) found that peel or flesh colour of cvs. 'Manila' and 'Atualfo' showed high correlations with the β-carotene content in flesh. However, using flesh colour to determine carotenoid content in fruit is a destructive technique and tested fruits cannot be marketed.

Near-infrared spectroscopy (NIRS) has been widely used as a non-invasive quality assessment technique for agricultural products. The potential of NIRS to determine internal qualities of fruits such as soluble solids, dry matter, acidity and firmness has been demonstrated in many studies (Saranwong et al., 2004; Zude et al., 2006; Cayuela, 2008; Camps and Christen, 2009; Nagle et al., 2010). Visible and near infrared spectroscopy (vis/NIRS) in the wavelength region between 400 and 2500 nm has been studied to evaluate carotenoid content in other crops, such as tomato (Baranska et al., 2006; Clément et al., 2008), potato (Bonierbale et al., 2009) and banana (Davey et al., 2009). Determination of β-carotene content in passion fruit was done by Oliveira et al. (2014) using NIRS in the region of 800–2000 nm. Using long-wave region NIRS (1100–2500 nm) to predict β-carotene content in Chinese kale and apricot was evaluated by Chen et al. (2009) and Ruiz et al. (2008), respectively. In addition, Brenna and Berardo (2004) studied the feasibility of using NIRS to evaluate β-carotene content in maize and found that using a long-wave region (1100–2500 nm) was more precise and required fewer factors than using the short-wave region. However, studies applying NIRS for prediction of β-carotene in mango are thus far limited. Therefore, the objectives of this study were to evaluate and compare the possibilities to determine β-carotene content in mango by both colorimetric measurement and NIRS.

2. Materials and methods

2.1. Samples

A total of 120 mango fruits (cv. 'Nam Dokmai' subcv. 'Si Thong') grown in Phitsanulok, Thailand was used in this study. Fruits with average weight of 305 ± 13.5 g were harvested at the green 'physiologically mature' stage and sorted according to specific gravity: fruits which were buoyant in water (density <1.0 g cm^{-3}) were designated as immature and eliminated. Fruits were then transported to Nakhon Pathom province within 1 day of harvesting, and experiments were carried out. Fruits without external injuries and blemishes were washed, air-dried and stored in baskets covered with paper at 33.0 ± 1.2 °C and 63.9 ± 6.9% relative humidity. Fruits were allowed to ripen for up to 8 days, with the arrival day set as the first day of ripening. For each ripening day, five sample fruits were randomly selected and subjected to colorimetric and NIRS measurements, as well as the respective reference analyses. The experiment was repeated three times.

2.2. NIRS analysis

2.2.1. Spectral acquisition

Spectra of mango samples were collected in reflectance mode using two different instruments, a portable vis/NIR spectrometer equipped with an interactance fibre optic probe (HandySpec Field 1000, tec5AG, Oberursel, Germany) and a Fourier-transform near infrared (FT-NIR) bench spectrometer equipped with an integrating sphere and an InGaAs detector (TANGO, Bruker Optics Hong Kong Ltd.). Prior to spectral measurements, the temperature of the fruits was adjusted to 25 °C. Measurement was done by placing the probe directly onto the skin at the fruit shoulder (90° from the fruit stem axis) around the centre of each cheek (Fig. 1). The vis/NIR spectrometer was used to acquire NIR spectra in a short-wave

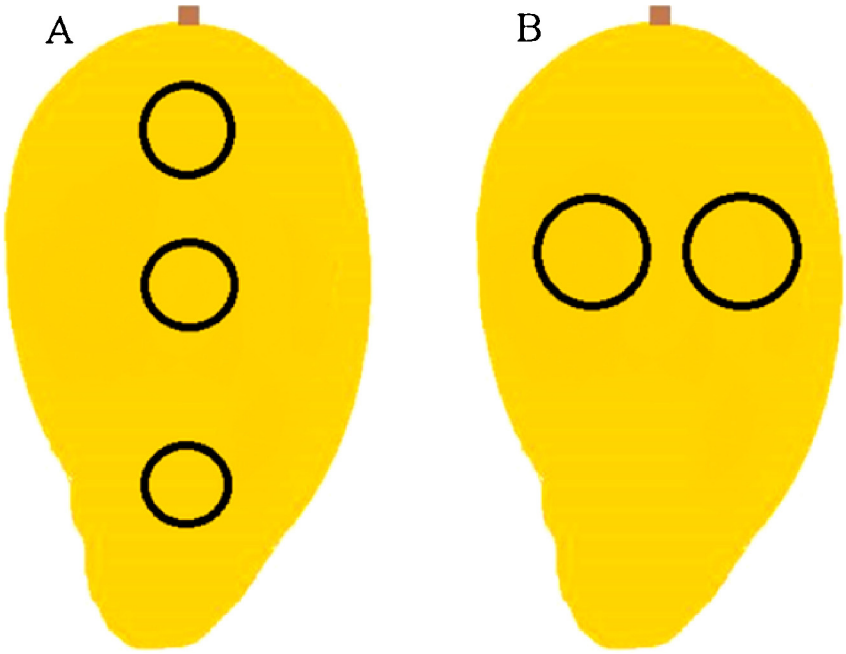

Fig. 1. Positions on the fruit surface corresponding to colour (A) and NIRS (B) measurements.