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Non-destructive evaluation of avocado fruit maturity using near infrared spectroscopy and PLS regression models

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ABSTRACT

Harvest maturity of avocado fruit is currently determined using indices such as mesocarp oil content, dry matter (DM) or moisture content (MC), both measured destructively using representative samples of a batch in an orchard. Although useful, destructive techniques are time-consuming and results reflect properties of specific produce evaluated. In this study, the feasibility of near-infrared spectroscopy (NIRS) as a rapid non-destructive method for predicting maturity parameters of individual avocado fruit was evaluated. NIRS prediction results showed that MC and DM were predicted accurately, with residual predictive deviation (RPD) of 2.00 and 2.13 respectively. However, models for predicting oil content, though promising, were not accurate, with RPD value of less than 1.0. The good prediction statistics between NIRS predicted MC and DM content demonstrated the potential of this system for non-destructive evaluation of avocado fruit maturity status. The stability and accuracy of models developed over two seasons, 2013 and 2014, to predict maturity parameters of avocado fruit demonstrated model robustness. NIRS combined with PLS models developed in this study are recommended for non-destructive evaluation of individual avocado fruit maturity status.

1. Introduction

Consumer assessment of avocado fruit quality which influence initial decision to make a purchase is often based on external attributes such as colour, shape and size (Opara and Pathare, 2014). However, the decision for subsequent purchases is dependent upon consumer satisfaction on flavour, eating quality and texture (Chen and Opara, 2013a,b; Magwaza and Opara, 2015). Eating quality which is often related to internal attributes, have become significant quality parameters in consumer perception of quality and value of avocado fruit (Cayuela and Weiland, 2010). Therefore, accurate evaluation of avocado harvest maturity is one of the important aspects determining avocado fruit postharvest quality. If harvested immature, avocado fruit typically shrivel during storage, ripen abnormally, have watery taste and rubbery texture (Chen et al., 2009). On the other hand, over-mature fruit will have short shelf life and are more susceptible to postharvest physiological disorders and diseases, resulting to major economic losses. In an export oriented industry, such as South Africa, harvesting avocado fruit at optimum maturity is of utmost importance.

Determining the commercial harvest time of avocado fruit is difficult because, unlike many other fruit, avocado do not exhibit external visual and physical changes during maturation. Instead, maturation of an avocado fruit, is characterized by a significant decline of mesocarp moisture content (MC) and reciprocal increase of dry matter (DM) content (Whiley et al., 1996; Ozdemir and Topuz, 2004; Clark et al., 2007; Magwaza and Tesfay, 2015). Mesocarp oil content has also been shown to increase steadily with fruit development (Hofman et al., 2002; Ozdemir and Topuz, 2004). As mesocarp oil content increases, water content decreases by the same amount, so that the total percentage of oil and water content remains constant during fruit life of any avocado cultivar (Ozdemir and Topuz, 2004). Hence, mesocarp oil, DM and moisture contents are used commercially in different countries as suitable indicators of avocado maturity. For instance, South African avocado industry prefer moisture contents (Hofman et al., 2013).

In many avocado producing countries, oil content is the oldest and considered the most reliable indicator of fruit maturity and eating quality (Lee et al., 1983; Kaiser, 1994). However, due to its

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cost and difficulty to measure, alternative parameters are now used by the industry. For instance, in South Africa, flesh moisture content forms the basis of maturity standards designed to ensure that only fully mature avocados are marketed (Kruger et al., 1995; Snijder et al., 2003). Studies by Lee et al. (1983) and Chen et al. (2009) showed a significant positive correlation (R-value of up to 0.97) between avocado oil content and dry matter content. Due to this correlation, mesocarp DM content is accepted as an indirect index to determine oil content, and hence maturity, in countries such as Australia, Chile, Israel, New Zealand and United States for different avocado cultivars (Ranney et al., 1992; Woolf et al., 2004; Chen et al., 2009; Hofman et al., 2013).

Although the current methods used to determine these indices are commercially useful, they are inherently destructive, time-consuming, cost ineffective and require precise sample preparation. Furthermore, these destructive measurements usually involve few representative samples on which the maturity of avocado batch is based (Blakey, 2011). The disadvantage of this method apart from its labour intensive and destructive nature, is that growers stand the risk of delivering poor quality fruit to the market due to variation within a batch. Poor quality resulting from immature fruit in batch, may lead to uneven ripening and consumer dissatisfaction and affect future purchases (Kruger and Lemmer, 2007). For the avocado industry to improve its competiveness and maintain consumer confidence in the product purchased, the industry should supply fruit of consistent quality with predictable and even ripening. There is therefore, a need to develop objective, fast and non-destructive techniques that can be used to accurately determine maturity of individual fruit.

Several Attempts have been made, in recent years, to develop reliable non-destructive technologies for determining quality-related parameters of avocado, such as firmness and maturity indices. For instance, Chen et al. (1993) and Kim et al. (1999) showed that nuclear magnetic resonance (NMR) has a potential to estimate mesocarp oil content of avocado fruit. In a study by Mizrach et al. (1996), dry matter and oil content were correlated with its ultrasonic parameters, indicating the potential of the ultrasonic system for non-destructive prediction of avocado maturity and ripening patterns. Although several techniques for non-destructive detection and prediction of avocado fruit maturity parameters have been developed, near infrared (NIR) spectroscopy (NIRS) is evidently the most advanced with regard to instrumentation, applications, accessories, and chemometric software packages (Magwaza et al., 2012a). The NIRS is rapid and equipment costs are cheaper compared with that of NMR, making it a commercially feasible alternative for maturity determination. As a result, the technology has become one of the mostly used methods for non-destructive evaluation of a wide range of postharvest quality assessments of fruit and vegetables (Nicolaï et al., 2007; Cozzolino et al., 2011; Magwaza et al., 2013).

Chemometric analysis is an important aspect of NIRS technology as it involves multivariate analysis for the interpretation of the large data sets of NIR spectra (Wang and Paliwal, 2007). Therefore, calibration model must first be developed by calibrating the spectra against conventional destructive data. Calibration models can be developed using various chemometric tools such as partial least square regression (PLS), multivariate linear regression (MLR) and principal component regression (PCR) (Nicolaï et al., 2007). PLS is by far the most preferred chemometric analytical tool for model calibration because of its ability to remove latent variables (LVs) that are not important to describe the variance of targeted quality variables (De Jong, 1993).

NIRS with suitable chemometric analysis has been used and shown to be a precise, rapid and non-destructive alternative to destructive methods for providing non-visible information about comparative proportions of C—H, O—H and N—H bonds (Magwaza et al., 2012a). Avocado fruit quality parameters such as DM, moisture and oil contents are based on organic molecules which contain C—H, O—H, C—O, and CC bonds; hence, it is possible to use NIR technology to quantify these parameters. Clark et al. (2003) used NIRS and PLS to determine dry matter content of intact 'Hass' avocado fruit and reported significantly accurate prediction results (R^2 = 0.88; RMSEP = 1.8%). Wedding et al. (2010) reported the potential of Fourier transform NIR (F-T-NIR) spectroscopy for non-destructive estimation of DM of intact avocado fruit with prediction co-efficient of determination (R_p^2) of 0.76 and root mean square error of prediction (RMSEP) of 1.53%. In a later study, Wedding (2011) reported better prediction statistics for DM with (R_p^2) of 0.93 and RMSEP of 1.48%. Because of spectral differences due to the biological variability of samples from different orchards and season, Wedding et al. (2013) tested model robustness and reported that models accurately predicted DM of samples from different locations and season. Although, NIR technology has been tested to predict quality parameters of avocado fruit, there have been limited or no investigations using NIRS to determine avocado maturity based on oil content, which is considered the most reliable parameter related to avocado eating quality (Lee et al., 1983; Kaiser, 1994). This research was therefore developed to evaluate the feasibility of using reflectance NIRS to predict maturity parameters of intact 'Hass' avocado fruit.

2. Materials and methods

2.1. Fruit sampling

The research was carried out during 2013 and 2014 seasons using 'Hass' avocado (*Persea americana* Mill.) fruit harvested from commercial farms (Bounty farm and Everdon Estate), located in the cool subtropical area of KwaZulu-Natal, South Africa. During 2013 season, 100 fruit were harvested at random from 20 trees for both destructive and non-destructive measurements from Bounty Farm (Latitude: 29°28′S; Longitude 30°161′E) during the early, (April), mid (July) and late harvesting (September and November) periods. In 2014 season, another set of 55 fruit was sampled from Bounty Farm and Everdon Estate (Latitude: 29°45′S, Longitude: 30°25′E) to add seasonal and orchard location variability even though the orchards share similar environmental conditions. The same sampling procedure and times used in 2013 season were followed in both farms. Harvested fruit were put in crates and immediately transported in a well-ventilated vehicle to the Postharvest Laboratory at the University of KwaZulu-Natal. Fruit were then sorted for size uniformity and absence of physical defects. Upon arrival in the laboratory, fruit were allowed to equilibrate at room temperature overnight, before scanning with NIRS.

2.2. NIR spectra acquisition

The NIR spectra of intact 'Hass' avocado fruit sample were acquired using a method described by Sabatier et al. (2013) with modifications. Briefly, spectral data was acquired in reflectance mode using a laboratory bench-top monochromator NIRSystems Model XDS spectrometer (Foss NIRSystems, Inc., Silver Spring, MD, USA) equipped with a quartz halogen lamp and PbS detector. The spectra were acquired with a circular sample cup with a quartz window (38 mm in diameter and 10 mm in thickness). The equatorial region of avocado sample were carefully positioned on the instrumental sample cup and then placed in an enclosed window before scanning so as to prevent light leakage. The NIR system was operated on Vision software (VisionTM, version 3.5.0.0, Tidestone Technologie Inc., KS, USA). Reflectance spectra were obtained at 2 nm intervals over the 700–2500 nm spectral range. Each spec-