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Research Paper

On-tree indexing of 'Hass' avocado fruit by non-destructive assessment of pulp dry matter and oil content

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Commercial harvest maturity of 'Hass' avocado fruit is estimated based on dry matter content (DM). Typically, a few samples representing the entire orchard are destructively analysed using time-consuming procedures such as oven or freeze drying the fruit's mesocarp. However, the maturity parameter of avocado, that is known to have a direct link to nutritional quality, is oil content (OC). This study was conducted to develop models for indexing maturity of on-tree avocado using a portable visible to near-infrared spectrometer. Rapid non-destructive models for assessing OC, DM and moisture content (MC) of avocado fruit were successfully developed using The Unscrambler® X chemometric software. Models robustness was assessed in an independent test set. There were non-significant differences ($p > 0.05$) between destructive and non-destructively assessed OC in terms of means (42.45 and 41.91%), standard deviations (4.79 and 4.87%) and coefficients of variation (11.34 and 11.62%) from the independent test set. The predictability of OC was associated with its high extractability caused by drying samples at high (75 °C) temperatures. The heat-drying technique can be used by other researchers to increase extractability and hence, the predictability of avocado OC during calibrations of alike non-destructive models. Commercial application of the developed models can improve maturity indexing since OC, DM and MC can be easily assessed without harvesting of sample fruit.

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Nomenclature

DM	Dry matter content
OC	Oil Content
MC	Moisture content
Vis-NIRS	Visible to near infrared spectroscopy
R2	Coefficient of determination
RMSEC	Root mean square error of calibration
RMSECV	Root mean square error of cross validation
RMSEP	Root mean square error of prediction
RPD	Ratio of performance deviation
PLS	Partial least square regression
CV%	Coefficients of variation

1. Introduction

Harvesting fruits at optimum maturity determines their quality and performance in postharvest storage. Fruits harvested when fully mature and containing optimum quantities of vital chemicals stand better chances of having good eating quality, extended shelf life, and high resistance to pathogenic attacks or physiological disorders (Bates, Morris, & Crandall, 2001; Magwaza & Tesfay, 2015; Sudheer & Indira, 2007).

At present, most avocado growers select few sample fruits to estimate when to harvest entire orchards (Magwaza & Tesfay, 2015). Destructive techniques are used to quantify a reference maturity parameter such as mesocarp dry matter content (DM) from selected samples. These techniques are time-consuming and inaccurate because of the human error involved during the random selection of samples and manual analysis based on standard guidelines (Magwaza & Opara, 2015). Fruits at different maturity levels are likely to be grouped together in one batch, which can result in uneven ripening caused by mismanagement of sorting lines, thereby reducing storage potential of the fruit at postharvest (Gwanpua, Qian, & East, 2018; Shivashankar, Sumathi, & Rao, 2017). Dry matter is an important parameter of fresh fruit. Its elevated levels can be directly associated with the fruit's resistance to shrivelling (Travers, Bertelson, Peterson, & Kucheryavskiy, 2014). Dry matter content is quantified as the ratio of dried mass to the fresh mass of a sampled mesocarp portion (Kaur, Kunnemeyer, & McGlone, 2017). DM and moisture content (MC) are complementary ratios, which enables calculation of % MC to be determined from % DM (Magwaza & Tesfay, 2015).

Avocado oil content (OC) is normally quantified by chemical-based extractions using complex laboratory equipment (Meyer & Terry, 2008; Olarewaju, Bertling, and Magwaza, 2016). The prohibitive costs and complexity of OC quantification result in its measurement being avoided on a commercial scale where large number of samples is required to sufficiently represent the whole crop. As a way of finding an alternative to OC analysis, previous studies have demonstrated a negative correlation between the MC and OC of avocado (Carvalho, Velásquez, & Van Rooyen, 2014; Chen, Wall, Paull, & Follett, 2009). Some studies have shown a reciprocal accumulation and depreciation of oil and moisture contents in the mesocarp of the fruit at different developing stages (Lee, Young, Schiffman, & Coggins, 1983; Ozdemir & Topuz, 2004). This implies that the ratio of oil and moisture contents remains constant throughout the life of the fruit, and either of the parameters can be used to calculate the other. At present, South Africa and other major avocado producers such as Australia, Chile, Israel and USA use mesocarp DM as an optimal fruit maturity indicator because of its ease of quantification compared to the OC (Hofman, Bower, & Woolf, 2013; Obenland, Collin, Sievert, Negm, & Arpaia, 2012).

Avocado fruit are harvested mature, but not ready to eat, which necessitates an accurate determination of harvesting time because the fruit are harvested at an immature stage and are likely to desiccate, shrivel, ripen abnormally or have a rubbery texture at postharvest storage resulting in insufficient eating quality (Magwaza & Tesfay, 2015). Estimating harvest maturity based on external appearance is challenging for 'Hass' variety avocado fruit. This is due to its rough surface causing an absence of obvious changes throughout its development stages. Avocado fruit with a range of DM levels from 20 to 40% are considered minimally mature to over mature, respectively (Avocado Certification Program, 2017; Clark, White, Jordan, & Woolf, 2007; Gamble et al., 2010). However, the sole use of DM creates communication issues during export because the preferred parameter for indexing differs from one country to another (Woolf et al., 2003). Increasing the number of reference maturity indices (inclusion of OC analysis) is, therefore, necessary to increase assessment reliability and choice of a parameter to refer to when indexing. Furthermore, it is practical to hypothesise that water availability for uptake by the avocado tree may have a direct effect on the MC but not the OC of fruit. Mystification in correlating DM and OC can happen if the fruit trees experience drought stress due to reduced rainfall, water restrictions due to water shortage and breakdown of the irrigation systems during fruit development.

Non-destructive techniques are popular for determining the internal parameters of fruits. They can possess higher accuracy because of reduced human error and they are rapid, inexpensive and eco-friendly compared to destructive techniques (Lee, Yoo, Choi, Vanrolleghem, & Lee, 2004; Santos, Lopo, Páscoa, & Lopes, 2013). Visible to near-infrared radiation (Vis–NIR) spectroscopy (Vis–NIRS) and chemometrics is one of the most widely used non-destructive techniques (Huang, Yu, Xu, & Ying, 2008; Lin & Ying, 2009; Magwaza et al., 2012; Nicolaï et al., 2007). Vis–NIRS application assesses surface and internal parameters of fruit by illuminating a sample with radiation and measuring the reflected radiation, absorption or transmission while radiation passes through the sample (Nicolaï et al., 2007). A spectrometer measures the change of overtone vibrations occurring in the Vis–NIR region, where overtones or combinations of fundamental biochemical stretching bonds found in organic samples, such as C–H, O–H, N=O, C=H, and N–H, respond (Antonucci et al., 2011). In a reflectance spectrometer this change is plotted and stored as the log of reflectance (1/R) versus wavelength (Lin & Ying, 2009).

Chemometric analysis is applied to extract analytical information from the saved spectrum (Naes, Isaksson, Fearn, & Davies, 2002). Previous studies proposing and demonstrating the ability of Vis–NIRS as a non-destructive technique to