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Evaluation of avocado fruit maturity with a portable near-infrared spectrometer

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ABSTRACT

There is considerable financial incentive for avocado (*Persea americana* Mill.) growers in South Africa to begin harvest as soon as the minimum fruit maturity has been reached. The need to quickly process a large amount of samples for maturity determination pre- and postharvest using a user-friendly instrument provided motivation this study. 'Fuerte', 'Hass' and 'Carmen®-Hass' fruit were included in the calibration of the portable near-infrared spectrometer. The calibration included fruit from three seasons and the external validation included fruit from two further seasons. With this portable NIR spectrometer, it was not possible to develop a calibration model to accurately measure the maturity of avocado fruit non-destructively ('Fuerte': $R^2 = 0.654$, RMSECV = 2.62, $RPD_{CV} = 1.23$, 'Hass' and 'Carmen®-Hass': $R^2 = 0.400$, RMSECV = 2.94, $RPD_{CV} = 0.79$). A model incorporating all three cultivars, with the fruit peel removed, provided comparable results to the commercial method when using at least four fruit per sample ($R^2 = 0.732$, RMSEP = 1.83, RPD = 1.14). The measurement of a single fruit took 30s, and could be conducted pre- or postharvest.

1. Introduction

In general, the commercial maturity index of avocado fruit is dry matter (DM) (Kader, 1997) while the complementary parameter of moisture content (MC) is used in South Africa (Anonymous, 1990). This research was conducted in South Africa so MC is used but the results are equivalent for both parameters, and the term MC/DM is used. Previously, oil content was used as the avocado maturity index, but was changed to MC/DM once it was found that there is a strong correlation between MC/DM and oil content and MC/DM is cheaper, quicker, and safer to measure (Swarts, 1976; Holzapfel and Kuschke, 1977; Arpaia et al., 2001). The minimum maturity of avocado fruit is determined in the country of origin for each cultivar. In South Africa, the minimum maturity for 'Fuerte' is 80% MC (20% DM) and for 'Hass' and 'Carmen®-Hass' it is 77% MC (23% DM) (Anonymous, 2010).

There is increasing interest in the non-destructive determination of fruit maturity and quality (Nicolaï et al., 2006). There have been of a number of studies, including related studies by the author, to determine the MC/DM of avocado fruit using near-infrared spectroscopy (NIRS) (Schmilovitch et al., 2001; Clark et al., 2003; Walsh et al., 2004; Blakey et al., 2009, 2015; Blakey and van Rooyen, 2011a; Blakey, 2014; Olarewaju et al., 2016) with the seminal work done by Wedding et al. (2011, 2013). Their study, using Fourier transform-NIRS, done over a period of three seasons provided validation results of $R^2 = 0.89$, RMSEP = 1.43% DM, and bias = −0.021% DM, in the range 16.1–39.7% DM (Wedding et al., 2013). The determination of avocado fruit maturity, including the use of NIR spectroscopy, was reviewed by Magwaza and Tesfay (2015).

The non-destructive determination of a range of fruit crops using handheld NIR spectrometers have been investigated (Teixeira dos Santos et al., 2013 and references therein). More specifically, the ability of the Phazir handheld NIR spectrometers has been evaluated to determine the internal quality of apricots (Christen et al., 2012), grapes (*Vitis vinifera*) (González-Caballero et al., 2012), mandarins (*Citrus reticulata*) (Sánchez et al., 2013), nectarines (*Prunus persica* var. *nucipersica)* (Sánchez et al., 2011), plums (*Prunus domestica*) (Pérez-Marín et al., 2010), and strawberries (*Fragaria* × *ananassa*) (Sánchez et al., 2012).

The aim of this study was to develop robust and accurate models for a portable NIR spectrometer to determine the MC of three major avocado cultivars ('Fuerte', 'Hass' and 'Carmen®-Hass') in South Africa.

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2. Materials and methods

A Phazir 1018 handheld micro-electro-mechanical system (MEMS)-based NIR spectrometer (Thermo Fisher Scientific Inc., Wilmington, MA, USA), working in reflectance mode (log(1/*R*)), was used in this study. This instrument operates in the wavelength region of 940–1798 nm with a resolution of 8–9 nm with 100 datapoints per spectra. The integration time was 6 s. Partial least squares (PLS) regression was done using Latentix (v2.12, LatentiX Aps, Frederiksberg, Denmark) and Polychromix Method Generator (v 3.101.0.0, Thermo Fisher Scientific). The mean standard deviation of 20 reference tile spectra was 3.16×10^{-4}.

2.1. Calibration

Avocado fruit were obtained from 132 commercial avocado orchards from 18 farms in Tzaneen (23°50′S, 30°10′E), Mooketsi (23°39′S, 30°00′E), Morebeng (23°26′S, 30°00′E) and Levubu (23°05′S, 30°17′E) in Limpopo Province, South Africa between 2011 and 2013. 'Fuerte', 'Hass', and 'Mendez No. 1' (fruit marketed as 'Carmen®-Hass') fruit were used.

For the calibration of the instrument in the 2011–2013 seasons, fruit were scanned at four or six equidistant, marked points around the equator of each fruit, depending on the size of the fruit. Fruit were scanned with the peel intact and then with the peel removed. Fruit were harvested between 08h00 and 11h00 and fruit were scanned and flesh MC was measured gravimetrically within 2 h of harvest. Flesh samples (approximately 1.0 g) were taken from each of the marked areas using a cork borer (15 mm diameter). Each core was halved and the outer half was oven-dried at 75 °C for at least 24 h and the inner half discarded (Blakey, 2013, 2014). This is referred to as the standard method henceforth. MC and DM are complementary (MC + DM = 100%), and only South Africa uses MC as a harvest index for avocados, "MC/DM" is used.

Cross validation was done by randomly selecting 25% of the samples in the dataset, reiterated 10 times, and the mean values used from the 10 iterations to determine the Root Mean Standard Error of Cross Validation (RMSECV) and Residual Prediction Deviation of Cross Validation (quotient of SD_Y/RMSECV; RPD_{CV}).

2.2. Internal validation

Internal validations were performed annually (Blakey and van Rooyen, 2011b; Blakey, 2013, 2014), and the results from a subset of fruit from the 2013 season are presented. The standard method for MC/DM was used. A sub-sample of 'Hass', 'Carmen®-Hass', and 'Fuerte' fruit harvested in calendar weeks 7–9 was randomly selected and incorporated fruit from seven farms and 39 orchards; these samples were not included in the calibration. This period was selected because there were mature and immature fruit on the trees. The two successful models ('Fuerte' fruit intact, and 'Hass', 'Carmen®-Hass', and 'Fuerte' peel removed) from the calibration stage were evaluated to determine the Root Mean Standard Error of Prediction (RMSEP) and Residual Prediction Deviation of Prediction (quotient of SD_Y/RMSEP; RPD_P).

2.3. External validation

To determine commercial acceptability of the portable NIR spectrometer, an external validation was done over two seasons (2014 and 2015) at a commercial packhouse in Tzaneen.

Avocado fruit MC was determined using the NIR spectrometer (peel removed) and the standard commercial method (Anonymous, 2010) on the same fruit. The MC of four fruit per orchard per week (total of 261 orchards) was measured using the two methods between calendar weeks 5 and 17 of both seasons. Fruit were sourced from orchards from the same farms in Tzaneen and Mooketsi that were used in the calibration. The fruit MC was initially measured using the NIR spectrometer at four equidistant points around the equator of the fruit, and the average of the four readings used as the MC of each fruit.

The fruit MC was then measured using the standard commercial method. Briefly, a fruit is bisected, and a grated 10 g sample of fruit flesh is dried in a microwave oven. This resulted in a sampling area discrepancy between the two methods. As results from the commercial method use individual fruit as a sample unit, and resulted are presented on an orchard basis, the results of the external validation are presented as such.

3. Results and discussion

3.1. Calibration and internal validation

This study concurs with the findings of Wedding et al. (2013) that at least three seasons' data were necessary to develop a robust model for the measurement avocado MC/DM. The model for measuring the MC of intact 'Hass' and 'Carmen®-Hass' fruit was unsuccessful with a residual prediction deviation (RPD_{CV}) of 0.79 and R^2 = 0.400. It is suggested that this is because of the thickness and rough texture of the peel, combined with the spectrometer's design, which reduced light penetration into the flesh and increased noise and specular reflectance, and the removal of the peel before measurement can improve model performance (Wedding et al., 2011). The model for intact 'Fuerte' fruit was improved (RPD_{CV} = 1.23 and R^2 = 0.654). This was probably due to the thinner peel of 'Fuerte' fruit resulting in increased light penetration into the flesh. However, this calibration model was also insufficient for commercial use (Table 1) The model for intact

Table 1
Calibration and cross validation statistics for moisture content (MC) of avocado fruit from the 2011–2013 seasons using a portable NIR spectrometer.

Fruit Tissue	Cultivars	n	Pre-Processing	λ Range (nm)	LV	R^2	$\bar{X}$ (% MC)	$\bar{Y}$ (% MC)	SD_X	SD_Y	$Bias_C$	$Bias_{CV}$	RMSEC	RMSECV	RPD_{CV}
Flesh Only	Fuerte, Hass, Carmen®-Hass	9948	SG 1,3,2	939–1797	7	0.830	76.4	76.4	5.33	4.85	4.1×10^{-7}	5.8×10^{-3}	2.20	2.25	2.16
Intact Fruit	Fuerte	9966	SG 1,3,2; NR	985–1733	8	0.654	79.0	79.0	4.00	3.23	-2.2×10^{-6}	7.0×10^{-2}	2.47	2.62	1.23
	Hass, Carmen®-Hass	8235	MSC	952–1756.4	7	0.400	76.0	76.0	3.68	2.33	1.2×10^{-5}	2.1×10^{-2}	2.85	2.94	0.79

n, number of samples; λ Range, NIR wavelength range; LV, Latent variable; R^2, coefficient of determination; $\bar{X}$, Mean using standard method; $\bar{Y}$, Mean using NIR spectrometer; SD_X, Standard deviation using standard method; SD_Y, Standard deviation using NIR spectrometer; $Bias_C$, Bias of calibration; $Bias_{CV}$, Bias of cross validation; RMSEC, Root mean square error of calibration; RMSECV, Root mean square error of cross validation; RPD_{CV}, residual prediction deviation of cross validation; SG 1,3,2, Savitsky-Golay with 1st derivative, 3 point smooth, 2nd order polynomial; NR, Normalise Range; MSC, Multiplicative scatter correction.