Non-destructive measurement of moisture content using handheld NIR

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ABSTRACT

The non-destructive measurement of early season fruit is a priority for the South African avocado industry. Handheld NIR (Phazir 1018, Polychromix) was investigated because it offers the opportunity to measure fruit maturity pre- and post-harvest. 'Fuerte' and 'Hass' fruit were collected from a number of Westfalia farms from the beginning of September to the end of October 2010 for moisture content testing. For each fruit, each quarter was scanned in duplicate at the equator and sampled immediately for moisture content analysis. Results from 2010 and early 2011 were promising. The resulting equation had a range of 50-87% MC, correlation of 96% and standard error of prediction = 2.8% MC. In a smaller experiment, the skin of fruit was removed prior to scanning to determine the effect of the skin on readings. If the skin was removed before scanning, the standard error of prediction improved to 2.2% MC. Work will continue in 2011 to increase the range and validate the equation to ensure that it is sufficiently robust to accurately measure the moisture content of fruit from any grower.

INTRODUCTION

Early season fruit fetch a premium, leading to some fruit being harvested when still immature, *i.e.* fruit that will not reach eating ripeness, resulting in consumer dissatisfaction at the costly poor quality. The current method to measure maturity is unsuitable to large sample sizes because it is destructive and labour intensive; it is also open to manipulation to attain a false minimum maturity. Publications on the use of NIR on avocados are scant but it has been shown to be able to measure dry matter or moisture content (Blakey *et al*., 2009; Clark *et al*., 2003) and has potential for use throughout the avocado industry (Blakey *et al*., 2008). Handheld NIR can be used as a method for the rapid non-destructive measurement of maturity pre- or post-harvest. Handheld NIR has been used to measure the internal quality of a number of fruit, including: mangoes (Subedi *et al*., 2007; Walsh & Subedi, 2010), plums (Pérez-Marín *et al*., 2010), nectarines (Pérez-Marín *et al*., 2011) and grapes (Haibach, 2008). Handheld NIR will enable large proportions of an orchard to be sampled repeatedly to provide a representative estimation of maturity. This is important because the maturity of fruit within an orchard or even a single tree is highly variable because of asynchronous flowering, fruit position on the tree and differential water relations.

The aim of this research was to develop a robust, accurate model to measure the moisture content of 'Fuerte' and 'Hass', and possibly other cultivars, across the full range of avocado maturity.

MATERIALS AND METHODS

Fruit

Fruit were obtained from a number of different farms and with a broad range in maturity for the model to be representative for future samples to be analysed. Late season 'Fuerte' and 'Hass' fruit were obtained from six Westfalia farms in the Tzaneen area from the beginning of September to the end of October 2010. During 2011 early season 'Fuerte' were harvested weekly from growers in Levubu and Tzaneen, and 'Ettinger' was harvested weekly from a grower in Hoedspruit.

Spectrum collection

Reflectance spectra were collected using a Phazir 1018 (Thermo Scientific, Wilmington, MA, USA). This instrument contains a tungsten light source, micro-electromechanical system (MEMS) spectrophotometer and a single InGaAs photodetector. This instrument has an 8 nm pixel resolution and 11 nm optical resolution with a spectral range of 1,000 – 1,800 nm. The instrument has no moving parts and in-built shock absorbers to enable the instrument to be safely used in-field.

Spectra were collected at five or six points around the equator of each fruit in duplicate, rotating the fruit 90° between duplications. The average of five scans was taken to provide one spectrum. The collection time per spectrum was five seconds.

Moisture content analysis
Samples were taken from the scanned area using a 15 mm cork borer. The skin was removed and approximately 1 g of flesh used to determine the moisture content. Samples were oven-dried for approximately 18 h.

Chemometric analysis
The chemometric analysis was done using Polychromix Method Generator™ version 3.101. The sample set was randomly and equally divided between the calibration and external validation set. Various pre-treatments were tested and it was found that a Savitzky-Golay (SG) derivative and a Standard Normal Variate (SNV) transformation were the most suitable pre-processing treatments. The SG derivative was a second order derivative with five point third order polynomial smoothing. Spectra with a Mahalanobis distance greater than 3.0 were deemed as outliers and were mostly because of poor spectral quality.

RESULTS AND DISCUSSION

Model for Moisture Content of Whole Fruit
The partial least squares (PLS) model was developed using seven principal components. The model had an excellent correlation (0.96) across the range of 51-86% moisture, but the standard error of calibration (SEC) and prediction (SEP) were higher than preferable. However, it must be pointed out that the error from the oven drying method is incorporated into the SEC and SEP (**Table 1**). The bias, or systematic error, in the calibration and validation sets is negligible.

As can be seen in **Figure 1**, the data set was not complete at the time of publication. More samples in the range of 71-79% MC need to be added to the model and this will be done in the 2011 season.

Table 1. Statistics of calibration and external validation sets of the model to measure moisture content of whole fruit using a Phazir 1018.

Statistic	Calibration	Validation
Samples	2795	2672
Range	51-85%	51-86%
Correlation	0.96	0.96
Standard error	2.78	2.78
Bias	$5.32x10^{-8}$	$-6.77x10^{-2}$

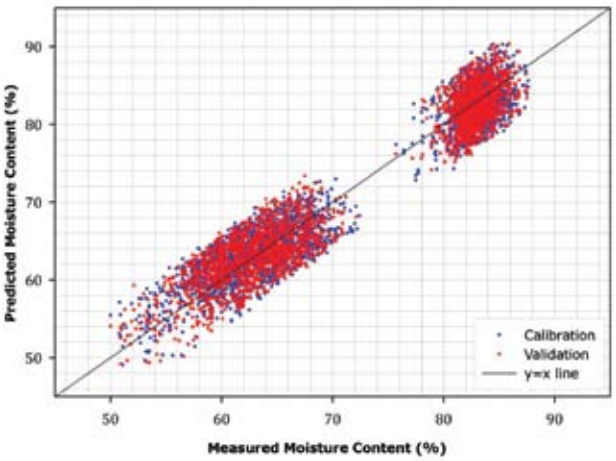

Figure 1. Measured vs. predicted moisture content for the calibration set (•) and external validation set (•) for the model developed to measure moisture content of whole fruit using a Phazir 1018.

Effect of skin on accuracy
A smaller experiment was conducted to ascertain the effect of the skin on the accuracy of readings, because the Phazir 1018 operates with a reflectance data collection method, meaning the NIR light has a limited penetration depth (approximately 5 mm) into the fruit. The removal of the skin and scanning the flesh directly reduced the SEP to 2.2% MC. This method is destructive and cannot be used for tracking fruit maturity pre-harvest. The only advantage this type of measurement can offer is the speed of analysis, compared to oven or microwave drying methods.

Method comparison
Three methods were compared to highlight the advantages and disadvantages of each (**Figure 2**). A pooled sample of ten fruit is currently recommended for the determination of fruit maturity in South Africa. For the pooled samples, the fresh mass (approximately 10 g) and dry mass of ten fruit were used to determine the average moisture content.

Accuracy
A major disadvantage of using a pooled sample is that it does not give any indication of the distribution of maturity of the fruit. As can be seen in Figure 2, there can also be appreciable differences in moisture content in fruit from the same orchard; in this example there was a 0.5% MC difference using the pooled samples, and the range when using the single fruit oven method was 7.3% MC, and when using the handheld NIR it was 10.7% MC, indicating that

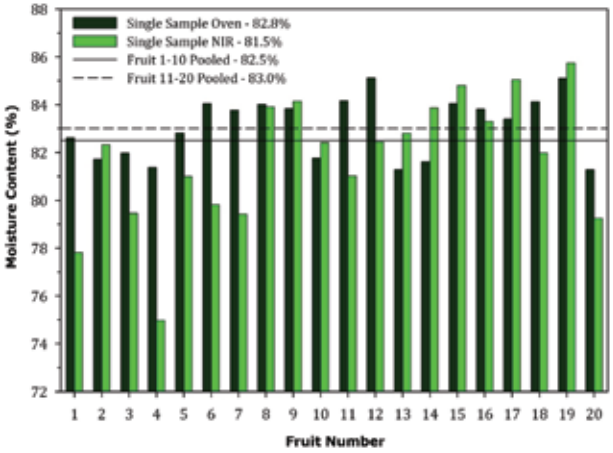

Figure 2. Comparison between moisture content measured on 20 fruit from Levubu using three methods: oven-dried single sample, handheld NIR single sample and oven-dried pooled samples. Means are provided in the legend.

there is considerable variation within a small sample of fruit. This difference could result in a false positive and fruit being harvested before being mature.

Time

The single fruit oven-dried method provides a distribution of the fruit maturity, but to measure the moisture content on ten samples will take up to an hour, excluding drying time which is at least 12 hours. In terms of analysis, the standard microwave oven drying method has an analysis time of at least 30 minutes.

The analysis time of the handheld NIR, scanning opposite halves of ten fruit, is 3-5 minutes and this method also provides a distribution of the fruit maturity. This distribution of maturity can be used for selective picking of more mature fruit – *e.g*. outside or fruit on the north-facing side of the tree. It is acknowledged that the handheld NIR underestimated four of the 20 fruit by greater than 4.0% MC (fruit 1, 4, 6 and 7), but this is expected with a standard error of prediction of 2.78% MC. This higher error is counter-balanced by being able to take many more samples non-destructively compared with the oven drying methods.

Cost and application

Both oven-drying methods are far cheaper than NIR, but the number of samples that can be analysed is limited and far from representative of the orchard mean. Handheld NIR can be used to ascertain the fruit maturity non-destructively pre-harvest to provide a representative sample of the orchard maturity without any fruit loss and greatly reduce the risk of harvesting immature fruit.

CONCLUSION

Handheld NIR can be used for the rapid non-destructive estimation of moisture content of avocados across the full range of moisture content. Handheld NIR can be used to take a representative sample of fruit maturity to reduce the risk of harvesting immature fruit. The use of handheld NIR to measure moisture content in avocado has progressed well to date; however, it is not at the commercial implementation stage at present. The project will continue during the 2011 season to complete the range of maturity from 50-87% MC and improve the accuracy of the model.

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