

Non-destructive measurement of moisture content in avocado's using handheld near-infrared spectroscopy

Medición no-destructiva de la madurez de aguacates usando un NIR manual

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Abstract (English)

The non-destructive measurement of maturity in early season avocado fruit is a priority for the South African avocado industry. Thus the measurement of maturity using a handheld near-infrared (NIR) gun was investigated because it offers the opportunity to measure fruit maturity both pre- and postharvest. 'Fuerte' and 'Hass' fruit were harvested from a number of farms from the 2010 and 2011 seasons for maturity testing. For each fruit, each quarter was scanned, in duplicate, around the equator and sampled immediately for moisture content (MC) analysis. Samples were oven dried for 18h at 70°C. The resulting Partial Least Squares regression model had a range of 51-86% moisture content (49-14% dry matter), the correlation between actual and predicted values was 96% and the standard error of prediction (SEP) of the independent test set was 2.8% MC. In a smaller experiment, the skin of fruit was removed prior to scanning to determine the effect of the skin on the SEP as this instrument operates in reflectance. If the skin was removed before scanning, the SEP improved to 2.2% MC. Although the SEP is relatively high, this method compares favourably to the current commercial method of maturity determination, which does not account for the large variation between fruit in the same orchard because samples from different fruit are pooled and only a small sample is taken; the use of handheld NIR will permit the non-destructive measurement of fruit maturity on a large number of fruit and provide a distribution pattern of the maturity of those fruit.

Abstract (Spanish)

La medición no-destructiva de fruta temprana es una prioridad para la industria aguacatera Sudafricana. Se investigó la medición de madurez utilizando un NIR manual (Phazir1018, Polychromix) que ofrece la opción de medir la madurez de la fruta en pre y post cosecha. Se cosechó fruta de variedad 'Fuerte' y 'Hass' de varios huertos en las temporadas 2010/2011 para pruebas de madurez. Para cada fruto, cada cuarto se escaneó, en duplicado, en el ecuador y fue testeada inmediatamente para un análisis de contenido de humedad. Las muestras se secaron en horno por 18h a 70°C. El resultado de la regresión de Mínimos Cuadrados Parciales tuvo un rango de 51-86% de contenido de humedad (49-14% materia seca), la correlación entre valores reales y predichos fue de 96%. El error estándar de predicción (SEP) del test independiente fue 2.8% MC. En un experimento menor, la piel del fruto se removió antes de escanearla para determinar su efecto en el SEP (este instrumento opera con reflectancia). El SEP mejoró a 2.2% MC. Aunque es relativamente

alto, este método compara favorablemente al método actual de determinación de madurez, el cual no contabiliza la gran variación entre frutos en un mismo huerto, ya que las muestras de distintos frutos se mezclan y sólo se toma una pequeña muestra; el uso de una máquina manual de NIR permitirá una medición no-destructiva de la madurez de la fruta en una gran cantidad de frutos y proveerá un patrón de distribución de la madurez.

Keywords: non-destructive, near-infrared, avocados, maturity

Introduction

Early season South African avocado fruit fetch a premium on the European market, leading to some growers harvesting immature fruit, i.e. fruit that will not reach eating ripeness, resulting in consumer dissatisfaction at the costly poor quality. The current commercial 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, Bower and Bertling 2009; Clark, McGlone, Requejo, White and Woolf 2003; Wedding, White, Grauf, Wright, Tilse, Hofman and Gadek 2011) and has potential for use throughout the avocado industry. Handheld NIR can be used as a method for the rapid non-destructive measurement of maturity pre- or postharvest. Handheld NIR has been used to measure the internal quality of a number of different fruit, including: mangoes (Walsh and Subedi, 2010, Subedi, Walsh and Owens, 2007), plums (Pérez-Marín, Paz, Guerrero, Garrido-Varo and Sánchez, 2010), nectarines (Pérez-Marín, Sánchez, Paz, González-Dugo and Soriano, 2011) and grapes (Haibach, 2008). Handheld NIR will enable a larger proportion of the fruit in an orchard to be sampled repeatedly to provide a more representative estimation of fruit maturity. This is important because the maturity of fruit within an orchard - and even a single tree - is highly variable because of asynchronous flowering, fruit position on the tree and differential water relations; the moisture content in an orchard can also have a range of 10% at a given time.

The aim of this research was to develop a robust, but accurate model to measure the moisture content of South African 'Fuerte' and 'Hass' fruit across a wide range of avocado maturity.

Materials and methods

Fruit

'Fuerte' and 'Hass' fruit were obtained from a number of different farms in the Tzaneen and Levubu growing regions (Limpopo Province, South Africa). The range in moisture content was 86 % to 51 % - the equivalent dry matter (DM) values are 14 % and 49 %.

Spectrum Collection

Reflectance spectra were collected using a Phazir 1018 (Thermo Scientific, Wilmington, MA, USA). 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 each scanned area using a 15 mm cork borer. The skin was removed and approximately 1 g of mesocarp used to determine the moisture content. Samples were oven-dried (70°C) for approximately 18 h. Approximately 20,000 samples were used in the model generation.

To determine the internal variation within a sample, a 2 g mesocarp core was vertically divided into two pieces and the MC of each segment determined.

A pooled sample of 10 fruit is currently recommended for the determination of fruit maturity in South Africa. The fresh mass (approximately 10 g) and dry mass of 10 fruit were used to determine the average MC.

Chemometric Analysis

The chemometric analysis was done using Polychromix Method Generator™ version 3.101 (Wilmington, MA, USA). The sample set was randomly and equally divided between the calibration and external validation set. A Savitzky-Golay (SG) derivative and a Standard Normal Variate (SNV) transformation were the most suitable pre-processing treatments. The SG derivative was a five point smoothing with a second order derivative with a third order polynomial smoothing. Spectra with a Mahalanobis distance greater than 3.0 were deemed as outliers and removed from the data set.

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 ($R^2 = 0.96$) across the range of 51-86 % moisture but the standard error of calibration (SEC) and prediction (SEP) were higher than preferable (Table 1), but the error from the oven drying method is incorporated into the SEC and SEP. The standard deviation in a MC sample divided into two pieces was 0.4 % MC. The results were comparable to published results for the measurement of avocado DM or MC using reflectance NIR (Clark et al, 2003, Blakey et al, 2009). When diffuse reflectance NIR was used (greater penetration depth of the light into the fruit), the SEP was 1.53 % DM (Wedding et al, 2011).

Table 1: Statistics of calibration and external validation sets of the model to measure moisture content of whole avocado fruit using a Phazir1018.

Statistic	Calibration	Validation
Range	51.1-85.3%	50.9-85.9%
Correlation	0.96	0.96
Standard Error	2.78	2.80

Effect of Skin on Accuracy

A smaller experiment was conducted to ascertain the effect of the skin on the accuracy of readings, because the Phazir1018 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 mesocarp directly reduced the SEP to 2.2 % MC; this was also noticed by Wedding et al (2011). This method is destructive and cannot be used for tracking fruit maturity pre-harvest, but does offer reduced analysis time compared to oven or microwave drying methods.

Maturity in a Commercial Orchard

The weekly average maturity and percentage of mature fruit of 20 fruit from an outside grower's orchard in Levubu (an early maturing region in South Africa) illustrate the shortcomings of using an average maturity method (Figure 1). Average moisture content declined from 84.5 % to 79.9 % during the six week period while the percentage of mature fruit increased from zero to 55%. The orchard was strip-picked on the 9th of March, when the average maturity was below the legal maturity level of 80 % MC.

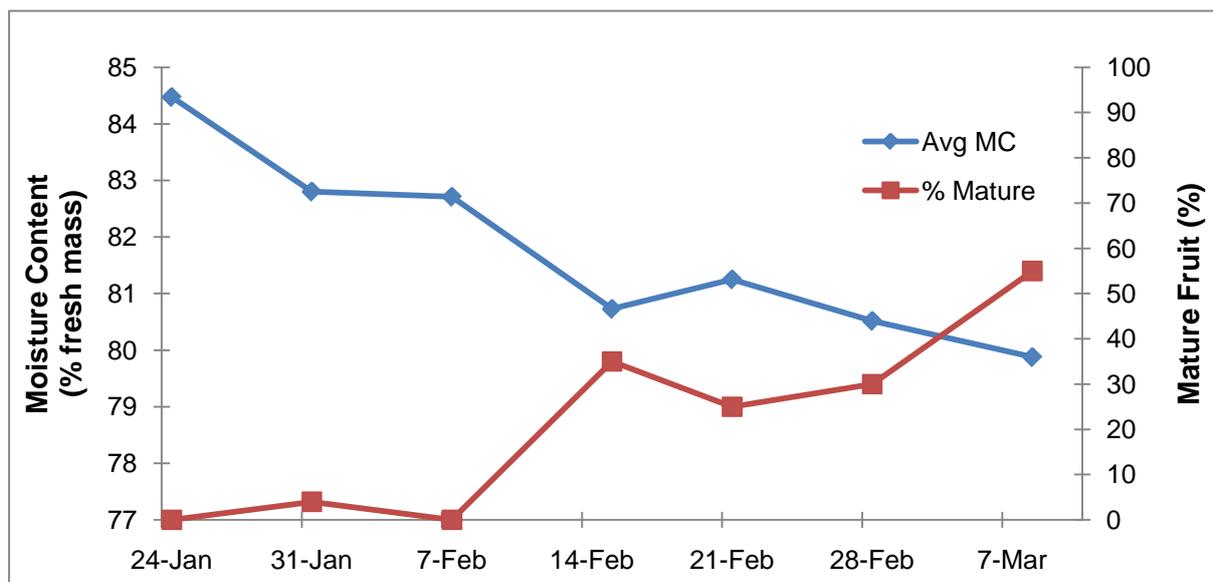


Figure 1: Average moisture content readings (left-hand Y-axis) and the percentage of legally mature fruit (right-hand Y-axis) from a 'Fuerte' orchard in an early maturing avocado region of South Africa taken during a six week period in 2011. Legal maturity is set at 80% MC or 20% DM.

Discussion

A major disadvantage of using a pooled sample for maturity determination, as is commercially done, is that one is only provided with an average, without any indication of the distribution of the fruit

maturity. As was the case of a commercial orchard in the 2011 season (Figure 1), a misleading, but legal, maturity value can result in the fruit being harvested before many of the fruit are mature. In this orchard, only 55% of the sampled fruit were mature two days before harvest. The large proportion of immature fruit harvested and sold to consumers would have resulted in consumer dissatisfaction and would also have negatively affected later sales in the market. It is acknowledged that there is a financial incentive to harvest fruit as early as possible, but the orchard could be non-destructively sampled using handheld and the harvest delayed until all the fruit are mature to ensure ripeness and improve eating quality.

Convection or microwave 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 average. As food prices are increasing, and consumers are becoming more discerning, growers and agri-processors need to move towards precision agriculture, necessitating the use of technology like NIR. For avocados, 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 thus greatly reduce the risk of harvesting immature fruit. Handheld NIR can also be used in conjunction with online NIR in the packhouse and ripening facility. The technology is costly, but it can be managed by a growers' association or co-operative to optimally utilise the expensive equipment.

Conclusion

Handheld NIR can be used for the rapid non-destructive estimation of moisture content or dry matter of avocados across a wide range of fruit maturity. This can be used to take a more representative sample for fruit maturity to reduce the risk of harvesting immature fruit. Further testing will continue to improve the accuracy of the estimated values of avocado MC, as an indication of maturity.

Acknowledgements

The financial support from the Hans Merensky Foundation, Westfalia Fruit Estates and SAAGA is gratefully acknowledged. Thanks are extended to Shirley Mathelemuse, Therese Bruwer and Stephanie Roberts. Grateful thanks to Amana, Bridelia, Bavaria Fruit Estates, Ledzee Estates, Westfalia Fruit Estates and Wolkberg for the donation of fruit.

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