The potential of near-infrared spectroscopy in the avocado industry

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ABSTRACT
Avocado fruit ripening and quality characteristics are often variable, making marketing and logistical decisions difficult. Near-infrared spectroscopy (NIRS) is a non-destructive technique which should be suitable for on-line measurement of various quality related factors. The various methods of measurement (reflectance, transmission and interactance) are outlined and discussed with respect to their suitability for use on avocado fruit. The present use of NIRS for the quality evaluation of various horticultural crops as well as the technical difficulties leading to the present limitations of use are discussed. Despite these limitations, it is suggested that the technique is a useful addition to packhouse operations and its application could lead to better marketing and logistical management decisions, and higher quality fruit for the consumer.

INTRODUCTION

Avocados are physiologically variable fruit and despite concerted efforts to minimise this variation using maturity indexing and quality parameters such as fruit mineral content measured in samples taken prior to harvest and grading, fruit remain highly variable. This results in variation within a shipment in ripening rates, shelf life and quality. Such variability within consignments makes it particularly difficult to manage the marketing of fruit, especially for the "ready-ripe" market. The difficulties arise because of the differences in development and physiology of avocado fruit within trees, orchards and regions. Although some parameters affecting ripening or fruit quality are known, orchard sampling using destructive tests only provides a general indication of the attributes of a consignment, without being able to determine information relating to any specific fruit. If a means can be developed to measure critical quality parameters in individual fruit non-destructively, grading and packing may yield more uniformly ripening consignments, allowing the packer, shipper and marketer to formulate decisions and protocols with greater accuracy. In addition, if a means to predict shelf life or quality can be included, greater consumer confidence in the product and higher returns are likely. Near-infrared spectroscopy (NIRS) is capable of rapid non-destructive measurement of a range of organic compounds.

The purpose of this literature review is not to provide a comprehensive, scientific review but rather to demonstrate the potential of this technology for the avocado industry, in particular for the measurement of fruit maturity based on a moisture content basis. Recent reviews on the use of NIR technology in agriculture and the food industry have been published by Roberts *et al*. (2004) and Williams *et al*. (2001). These reviews provide detailed chemical, physical and statistical theory behind NIR spectroscopy and analysis.

BACKGROUND

Near-infrared spectroscopy is a non-destructive technique using electromagnetic radiation in the region of 780 to 2500 nm (Workman *et al*., 2004). The primary information that can be gathered from the interaction of NIR radiation with biological materials is its molecular composition, due to the stretching and bending of CH, OH and NH bonds in the material (Workman & Shenk, 2004). NIR is a remarkable analytical technique. Analysis time is less than 30 seconds, it is non-destructive, versatile (able to measure compounds with concentrations of 0.1%), and easy to use (Burns *et al*., 2001).

NIRS was largely developed by Karl Norris of the US Department of Agriculture, starting in the 1960s, for the analysis of a range of compounds in agronomic crops such as moisture content in soybean and fat content in milk (Raghavachari, 2001; Roberts *et al*., 2004). The prediction of chemical compounds is achieved by calibrating NIR spectral information against laboratory reference data (Workman & Shenk, 2004). A calibration equation is then developed to predict concentrations of the compounds in future samples. To be useful commercially, a calibration equation should include samples from various production locations, seasons and cultivars – if relevant. It is possible to obtain a stable global calibration equation if the sample set has sufficient variation in the above mentioned factors (Kawano, 2002). This global calibration equation will thus be able to accurately measure the compound of interest in any sample, i.e. avocado fruit.

MEASUREMENT TECHNIQUES

There are three means of measuring a sample's NIR absorption spectrum: reflectance, transmission and interactance. In reflectance mode, the light source and detector are located on the same side of the sample. In transmission mode, the two components are located on opposite ends of the sample, while interactance measures the unabsorbed (i.e. internally reflected) light from a sample, on the same side as the light emitter.

Reflectance NIR has been used for about half of the research on fruit and vegetables, with transmission and interactance comprising about 25% each (Slaughter *et al*., 2004). Reflectance and transmission spectrophotometry are the traditional methods, and are applicable if the surface of the sample is of interest or similar to the interior (or the skin sufficiently thin to absorb a minimal amount of radiation).

Interactance spectrophotometry allows the optical absorption spectrum to be collected from intact, optically dense biological specimens of irregular size and does not require a correction for pathlength differences for fruit of different sizes. Birth *et al*. (1984) could distinguish between the later maturity stages of papayas using reflectance NIR, but not between immature and mature green fruit. Using interactance, this discernment was possible. Schaare *et al*. (2000) compared all three modes of NIRS and found that interactance proved the most accurate in predicting soluble solid content, density and internal colour. They concluded this was because the interactance mode is less affected by the peel and had a superior signal / noise ratio (i.e. more sensitive) when compared to direct transmission. Interactance NIR may be the best option for the avocado industry (especially whole fruit) because of the above reasons. To illustrate this point, the correlations between NIR measurement and actual determination of compounds of interest from (Clark *et al*., 2003) and the authors' research in 2007/8 are included in **Table 1**.

Table 1. Comparison of correlation (R^2) and standard error (SE) using reflectance and interactance modes between near infrared spectroscopy and actual measurements of compounds of interest.

Mode of detection	Clark *et al*. (2003)		Current research
	Interactance	Reflectance	Reflectance
R^2	0.88	0.75	0.92
SE	1.8% DM	2.6% DM	2.0% MC

Although R^2 values of the current research appear good, it is notable that the standard error term is considerably greater for the reflectance mode. This means that there will be greater accuracy in predictions if the interactance mode is used. The possible need for interactive mode equipment will complicate the online implementation of NIR, because the probe needs to be in contact with the fruit during the scan. Some commercial companies are using the interactance mode (Clark *et al*., 2003) but most commercial machinery is in reflectance mode.

USE ON HORTICULTURAL CROPS

NIR has been used for decades for analysing grains and seeds but has had limited use in horticultural crops because fruit and vegetables contain large amounts of water (water dominates the spectrum, complicating the prediction of other compounds), have an irregular shape (which results in pathlength differences), are highly heterogeneous, and have a thick rind or skin (Slaughter & Abbott, 2004). The larger sample size of fruit – compared to grains – decreases accuracy of prediction because NIR radiation will only penetrate 3-10 mm into the product (Workman & Shenk, 2004). The development of the interaction probe (Kawano, 2002) solved the problem with sample shape and presentation.

Apples (Malus domestica Borkh.) are the most commonly studied fruit in NIRS (Slaughter & Abbott, 2004). A number of compounds and attributes have been successfully determined non-destructively: bruised tissue, water core, external colour, firmness, fructose, glucose, sucrose, sorbitol, malic acid, dry matter, maturity, water content, nitrogen, pH, total acidity, and total soluble solids (TSS) (Slaughter & Abbott, 2004).

Very little research has been published on the use of NIRS in avocado. Work has been done to measure dry matter in 'Hass' (Clark *et al*., 2003; Schmilovitch *et al*., 2001; Walsh *et al*., 2004) and the concentration of perseitol (a seven-carbon sugar alcohol unique to avocado) in honey (Dvash *et al*., 2002). However, there is a lack of research into the prediction of organic compounds in avocado and avocado products. Nevertheless, "there is considerable potential for its use in packing house lines as a non-destructive indicator of maturity" (Hofman *et al*., 2002).

The technology is commercially used in pack houses in Japan and New Zealand. Sugar content is estimated in apple, peach and pear (Kawano, 1994) and as a commercial oil test in oil seeds (Williams and Sobering, 1993). In 1989, the Mitsui Mining and Smelting Co. Ltd. developed the first machine to sort according to internal quality. Apples, peaches and Japanese pears were sorted according to Brix value on-line by this machine. The machine used reflectance NIR and could sort fruit at a rate of 3 fruit/s/lane (Kawano, 1994). With similar machines, on-line sorting for quality becomes possible. If this data can be correlated to corresponding producing conditions and practices such as soil condition, fertilization rates, climate, irrigation and harvest date, better guidance for high-quality production will be possible (Kawano, 2002).

Dry matter (DM) percentage (or the complementary value of moisture content in South Africa) is used as an industry standard for maturity (Hofman *et al*., 2002). While oil content is the most reliable indicator of maturity (Kaiser, 1994), its determination is costly and time-consuming. Total oil content and DM are strongly correlated (Lee *et al*., 1983; Ranney, 1991) hence DM is used as the industry standard. The relationship between DM and ripe fruit quality is sometimes not accurate, indicating a need for an improved standard (Hofman *et al*., 2002).

NIRS can be used to predict maturity more accurately by non-destructively measuring total oil content, or dry matter. With newer technology becoming available, there is potential to use NIRS on-line in pack houses to rapidly measure a range of compounds.

The ability to predict the number of days a fruit takes to ripen would be very useful in the avocado industry. Prepacking operations face serious logistical problems with fruit in the same consignment showing severe mixed ripening. If fruit were graded accordingly, these logistical problems would be solved, operating costs reduced and fruit quality maintained because fruit would not be handled as often. The potential for this has been shown, in that avocado fruit moisture content at harvest was the single most important factor determining ripening rate (Bower *et al*., 2007). Work is continuing in the measurement of ripening rate using NIRS.

Avocado oil is marketed as an alternative to olive oil, with a favourable ratio of mono-unsaturated to poly-unsaturated to saturated fatty acids (Requejo-Tapia, 1999). Authentication of registered designation of origin (RDO) olive oil from France based on the fatty acid and triacylglycerol composition has been achieved, and could be rapidly authenticated in any sample by NIRS (Galtier *et al*., 2007). There is a theory that growing climate affects the degree of unsaturation of avocado oil (Requejo-Tapia, 1999). The quality attributes free fatty acids, peroxide value, total polyphenols, oxidative stability, moisture and purity of olive oil have also been measured using NIRS (Garrido *et al*., 2000) and Pérez-Vich *et al*. (1998) were able to measure the fatty acid profile of a range of sunflower products using reflectance NIR. This suggests that the same will be possible with a range of avocado products (whole fruit, guacamole and oil). These attributes would be useful to avocado oil and guacamole manufacturers as the quality and shelf life of the oil would be known during processing. This will improve product quality (substandard batches will not be processed or released for distribution) and income losses reduced.

LIMITATIONS OF NIRS

There are some limitations to NIRS. There are no absorption bands for mineral species in the NIRS region (Burns & Ciurczak, 2001). This would be useful, as nutrients have a role to play in fruit quality and ripening (Van Rooyen, 2006).

Further, the localized nature of the scanning may not accurately predict the average internal quality because of spatial variability in the fruit (Slaughter & Abbott, 2004). Martinsen *et al*. (1998) and Martinsen *et al*. (1999) discussed the difficulty in developing an NIRS imaging system on produce due to the spatial variability in the constituent to be determined across the sample. This is a potential problem in the avocado industry, because it is well known that there are gradients of many compounds throughout the fruit (Schroeder, 1985). Avocado fruit have the highest mesocarp DM percentage mid-way between the exocarp and seed (Schroeder, 1985).

CONCLUSIONS

With the emphasis on fruit quality by importers, there is a need in the avocado industry for rapid, accurate, on-line sorting of product into quality categories by a combination of quality attributes. This allows the importers to receive consistent batches of fruit, and marketers to make decisions relating to sales and logistics to maximise returns to growers. NIRS has the potential to detect most quality attributes. It is possible to predict (and by implication sort) avocado ripening rate. This would allow for improved market planning and simplified logistics in pre-packing facilities.

While there are still technical difficulties relating to the speed at which NIR scanning can be done on a pack line, and the degree of accuracy within such a commercial situation, the technology suited to fruit and vegetables is advancing rapidly. Increased speed of scanning by the hardware, coupled to the accuracy of the resultant information, together with software becoming more advanced and able to calculate quality attributes more accurately and sort products accordingly, indicates that commercial usage of such systems could be viable. Hardware is even advancing to a stage where portable NIR systems are available and will be simple to use and calibrated for a wide range of products (Slaughter & Abbott, 2004).

NIRS has proven to be a valuable analytical method in agriculture for the last 40 years. Further advances, overcoming the restrictions such as speed and accuracy of determinations relating to on-line evaluations during packing have been made in recent years. There is thus potential for its implementation in the avocado industry, from maturity testing, to sorting whole fruit on-line according to various quality factors, and quality control and assurance in processing. While further research will be necessary to fully utilise the potential of the technique, some aspects are suitable for upscaling to pack house operations, which has the potential to considerably enhance grower returns.

LITERATURE CITED

BIRTH, G.S., DULL, G.G., MAGEE, J.B., CHAN, H.T. & CAVALETTO, C.G. 1984. An optical method for estimating papaya maturity. *J. Am. Soc. Hort Sci*., 109: 62-66.

BLAKEY, R.J., TESFAY, S.Z., BOWER, J.P. & BERTLING, I. 2007. Determination of water content and seven-carbon sugar concentration in 'Hass' avocados using NIR spectroscopy. World Avocado Congress. Viña del Mar, Chile.

BOWER, J.P., VAN ROOYEN, Z., BERTLING, I. & BLAKEY, R.J. 2007. Variable ripening of fruit in avocado consignments. World Avocado Congress. Viña del Mar.

BURNS, D.A. & CIURCZAK, E.W. 2001. Handbook of near-infrared analysis. 2nd ed. Marcel Dekker, Inc., New York.

CLARK, C.J., MCGLONE, V.A., REQUEJO, C., WHITE, A. & WOOLF, A.B. 2003. Dry matter determination in 'Hass' avocado by NIR spectroscopy. *Postharvest Biol. Technol*., 29: 300-307.

DVASH, L., AFIK, O., SHAFIR, S., SCHAFFER, A., YESELSON, Y., DAG, A. & LANDAU, S. 2002. Determination by near-infrared spectroscopy of perseitol used as a marker for the botanical origin of avocado (*Persea americana* Mill.) honey. *J. Agric. Food. Chem*., 50: 5283-5287.

GALTIER, O., DUPUYA, N., LE DRÉAU, Y., OLLIVIER, D., PINATEL, C., KISTER, J. & ARTAUD, J. 2007. Geographic origins and compositions of virgin olive oils determinated by chemometric analysis of NIR spectra. *Analytica Chimica Acta*, 595: 136-144.

HOFMAN, P.J., FUCHS, Y. & MILNE, D.L. 2002. Harvesting, Packing, Postharvest Technology, Transport and Processing. In: Whiley, A. W., Schaffer, B. and Wolstenholme, B. N. (Eds.). The Avocado: Botany, Production and Uses. CABI Publishing, Wallingford, United Kingdom: 363-391.

KAISER, C. 1994. Evaluation of maturity standards in avocado fruit. *Subtropica*, 15: 18-20.

KAWANO, S. 1994. Present condition of nondestructive quality evaluation of fruits and vegetables in Japan. *Jap. Agric. Res. Quarterly*, 28: 212-216.

LEE, S-K., YOUNG, R.E., SCHIFFMAN, P.M. & COGGINS, C.W. 1983. Maturity studies of avocado fruit based on picking dates and dry weight. *J. Am. Soc. Hort Sci*., 108: 390-394.

MARTINSEN, P. & SCHAARE, P.N. 1998. Measuring soluble solids distribution in kiwifruit using near-infrared imaging spectroscopy. *Postharvest Biol. Technol*., 14: 271-281.

MARTINSEN, P., SCHAARE, P.N. & ANDREWS, M. 1999. A versatile near-infrared imaging spectrometer. *J. Near Infrared Spec*.,

7: 17-25.
PÉREZ-VICH, B., VELASCO, L. & FERNÁNDEZ-MARTÍNEZ, J.M. 1998. Determination of seed oil content and fatty acid composition in sunflower through the analysis of intact seeds, husked seeds, meak and oil by near infrared reflectance spectroscopy. *J. Am. Oil Chem. Soc*., 75: 547-555.
RAGHAVACHARI, R. 2001. Near-infrared applications in biotechnology Marcel Dekker, Inc., New York.
RANNEY, C. 1991. Relationship between physiological maturity and percent dry matter of avocados. *Cal. Avocado Soc. Yrbk*. 75: 71-85.
REQUEJO-TAPIA, L.C. 1999. International trends in fresh avocado and avocado oil production and seasonal variation of fatty acids in New Zealand-grown cv. Hass, Massey University. MSc.
ROBERTS, C.A., WORKMAN, J. & REEVES, J.B. 2004. Near-infrared spectroscopy in agriculture. American Society of Agronomy, Crop Science Society of America, Soil Science Society of America, Madison, Wisconsin.
Schaare, P.N. & Fraser, D.G. 2000. Comparison of reflectance, interactance and transmission modes of visible-near-infrared spectroscopy for measuring internal properties of kiwifruit (*Actinidia chinensis*). *Postharvest Biol. Technol*., 20: 175-184.
SCHMILOVITCH, Z., HOFFMAN, A., EGOZI, H., EL-BATZRI, R. & DEGANI, C. 2001. Determination of avocado maturity by near-infrared spectrometry. *Acta Hort*., 562: 175-179.
Schroeder, C.A. 1985. Physiological Gradient in Avocado Fruit. *Cal. Avocado Soc. Yrbk* 69: 137-144.
SLAUGHTER, D.C. & ABBOTT, J.A. 2004. Analysis of fruit and vegetables In: Roberts, C.A., Workman, J. and Reeves, J.B. (Eds.). Near-infrared spectroscopy in agriculture. American Society of Agronomy, Inc., Crop Science Society of America, Inc., Soil Science Society of America, Inc., Madison, Wisconsin: 377-398.
VAN ROOYEN, Z. 2006. Factors affecting mesocarp discolouration severity in 'Pinkerton' avocados. Horticultural Science, School and Agricultural Sciences and Agribusiness. Pietermaritzburg, University of KwaZulu-Natal. PhD.
WALSH, K.B., GOLIC, M. & GREENSILL, C.V. 2004. Sorting of fruit using near infrared spectroscopy: application to a range of fruit and vegetables for soluble solids and dry matter content. *J. Near Infrared Spec.*, 12: 141-148.
WILLIAMS, P. & NORRIS, K. 2001. Near-Infrared Technology in the Agricultural and Food Industries. 2 nd. American Association of Cereal Chemists St Paul.
WILLIAMS, P.C. & SOBERING, D.C. 1993. Comparison of commercial near infrared transmittance and reflectance instruments for analysis of whole grains and seeds. *J. Near Infrared Spec.*, 1: 25-32.
WORKMAN, J. & SHENK, J. 2004. Understanding and using the near-infrared spectrum as an analytical method. In: Roberts, C. A., Workman, J. and Reeves, H. C. (Eds.). Near-Infrared Spectroscopy in Agriculture. American Society of Agronomy, Crop Science Society of America, Soil Science Society of America, Madison, Wisconsin: 3-10.