Impact assessment and prediction of rot susceptibility of Hass avocado fruit using FT-NIR spectroscopy

Brett Wedding[1,2,4]*, Carole Wright[3], Steve Grauf[1], Ron White[2] and Paul Gadek[4]

[1]Rapid Assessment Unit, Crop and Food Science, Department of Employment, Economic Development and Innovation, Cairns, 4870, Queensland, Australia
[2]Rapid Assessment Unit, Centre for Tropical Agri-tech Research, and School of Engineering and Physical Sciences, James Cook University, Townsville, 4811, Queensland, Australia
[3]Rapid Assessment Unit, Horticulture and Forestry Science, Department of Employment Economic Development and Innovation, Townsville, 4811, Queensland, Australia
[4]Rapid Assessment Unit, Centre for Tropical Agri-tech Research, and School of Marine and Tropical Biology, James Cook University, Cairns, 4870, Queensland, Australia
*Corresponding author: brett.wedding@deedi.qld.gov.au

Introduction

Avocado fruit maturity and quality characteristics are often variable and this results in variation within a shipment in ripening rates, shelf-life and quality.[1] Retail and consumer surveys over the last 15+ years have shown that consumers are not always satisfied with avocado quality, mainly because of poor flesh quality that can not be determined until the fruit is cut.[2] The surveys show that only 30% of the Australian population eat avocados and they expect to discard one in every four pieces of fruit they purchase because of poor internal quality.[3] Other reasons contributing to reduced consumption include concerns over spoilage, convenience, price and limited availability.[4] The surveys revealed that consumers select bruising as the major defect, followed by body and stem end rots.[4] Bruising was found to be a more important barrier to purchasing than price.[4] Thus, fruit quality reliability is a key factor impacting on supply chain efficiency and related profitability.

Repeat purchasing is significantly affected by a bad consumer eating experience. With avocado, internal defects of 10% or more has a dramatic impact on the consumer repurchasing.[5] Research has shown that if a consumer is dissatisfied with fruit then that consumer will not purchase that commodity for another 6 weeks.[5] Australian avocado quality surveys have shown that increased levels of purchase can be achieved by improving overall quality. For example, there is potential to increase purchase by 9% by reducing the average level of damage by 15%.[5] The key factor for retaining and expanding both domestic and international markets is removing inconsistency and providing what the consumer expects. That is a consistent quality product with suitable dry matter content and fruit free of bruises and flesh disorders.

Reliable export of avocados from Australia requires two to four weeks sea freight depending on destination. The biggest risk during transport is the development of rots and flesh disorders due to disruption of cell structure and function. Fruit rot severity is dependent on both the amount of disease inoculum and the minerals concentration of the fruit.[6,7] Research has shown that avocadoes with higher calcium and lower potassium concentrations are associated with a lower prevalence of rots and flesh disorders.[6,8] Other major factors affecting fruit disease development are fruit storage systems and time between harvest and consumption. The additional time and distance associated with most export markets results in longer times from harvest to consumption which increases the risk of quality loss before the consumer receives the fruit.

Currently, there is no reliable non-invasive system to predict if avocado fruit will arrive at the consumer in acceptable quality. Fruit with physical defects are sorted during packing on the farm, but many of the flesh disorders only appear once the fruit ripen and age. Measuring fruit at harvest may identify fruit that are less prone to rots and internal disorders. These fruit can be sent to more distant domestic markets and exported with greater confidence that the fruit will arrive at the consumer in acceptable quality.

The development of automated technologies has enabled commercially feasible non-invasive methods for estimating quality attributes of horticultural products. Near infrared (NIR) spectroscopy in particular has received considerable attention for determining internal quality attributes in fruit and vegetables. However, there have been limited investigations reported in literature on the prediction of storage disorders in fruit by NIR. Clark et al.[9] reported successfully using visible-NIR spectral characteristics to predict storage disorders of kiwifruit at harvest by separating into categories of 'sound' fruit and chill-injured 'affected' fruit. Pérez-Marín et al.[10] demonstrated that NIRS could be used to classify nectarines in post-harvest storage, as a function of pre-harvest irrigation strategies applied and post-harvest cold storage duration. Sánchez et al.[11] reported successfully using NIR spectral data for intact asparagus stored in refrigeration under controlled atmosphere, both by storage time and by post-harvest treatments applied.

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In this study we investigated the potential of FT-NIR spectroscopy as a non-invasive tool to detect bruises in whole avocado fruit and to predict susceptibility to rots as an indication of potential shelf-life.

Materials and Methods

Hass avocado fruit were obtained over the 2008 growing season from two farms in Queensland, Australia. The first farm is located near Ravenshoe on the Atherton Tablelands in North Queensland (Latitude: 17° 38' 0" South, Longitude: 145° 29' 0" East) and the second farm is located in the major production district of Toowoomba, South East Queensland (Latitude: 27° 33' 0" South, Longitude: 151° 58' 0" East). Fruit from Ravenshoe were used for the impact assessment trials (n = 102), while Toowoomba fruit (n = 125) were used for rot susceptibility (shelf life) trials.

In both instances, diffuse reflectance spectra of whole avocado fruit were collected in the 780–2500 nm range using a Bruker Matrix-F FT-NIR spectrophotometer (Bruker Optics, Ettlingen, Germany; operating software: OPUS™ version 6.5) linked with an external fibre-coupled emission head utilising a 4 × 20 W tungsten light source. A path-length of approximately 170 mm from the light source to the surface of the fruit provided a spectral scan diameter on the avocado of approximately 50 mm. In obtaining each sample spectrum 32 scans at a resolution of 8 cm^{-1} were collected and averaged.

Spectra for rot susceptibility prediction were collected from each opposing half of the hard green fruit prior to fruit being placed into 20°C storage at 85–95% relative humidity. At eating ripe fruit were then assessed for rots based on a weight percentage of the flesh volume affected.

For impact assessment, hard green fruit were stored at 20°C and 85–95% relative humidity until fruit reached the sprung stage of ripeness. The sprung stage of ripeness is where the flesh deforms by 2–3 mm under extreme thumb pressure. Individual spectra were collected from a single side of the fruit on reaching the sprung stage of ripeness. Following initial spectra collection, fruit were dropped from a height of 100 cm against a slate paver (height: 400 mm, length: 400 mm, width: 40 mm) placed upright and supported by concrete blocks to simulate impact damage. Individual fruit were placed into a cotton mesh bag which was firmly suspended by two strings attached to the laboratory ceiling. The fruit was positioned so that the scanned area would impact against the paver. The fruit in the mesh bag was pulled backwards away from the slate paver and released to swing in a pendulum motion to impact against the slate paver. Fruit were only allowed to impact the paver once. The height from the ground to the middle of the fruit was measured with the fruit sitting freely against the slate paver. The drop height was measured as a difference between the height at the top of the arch, and the height at the bottom of the arch where the fruit hit the paver.

The impacted area was re-scanned after 1-2 h (maximum of 4 h) and again after 24 h. Fruit were then placed back into 20°C storage at 85-95% relative humidity and assessed for bruises at eating ripe (approximately 5 days following impact). Bruise assessment was based on visual estimate of percentage bruise development of the flesh within the scanned area.

TQ Analyst™ chemometric software (Version 8.0.36, Thermo Fisher Scientific Inc. Madison, WI USA) was used for discriminative analysis to separate the avocados into categories based on percentage rot and percentage bruise development of the scanned area. The rot prediction models presented in this study were based on (i) a combination of spectral mean centering, with a 25 point Savitzky-Golay (SG) spectral smoothing (second order polynomial) and a multiplicative scatter correction (MSC) transformation over selected wavelength regions (not shown) for the ≤30% and ≥31% rot model; (ii) a combination of spectral mean centering, variance scaling and a first derivative transformation (41 point SG smoothing, first order polynomial) over selected wavelength regions (not shown) for the ≤10% and ≥11% rot model. A data normalisation technique of variance scaling was applied to all bruising assessment spectra used to develop the models presented in this study.

Results and Discussion

Classification statistics for the prediction of percentage rot development are presented in Table 1. The preliminary study found that by applying discriminative analysis techniques, 84.8% of the test population could be correctly classified into 2 categories, above and below 30% rot development for the area scanned. The percentage correctly classified decreased slightly to 82.4% when the classification was reduced to above and below 10% rot development for the scanned area.

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Table 1. Classification statistics for prediction of percentage rot development (shelf life) of whole Hass avocado fruit.

Item assessed	Spectra (n)	Defined classification (%)	LV	Spectra misclassified (%)	Spectra correctly classified (%)
%Rots of scanned area	250	(i) 0-30; (ii) 31-100	8	15.2 (n = 38)	84.8 (n = 212)
	250	(i) 0 -10; (ii) 11 - 100	9	17.6 (n = 44)	82.4 (n = 206)

Note: LV = Latent Variables.

Table 2 depicts the classification statistics for the prediction of percentage bruise development. The results indicate that 85% of the population could be correctly classified into 2 categories based on percentage bruise development in the scanned area (≤10%, >10%) using scans conducted 1-2 h following impact. Of the 15 (14.7%) samples misclassified, 3 (2.9%) samples with bruising visually rated below 10% were placed into the >10% bruise category; 12 (11.8%) samples visually rated with bruising greater than 11% were placed into the <10% bruise category, with 5 (4.9%) of these samples being right on the ambiguous change over point of the two defined classification categories at 10% bruising.

These results improved significantly to >90% correctly classified when the fruit were rescanned 24 h following impact. It appears the 24 h time delay allowed more time for the bruising to develop assisting with classification. Of the 9 (8.8%) samples misclassified, 1 (1%) sample with bruising visually rated below 10% was placed into the >10 bruise category; 8 (7.8%) samples with bruising visually rated greater than 11% were placed into the ≤10% bruise category, with 5 (4.9%) of these samples being at the ambiguous change over point of the two defined classification categories at 10% bruising.

Table 2. Classification statistics for prediction of percentage bruise development in whole Hass avocado fruit.

Item assessed	Time after impact (hours)	Spectra (n)	Defined classification (%)	LV	Spectra misclassified (%)	Spectra correctly classified (%)
%Bruising of scanned area	1-2	102	(i) 0 - 10; (ii) 11 - 100	8	14.7 (n = 15)	85.3 (n = 87)
	24	102		8	8.8 (n = 9)	91.2 (n = 93)

Note: LV = Latent Variables.

Conclusion

The results of this preliminary study indicate there is great potential to use FT-NIR as a tool to predict impact damage of whole avocados based on percentage bruise development, and to predict shelf-life based on rot development (susceptibility). The technique correctly classified >85% of the population based on two categories ((i) ≤10%; (ii) >10%) of percentage bruising using scans conducted 1-2 h after impact. This improved to >90% if scans were conducted 24 h after impact damage (bruising) allowing sufficient time for bruise development to be detected. This would indicate that in a commercial situation it would be an advantage to hold the fruit for 24 h prior to scanning. It should be considered that the work here presented is a first step towards shelf-life prediction and bruise detection for avocado fruit. However, this was only a preliminary study and the classification models require many more samples incorporating seasonal and geographical biological variations to enable the development of a robust model suitable for commercial use.

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