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Evaluating the performance of a consumer scale SCiO™ molecular sensor to predict quality of horticultural products

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ABSTRACT

Near infrared spectroscopy has been widely used in the horticultural industry as a non-destructive tool to provide quality prediction of fresh and stored products. In this work, a low-cost portable NIR sensor, SCiO™ molecular sensor (Consumer Physics Inc., Tel-Aviv, Israel) is assessed for its ability to provide this information. Fruit samples of kiwifruit, apple, feijoa and avocado were collected and their spectral and quality measurements obtained in order to develop NIR predictive models. The performance of the SCiO™ sensor for quality prediction was assessed by developing estimation or classification models using the SCiO™ Lab online application and then compared to that of existing commercial NIR spectrometers. The SCiO™ sensor was useful in predicting the total soluble solids of 'Zesy002' kiwifruit (R_{Val}^2 = 0.77; $RMSE_P$ = 0.76%), and identifying fruit with high dry matter concentration (78% validation accuracy). Prediction of 'Braeburn' apple quality was less successful due to poor validation performance. For 'Kakariki' feijoa, the best regression model was obtained for hue angle (R_{Cal}^2 = 0.68; RMSE = 2.4°). The feijoa maturity identification model showed potential in classifying mature fruit (84% calibration accuracy) compared to immature and overmature fruit (44 and 67% calibration accuracy respectively). The classification of ripeness stages of 'Hass' avocado was moderately successful with good repeatability in model validation (≈ 50–70 % validation accuracy). For the four products investigated in the current study, the SCiO™ sensor performed similarly to commercial NIR sensors although there is a need to improve the robustness of the calibration models. In order to confirm the promising results obtained in this paper, further model validation using fruit from a wider range of variability is required. A rapid and economic sensor like the SCiO™ would enable wider industrial applicability of the NIR technique and potentially provide fast sorting and screening capability to assist with quality predictions and decision making processes throughout the supply chain.

1. Introduction

Near-infrared (NIR) spectroscopy studies the spectral property of an object when irradiated with electromagnetic radiation between 780–2500 nm or 12,820.5–4000 cm^{-1} wavenumbers (Miller, 1987, 2001; Dufour, 2009). When NIR radiation reaches an object, the incident radiation may be reflected, absorbed or transmitted, depending on the physical properties and chemical composition of the sample. The amount of light reflected or absorbed can be related to the qualities of the object by creating mathematical models. Predictions of quality of new samples can be made based on previous training sets for any known product property.

Fruit tissue contains water, carbohydrates and proteins which have large numbers of NIR-active chemical groups (Feng, 2003). For decades NIR spectroscopic techniques have been used as non-destructive and rapid tools to evaluate various quality attributes of fruits and vegetable (Williams et al., 2006; Jha, 2010). Previous studies demonstrated the ability of NIR to provide instant estimation of fruit quality at the time of measurement (McGlone and Kawano, 1998; Schaare and Fraser, 2000; Moghimi et al., 2010) and *a priori* prediction of future quality (McGlone et al., 2007; Ignat et al., 2014; Li et al., 2017). Because of this, NIR sensors have been adapted to devices with various configurations to cater for both research and commercial purposes. For instance, bench-top Vis-NIR spectroscopy systems such as the FieldSpec® Pro (PANalytical, B.V, Boulder, Colorado, USA) are available in the range between 350–2500 nm and suitable for both industrial and laboratory analysis. Handheld NIR sensors such as the F-750 Produce Quality Meter (Felix Instruments Inc., Camas, WA, USA) are useful for in-field measurements of quality metrics of various crops. Online industrial multilane NIR sensors such as InSpectra (Compac, Auckland, NZ) fitted to a

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commercial crop grader (Compac™ grading equipment, Auckland, NZ) have been implemented by packhouses for sorting of fruit according to internal quality such as sweetness.

More recently, the ability to produce a compact low-cost spectrometer for use in mobile devices (Goldring and Sharon, 2012) led to the development of consumer-scale NIR devices such as the SCiO™ molecular sensor (Consumer Physics Inc., Tel Aviv, Israel), LinkSquare (Stratio Inc., Seoul, Korea) and Tellspec® Food Sensor (Tellspec Inc., Toronto, Canada). Beyond the cheap cost, these sensors have high portability enabling measurement anywhere and anytime, and provide the linkage of the data captured to cloud databases and analytics, meaning that rapid diagnostic information is able to be displayed on devices connected to the internet should there be cloud connectivity. Integration into smartphones and other household devices will make applications of NIR assessable and affordable to the general public (Coates, 2014; Haughey et al., 2015). In addition, the first smartphone with a built-in molecular NIR sensor was launched in January 2017 (Pradip, 2017). Despite the public interest, there is little scientific record on how these sensors perform compared to existing commercial NIR sensors. Kaur et al. (2017) found that the performance of SCiO™ (version 1.1) for quality predictions of apple and kiwifruit was inferior compared to benchtop NIR spectrometers. However, this study only focused on the prediction of dry matter concentrations (DMC).

For horticultural products, other quality data that may be useful to determine by producers through to consumers include maturity, ripeness, flesh firmness (FF), sweetness (total soluble solids concentration, TSS) and acidity amongst others. In this work, the SCiO™ molecular sensor developed by Consumer Physics Inc. is assessed for its ability to provide this potentially useful information. Fruit samples from a few crops, namely, kiwifruit, apple, feijoa and avocado, were collected and their spectral and quality measurements obtained in order to develop NIR predictive models. The performance of the SCiO™ in terms of quality prediction was compared to that of existing commercial NIR spectrometers reported in previous studies.

2. Materials and methods

2.1. SCiO™ spectral acquisition

Two versions of the SCiO™ molecular sensors (v1.0 and 1.2, Consumer Physics Inc., Tel-Aviv, Israel) were used to acquire the spectral data of intact fruit samples in the wavelength range of 740–1070 nm. The device was set up in interactance mode as illustrated in Goldring and Sharon (2012). The wavelength resolution was < 10 cm^{-1} and the sampling interval was 1 nm. The SCiO™ Lab online application (Consumer Physics Inc., Tel-Aviv, Israel) which can be installed on a smartphone or a desktop PC was required for data collection, storage and analysis. For spectra acquisition, three scans per fruit were carried out at different positions (approximately 120° apart) around the equator with the illuminator pointing at the fruit skin. Prediction of quality attributes was based on an overall state of the fruit captured by the sensor, which can be indicative of various physical and chemical properties such as skin colour, surface scattering characteristics and near surface sugar content.

All spectral measurements were collected with an attached light shield (9 mm width) to ensure adequate light seal from background noises and consistent distance between the sample surface and the illuminator. During measurement each fruit was gently held against the outer rim of the light shield. A light source illuminated the sample, and the reflected light was captured by the detector. The reflectance spectrum was then sent to a smartphone via Bluetooth, and then uploaded to the online SCiO™ cloud database for spectral analysis. Calibration was carried out after approximately every 10 fruit for the sensor v1.0 and daily for the sensor v1.2 using the white tile located inside the sensor cover.

2.2. Kiwifruit quality estimation trial

This experiment consisted of 53 trays (count 30 size) of 'Zesy002' kiwifruit (*Actinidia chinensis*) from 26 grower lines sourced from commercial orchards located in the Bay of Plenty region, New Zealand in April–May, 2017. The at-harvest spectral data of one tray each of 19 grower lines were collected using the SCiO™ sensor (v1.2), followed by DMC measurements of the same fruit. This data set was used to develop both a regression model for instant estimation of DMC, and a classification model for categorising 'Zesy002' kiwifruit based on two DMC grades (< 17.5% and ≥ 17.5%). The remaining 34 trays were stored at 20 °C and 60% relative humidity (R.H.), with spectral data, FF and TSS of fruit from three random trays measured at 2-day intervals for 16 days. This data set was used to develop regression models for quantitative prediction of FF and TSS respectively.

Additionally, 300 fruit from five of the 26 grower lines were used for external model validation. The spectral data of the fruit were first obtained to allow generations of predictions by the developed predictive models. The robustness and repeatability of the models were then assessed by comparing the actual and predicted FF, TSS and DMC measurements.

For fruit quality assessment, the DMC (%) was determined using an oven drying technique by dehydrating a known mass of 2–3 mm thick equatorial fruit slice at 60–65 °C for 24 h. Data were expressed as percentage of the wet mass. The FF (N) was measured using an electronic QALink Penetrometer (Willowbank Electronics Ltd., Napier, New Zealand) fitted with the standard 7.9 mm Magness-Taylor probe. Two measurements of peak penetrating force were made at two locations (90° apart) around the equator of the fruit after removal of a thin (1 mm) layer of the fruit skin. The penetration speed was 8 mm s^{-1} and the puncture depth was 8 mm into the flesh. The TSS (%) was measured using a digital pocket refractometer (PAL-1, Atago, Japan) using the juice collected from both 15 mm end caps.

2.3. Apple quality estimation trial

This experiment consisted of 373 'Braeburn' apple (*Malus domestica*) sourced from a plant growth unit (PGU) at Massey University, Palmerston North as well as local supermarkets in Palmerston North, New Zealand, in January–February, 2016. At the time of collection fruit were considered to be at various maturity and ripeness stages. Spectral data of the fruit were collected using the SCiO™ sensor (v1.0), followed by destructive measurements of fruit quality (DMC, TSS and FF). Regression models were developed using the spectral and quality data, to provide instant estimation of the measured quality attributes. External model validation was carried out by testing an additional 100 'Braeburn' apples purchased from six supermarkets and stores in Palmerston North in June, 2017. The predicted and measured quality values were compared in order to assess the performance of model predictions.

For fruit quality measurement, the DMC (%) was determined using the same method described in Section 2.2. The FF (N) was measured using a QALink Penetrometer (Willowbank Electronics Ltd., Napier, New Zealand) fitted with an 11.1 mm Magness-Taylor probe. Two measurements of peak penetrating force were made at two locations (90° apart) around the equator of the fruit after removal of a thin layer (1 mm) of the fruit skin. The penetration speed was 8 mm s^{-1} and the puncture depth was 8 mm. The TSS (%) was measured using a digital pocket refractometer (PAL-1, Atago, Japan) using the juice collected from the puncture holes immediately after FF testing.

2.4. Feijoa maturity trial

A total of 296 'Kakariki' feijoa (*Acca sellowiana*) fruit were collected from Southern Belle Orchard located in Matamata, New Zealand in 2016. Five batches of fruit consisting of 2 trays (approx. 30 fruit each)