Available online at www.sciencedirect.com
ScienceDirect
Postharvest Biology and Technology 46 (2007) 1–9
Postharvest Biology and Technology
www.elsevier.com/locate/postharvbio

Comparing density and VNIR methods for predicting quality parameters of yellow-fleshed kiwifruit (*Actinidia chinensis*)

V. Andrew McGlone *, Christopher J. Clark, Robert B. Jordan

BioEngineering Sector, HortResearch, Ruakura Research Centre, Private Bag 3123, Hamilton, New Zealand

Received 2 June 2006; accepted 11 April 2007

Abstract

Non-destructive density and visible-near infrared (VNIR) measurements have been made on yellow-fleshed kiwifruit (*Actinidia chinensis* Planch. var. *chinensis* 'Hort16A') harvested on four occasions across a commercial harvest period. The fruit were examined both at harvest and/or after 12 weeks' cold storage to predict the internal quality parameters of dry matter (DM), soluble-solids content (SSC) and flesh colour using hue angle (Hue). Density measurements were made by flotation and the VNIR measurements using a polychromatic spectrometer system operating over the range 300–1140 nm, although much smaller spectral regions were better for predicting DM and SSC (both 800–1000 nm), or Hue (500–750 nm). Harvest-time and post-storage data sets were formed and used to develop models for predicting harvest-time and/or post-storage quality parameters. The VNIR method proved superior to the density method in every case, especially for DM and SSC predictions where the VNIR method was close to twice as accurate. The VNIR method yielded accuracies (standard errors in prediction) of ±0.40%, ±0.71% and ±1.05° for predictions of harvest DM, SSC and Hue, respectively. Predictions of post-storage DM, SSC and Hue, from post-storage spectra, had improved accuracies of ±0.24%, ±0.31% and ±0.98°, respectively. The increased accuracy for SSC prediction, from ±0.71 to ±0.31%, is theorised to be a consequence of the VNIR method being better at predicting the total carbohydrate concentration, which comprises starch and soluble sugars in about equal amounts at harvest but is mainly soluble sugar after the fruit ripens during cold storage. That theory was supported by the observation that post-storage SSC predictions based on harvest-time VNIR spectral models were also more accurate (±0.38%) than the equivalent harvest-time SSC predictions. In addition, harvest-time DM predictions were shown to be capable of at least rank ordering ($R^2 = 0.87$) kiwifruit in terms of post-storage SSC.

Keywords: Density; NIR; Non-destructive test; Kiwifruit; Fruit quality; Dry matter; Soluble-solids content; Flesh colour

1. Introduction

Visible-near infrared (VNIR) analysis was recently used to successfully predict the storage potential of the yellow-fleshed 'Hort16A' kiwifruit (*Actinidia chinensis* Planch. var. *chinensis*), particularly the incidence of rots due to chilling injury (Clark et al., 2004). The analysis revealed that less mature fruit at harvest were more likely to develop storage rots. In particular, it was noted that fruit were more prone to rots if, at harvest, they had lower dry matter (DM), lower soluble-solids content (SSC) and greener flesh colour (hue angle or Hue). These attributes are already measured extensively in the New Zealand kiwifruit industry but generally only using destructive assessments of representative sub-samples for determining maturity and/or quality profiles. Non-destructive on-line sorting is an attractive option for the kiwifruit industry, inviting economic benefits that accrue with the provision of consignments of uniform quality. The addition of a storability profile, following the findings of Clark et al. (2004), indicates potential further benefits. For example, on-line sorting could allow appropriate consignment management during extended storage to maximise out-turn quality.

Density measurement, by flotation, is a simpler and lower cost alternative to VNIR analysis, and has been found to have comparable accuracy for predicting DM and fully ripened SSC on the green-fleshed 'Hayward' kiwifruit (*Actinidia deliciosa* var. *deliciosa*) (McGlone et al., 2002). However, it is uncertain whether density measurement could be applied equally well to 'Hort16A' kiwifruit. 'Hort16A' is a different species and although harvested at similar times to 'Hayward', they flower about 30 days before and so are physiologically older. Hence, the relationships between density and DM might be different and/or more variable.

In this paper, we report the results of comparisons between the density and VNIR methods for use with 'Hort16A' kiwifruit, and

* Corresponding author. Tel.: +64 7 8564754; fax: +64 7 8584705.
E-mail address: amcglone@hortresearch.co.nz (V.A. McGlone).

0925-5214/$ – see front matter © 2007 Elsevier B.V. All rights reserved.
doi:10.1016/j.postharvbio.2007.04.003

in particular for the prediction of DM, SSC and Hue. The experiments involved collections of data sets corresponding to fruit at harvest and after 12 weeks' cold storage, with fruit density and VNIR spectra made at both times. The performance of predictive models was examined for two separate situations: (1) where the non-destructive measurements and predicted quality parameters were simultaneous, either at harvest or after storage, and (2) where the non-destructive measurements made at harvest-time were used to predict quality parameters after storage. The second situation is advantageous when it is more practical or economic to grade and sort fruit before storage for properties they will have after storage. In particular we consider use of harvest-time DM estimates, generated using predictive models calibrated with harvest-time DM data, for predicting post-storage SSC. Harvest-time DM should correlate strongly with ripe fruit SSC, as it does for 'Hayward' kiwifruit (Jordan et al., 2000). Harvest-time DM models will be easier to build and maintain compared to direct post-storage SSC models that necessarily require fruit to be stored and ripened to provide the necessary SSC calibration data.

2. Materials and methods

2.1. Kiwifruit data sets

Fruit were harvested from four different commercial orchards (Te Puke, NZ) on four occasions during a 5-week commercial harvesting period. At each harvest, approximately 75 fruit were randomly selected from each orchard and transported to the laboratory, held overnight in an air-conditioned room (~20 °C) before being examined the following morning by the density and VNIR methods. All fruit from a harvest were pooled, and then randomly divided into two groups of 150 fruit each, designated 'harvest' and 'storage'. The 'harvest group' was destructively examined immediately for DM, SSC and Hue. The 'storage' group were placed in a temperature controlled cool store at 0 °C for a period of 12 weeks. At the end of 12 weeks, the fruit were removed from cool storage and warmed to room temperature. The fruit were then re-examined by VNIR and density methods before final destructive DM, SSC and Hue measurements were made.

Three data sets for analysis were created using combinations of these groups of fruit measurements accumulated over the four harvest dates. They were:

HH data set containing *h*arvest-time VNIR and density measurements and *h*arvest-time destructive DM and SSC measurements all made on the harvest group of fruit. $N = 491$.
HP data set containing *h*arvest-time VNIR and density measurements, with corresponding destructive DM, SSC and Hue measurements made *p*ost-storage using the storage group of fruit. $N = 492$.
PP data set also containing results from the storage group but with all measurements (VNIR, density, DM, SSC and Hue) made *p*ost-storage. $N = 492$.

Although the total number of fruit measured was 600, the actual numbers in each data set are less than this due to operational issues, particularly on the first measurement day that meant some measurements were not available.

2.2. VNIR method

VNIR spectra (300–1140 nm with a 3.3 nm sampling interval) were obtained in an interactance mode using the equipment and procedures described in McGlone et al. (2002). In brief, each fruit was placed on its side with the transverse equator located on top of a small rubber grommet (12 mm o.d.) that provided a simple means for holding the fruit in a light-tight manner against the entry port of a light collection fixture. The fruit exterior to the grommet was illuminated from below by a broad band quartz-halogen light source, and light diffusing through the flesh into the light collection fixture inside the grommet was redirected to the spectrometer (Zeiss MMS1-NIR, Germany). Each spectrum was accumulated over 1.75 s from five contiguous acquisitions at a 350 ms integration time. All spectra were subsequently converted to relative spectra by subtracting the dark current and scaling relative to a reference spectrum, which was recorded separately from a Teflon block standard placed directly above the fruit holder. Reference and dark current spectra were obtained at the beginning of each session, and every 25 spectral readings thereafter. Two separate spectral measurements were made on each kiwifruit, on opposing sides of the transverse equator.

2.3. Density method

Fruit density was measured by Archimedes' principle using a purpose-built apparatus for fruit volumetric measurement by weighing the fruit when fully immersed in 5 L of clean tap water. Fruit were pre-wet before placement in the apparatus, to minimise air bubbles forming on the fruit surface during immersion. Appropriate procedures and corrections were used to account for the volume of the suspension apparatus, and the fruit and water temperatures (Jordan et al., 2000).

2.4. DM, SSC and hue angle

Fruit DM was measured by cutting two equatorial slices, of approximately 3 mm thickness, and drying them at 65 °C for 24 h. The fruit DM was calculated from the final dry weight and initial wet weight of the slices, recorded as a percentage of fresh weight. The SSC, recorded as a percentage of fresh juice, was measured by two different sampling methods using a digital refractometer (Atago; Japan). The first method (SSC_{end}), considered the standard kiwifruit industry method, involved taking readings for the juice expressed from 10 mm caps removed from the stem and calyx ends of the fruit. The second method (SSC_{side}), our preferred method, involved taking readings from juice expressed from ~2 mm slices of outer skin and flesh removed from the locations on each side of the fruit used for the two VNIR measurements. The flesh colour, recorded as the degrees of hue angle (Hue), was measured at these same two sites using a chromameter (Minolta CR300, Japan), under D65 illumination, on the top surface of the exposed inner flesh.