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Segregation of apricots for storage potential using non-destructive technologies

Jinquan Feng[a,*], Jill Stanley[b], Mohammed Othman[c], Allan Woolf[a], Maureen Kosasih[d], Shane Olsson[a], Graeme Clare[a], Nick Cooper[c], Xirui Wang[e]

[a] The New Zealand Institute for Plant & Food Research Limited, Mt Albert Research Centre, Private Bag 92169, Auckland 1142, New Zealand
[b] The New Zealand Institute for Plant & Food Research Limited, Clyde Research Centre, 990 Earnscleugh Road, RD 1, Alexandra 9391, New Zealand
[c] Taste Technologies Ltd., 64-72 Victoria Street, Onehunga, Auckland 1061, New Zealand
[d] Westland Milk Products, 56 Livingstone Street, Hokitika 7810, New Zealand
[e] Rural Science and Technology Development Centre of Shaanxi Province, Xian, China

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ABSTRACT

This study was set up to identify critical maturity indices affecting storage potential of apricots and demonstrate the potential for using non-destructive measurements to segregate harvested crops for sequential marketing. Fruit of two apricot (*Prunus armeniaca*) cultivars ('Clutha Gold' and 'Genevieve') were harvested and stored for four weeks at 0 °C followed by four days of simulated shelf life at 20 °C. Fruit colour, acoustic firmness, impact firmness, flesh firmness (FF_0), dry matter content and soluble solids content measured non-destructively at harvest were correlated to the flesh firmness measured at the end of refrigerated storage and simulated shelf life (FF_{Final}) through stepwise regression. The regression models indicated that FF_0 is a predominant factor determining FF_{Final}. According to the exponential model describing the relationship between FF_0 and FF_{Final}, 'Genevieve' and 'Clutha Gold' could be stored at 0 °C for four weeks if harvested at firmness above 47 or 56 N, respectively. Segregation of harvested crops according to FF_0 estimated from VNIR would enable sequential marketing of fruit according to storage potential to reduce fruit loss.

1. Introduction

Apricot (*Prunus armeniaca* L.) is one of the most popular summer fruit grown in temperate climate zone with a total world production of about 3.8 million tonnes (FAO 2009). New Zealand currently exports 1000–1500 tonnes of fresh apricots annually worth $NZ7-9 million, which accounts for about 2% of world trade in fresh apricots. Apricots are climacteric fruit with limited storage life of 1–4 weeks (Fan et al., 2000). Mixed maturity at harvest affects storage life and fruit quality in the market, which causes concern (Bruhn et al., 1991; Fan et al., 2000; Infante et al., 2008). Fruit background colour, soluble solids content (SSC) and flesh firmness (FF) have been considered important maturity indices (Visagie, 1988; Brown and Walker, 1990; Biondi et al., 1991; Aubert and Chanforan, 2007; Infante et al., 2008; Gouble et al., 2010). However, the relative importance of these maturity indices for storage potential has not been established.

Traditionally, apricots were harvested and graded based on visual assessment of fruit colour. For example, 'Palsteyn' apricots with orange-yellow skin colour were considered ripe and providing the highest acceptability, and those harvested at an intermediate stage of maturity (light yellow skin colour) provided an average acceptability, while unripe fruit (greenish skin colour) were not acceptable (Infante et al., 2008). However, visual assessment of fruit colour is subjective and can be affected by environmental factors such as sunlight and temperature. Fruit colour is not a reliable representation of flesh firmness or soluble solid content and therefore is only an approximate indication of maturity at harvest. For long-term storage or transport, fruit should be harvested at the pre-climacteric stage, before they attain their full flavour and colour, and are more tolerant to handling and prolonged cold storage (Aubert and Chanforan, 2007). Therefore, the optimal maturity at harvest for each cultivar should be a balance between eating quality and storage potential. Identifying key factors affecting storage potential, and developing a quantitative model to describe the relationship between maturity indices at harvest and fruit quality at the end of targeted storage duration, are important steps to optimising harvest maturity.

Recent developments in non-destructive technologies to measure maturity indices offer the possibility of non-invasive on-line packinghouse screening of colour, SSC and firmness at harvest (Muramatsu et al., 1996; Carlini et al., 2000; McGlone and Jordan,

* Corresponding author. Tel.: +64 9 9258618; fax: +64 9 9257001.
E-mail address: Ringo.Feng@plantandfood.co.nz (J. Feng).

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2000; Camps and Christen, 2009; Bureau et al., 2010; Berardinelli et al., 2010). These same technologies provide the opportunity to measure both maturity indices at harvest and fruit quality after storage on the same fruit, and to investigate the relationship between these on an individual fruit basis. It was hypothesised that the relationship between maturity indices at harvest and fruit quality at the end of storage could be revealed more clearly on an individual fruit basis than on a fruit batch basis because of the large differences among individual fruit and the elimination of sample error. In this study, a total of 450 fruit from each cultivar were measured using three types of non-destructive measurement technologies at harvest. FF, SSC and dry matter content (DM) were measured destructively on a subsample of 180 fruit from each cultivar immediately after non-destructive measurements so that to develop calibration models to estimate these attributes for the remaining fruit (270 fruit per cultivar) that were stored for four weeks at 0 °C followed by four days of simulated shelf life at 20 °C. Fruit quality measured at the end of refrigerated storage and simulated shelf were correlated with maturity indices measured non-destructively at harvest on an individual fruit basis.

2. Materials and methods

2.1. Fruit harvest

Four hundred and fifty apricot fruit for each of the two cultivars ('Clutha Gold' and 'Genevieve') were harvested from Central Otago, a major apricot production area in New Zealand. Fruit were graded into three maturity classes based on visual assessment of fruit colour (background colour and percentage of blush) and packed separately into single layer trays with plastic Plix® trays. This separation was aimed to reduce maturity variation within each package to minimise the effect of released ethylene from more mature fruit contributing to the softening of less mature fruit. It also ensured that a range of fruit maturities was represented in the sample. Packed fruit were sent to the Plant & Food Research in Auckland on the same day by airfreight. Fruit were kept at ambient temperature overnight before measurements were made.

2.2. Non-destructive measurements at harvest

Fruit colour was measured on opposite flat sides of each fruit along the equatorial zone using a Minolta Chroma Metre (CR-300, Konica Minolta Sensing Americas, Inc., USA) equipped with 6-eliment silicon photocells (detector) operated with D65 light source and calibrated with a white calibration plate. Measurement on each fruit was taken on the blushed side, then the shaded side. Measured values were expressed in L (lightness), C (chroma) and H (°hue) colour space. The two readings from each fruit were averaged to give one reading for each fruit (i.e. L_0, C_0 and H_0, where "0" indicates that the parameter was measured when storage time = 0 days. This applies to all the fruit attributes measured at harvest).

Acoustic firmness and impact firmness were measured using an AWETA AFS (AWETA™ Impact & Acoustic Firmness System, Nootdorp, Holland). The AFS is a small bench top unit that gently taps the fruit and 'listens' to the acoustic response. The vibration pattern (resonance attenuated vibration) of the fruit is analysed and translated into an acoustic firmness (AF_0, Eq. (1)) that is characteristic of the overall stiffness of the fruit (Cooke, 1972). The AFS also measures fruit weight and impact firmness (IPF_0, a measure of the local fruit surface elasticity). Two AFS measurements were made on two flat sides of each fruit along the equatorial plane. The two readings from each fruit were averaged to give a single value for each fruit.

$$AF_0 = Fo_0^2 M_0^{2/3} \quad (1)$$

where Fo_0 is the resonant frequency of the first elliptical mode (Hz) and M_0 is the mass of the fruit (kg).

Visible-near-infrared (VNIR) spectra measurements were carried out using a commercial VNIR grading system (Taste Technologies, New Zealand). A continuous beam of light generated from a halogen lamp was focused on fruit passing through the VNIR unit while spectra in a wavelength range of 300–1100 nm with a resolution of 10 nm were taken in a reflectance mode. Each fruit passed through the VNIR unit twice and two VNIR spectra were taken on each fruit. Each plectrum was normalised to reference spectra taken when there were no fruit loaded and transformed into a second derivative spectrum (Savitsky and Golay, 1964; Steinier et al., 1972) before calibration and prediction. These are the most commonly used data transformations necessary to achieve robust calibration models.

2.3. Destructive measurements at harvest

Destructive measurements of soluble solids content (SSC_0), dry matter content (DM_0) and flesh firmness (FF_0) were made on 180 fruit per cultivar to provide data to develop calibration models to predict FF_0, SSC_0 and DM_0 for the other 270 fruit per cultivar that went to refrigerated storage and simulated shelf life test.

FF_0 was measured on two sides of each fruit along the equatorial zone using a 7.9-mm diameter probe attached to a GUSS FTA (GUSS Manufacturing Ltd., South Africa). Penetration speed, trigger force and penetration distance were set to 10 mm s^{-1}, 50 g and 8 mm, respectively. A patch of skin about 1 mm in thickness was removed from each side of the fruit before firmness measurement. SSC_0 was measured using a Digital Hand-Held "Pocket" Refractometer (Model PAL, Atago, Tokyo, Japan) with combined juice expelled from FF_0 measurements on each fruit.

Dry matter content (DM_0) was measured using a cross section slice (including skin and flesh, but excluding the stone) cut along the equator of each fruit. The slice was weighed immediately after cutting and then after drying to a constant weight at 65 °C over a period of 24 h.

2.4. Storage and final firmness assessment

The remaining 270 fruit per cultivar were stored at 0 °C for four weeks and subjected to four days of simulated shelf life at 20 °C under ambient light before the final assessment of flesh firmness (FF_{Final}) and disorders such as rots, soft patches and chilling injury that render fruit unsalable.

2.5. Data analysis

Calibration models to predict FF_0, SSC_0 and DM_0 from VNIR spectra were developed based on data from 130 fruit per cultivar. Data from the other 50 fruit per cultivar destructively measured at harvest were used as cross validation data. Calibration models were established using partial least square (PLS) regression between second derivative spectra and the reference data (SSC_0, DM_0 and FF_0). The reference data measured on each fruit were duplicated to match the two spectra taken on each fruit.

For the stored fruit, SSC_0, DM_0 and FF_0 predicted from VNIR spectra, measured values of fruit colour (L_0, C_0 and H_0), acoustic firmness (AF_0) and impact firmness (IPF_0) at harvest were correlated to FF_{Final} using stepwise regression. For this analysis, squared values of the fruit attributes measured at harvest were also calculated to take into account possible nonlinear relationships. Data from each cultivar were randomly divided into calibration data set (180 fruit per cultivar) and validation data set (90 fruit per cultivar). Fruit attributes that had significant contribution to reduce