Postharvest Biology and Technology 120 (2016) 127–137

Contents lists available at ScienceDirect

Postharvest Biology and Technology

journal homepage: www.elsevier.com/locate/postharvbio

Kiwifruit firmness: Measurement by penetrometer and non-destructive devices

Huajia Li[a,b,*], Paul Pidakala[b], David Billing[b], Jeremy Burdon[b]

[a] Institute of Agro-Products Processing Science and Technology, Sichuan Academy of Agricultural Sciences, Chengdu 610066, China
[b] The New Zealand Institute for Plant & Food Research Ltd (PFR), Private Bag 92169, Auckland Mail Centre, 1142, Auckland, New Zealand

ARTICLE INFO

Article history:
Received 19 April 2016
Received in revised form 7 June 2016
Accepted 8 June 2016
Available online 20 June 2016

Keywords:
Firmness
Non-destructive
Penetrometer
Speed
Actinidia

ABSTRACT

Kiwifruit texture or firmness is critical to the commercial handling and eating quality of the fruit, with fruit acceptability based on firmness thresholds. Two aspects of kiwifruit firmness measurement have been investigated: i) the effect of speed of penetrometer probe movement before (approach speed) and during firmness measurement (measurement speed) and ii) a comparison of firmness values derived from compression, impact and acoustic impulse non-destructive measurements compared with a standard penetrometer measurement. Both series of experiments were repeated on fruit from two commercially available cultivars ('Hayward' and 'Zesy002' – commonly called Gold3). It is concluded that the approach speed did not affect the firmness value obtained, whereas a faster measurement speed increased the firmness value obtained for 'Hayward' and Gold3 fruit at <40 N firmness. The use of non-destructive firmness measurement techniques tended to give good overall relationships in line with penetrometer measurements of firmness. However, for any given penetrometer firmness value, it appears that the non-destructive value obtained may depend on when in storage the measurement was made. The cause of the storage-related variability in the relationship requires further investigation of both the biological and physical processes occurring.

1. Introduction

Commercially, kiwifruit (*Actinidia* spp.) are harvested when mature but unripe (Burdon and Lallu, 2011) and ripening may occur slowly during storage at low temperatures or may be accelerated by exposure to ethylene at elevated temperatures (Lallu et al., 1989; Ritenour et al., 1999). A major component of the ripening process is the textural change of the fruit from hard and crisp to soft and melting (MacRae and Redgwell, 1992), with the eating quality of the fruit being very much dependent on the texture of the fruit (Stec et al., 1989). The fruit texture or firmness is indicative of the fruit ripeness, and is also used to determine the suitability of fruit for critical steps in postharvest handling, including storage in bulk bins, passing across a grading line, or whether a particular line of fruit is suitable for export. All these processes are problematic if the fruits are too soft.

Kiwifruit firmness has for many years been quantified destructively by measurement with a penetrometer (Watkins and Harman, 1981). First, the fruit skin and flesh are removed to a depth of ~1 mm and the penetrometer then pushed into the exposed fruit flesh. Usually, each fruit is measured twice at the equator, with measurements made at 90° to each other. The averaged value is then taken as the firmness of that fruit.

Initial work using a penetrometer often used hand-held Effegi™ penetrometers (Alfonsine, Italy), or similar (Magness and Taylor, 1925), with a 7.9 mm (5/16th inch) probe being inserted into the fruit flesh to a depth of 7.9 mm (5/16th inch) over a couple of seconds, giving an approximate rate of penetration of 4 mm s^{-1}. More recently, motorised penetrometers, or fruit texture analysers, have been used (Hopkirk et al., 1996; Abbott, 1999; Feng et al., 2011). These devices give equivalent data to the hand-held devices and eliminate, or minimise, the operator element to making a measurement (Hopkirk et al., 1996). However, motorised penetrometers also increase the range of variables that may be adjusted in taking a measurement, principal of which is the speed of the penetration. As laboratories increase the throughput of fruit, the temptation is to speed up the measurement process, to be able to process fruit more rapidly. However, initial observations on soft kiwifruit suggest that the penetrometer speed affects the values

* Corresponding auther at: Institute of Agro-Products Processing Science and Technology, Sichuan Academy of Agricultural Sciences, No.4 Shizishan Road, Chengdu 610066, China.
E-mail address: huajia611@163.com (H. Li).

http://dx.doi.org/10.1016/j.postharvbio.2016.06.007
0925-5214/

obtained (Feng et al., 2011). This initial finding supports the need for full reporting of penetrometer variables, including the instrument, probe geometry, penetration speed and distance, to enable comparison of data from different trials or laboratories (Abbott, 1999).

Penetrometer speed seems to be the most variable measurement parameter reported in different studies. A speed of 4 mm s^{-1} was established when using the hand-held penetrometer (Watkins and Harman, 1981), although more recently, penetrometer speeds of 5 mm s^{-1} (McGlone et al., 1997; Burdon et al., 2014), 10 mm s^{-1} (Hertog et al., 2004b; Feng et al., 2006), 20 mm s^{-1} (Burdon et al., 2013) and 25 mm s^{-1} (Harker et al., 1996) have all been reported. There has been little research into the impact of penetration speed on the firmness values obtained, although the potential to establish a model to adjust for measurement speed has been investigated on soft (~10N) stored kiwifruit (Feng et al., 2011). There is little mention of the trigger force at which the depth of penetration measurement commences, although Feng et al. (2011) reported using a 0.49 N force (0.05 kgf). Likewise, the approach speed before triggering the measurement seems not to have been investigated, even though this is the speed at which the probe is travelling when it first makes contact with the fruit, and before the measurement is triggered, dependent on the trigger force selected.

There has been a significant amount of research into kiwifruit firmness or texture measurement using non-destructive devices, largely in comparison with a 'standard' penetrometer measurement (including: Abbott and Massie, 1995; Davie et al., 1996; Hopkirk et al., 1996; Burdon et al., 1999). Non-destructive devices allow repeated measurements of the same fruit or even the possibility of all fruit being assessed on a grading line. Commonly used non-destructive technologies include compression, impact response and acoustic impulse response, with instruments available commercially (including from: Aweta, Durofel, Sinclair, Turoni). A key aspect of non-destructive measurement is that the whole fruit is assessed, although the particular technology applied will determine whether a specific part of the fruit has a large impact on the measurement made.

Compression using a motorised penetrometer or fruit texture analyser is used for whole-fruit deformation measurement, although for some fruit, or fruit of some ripeness stages, this may damage the fruit (Abbott and Massie, 1995; Schotsmans and Mawson, 2005). Impact methods have been developed for use as a small hand-held device (Kiwifirm; a prototype device developed at PFR in conjunction with TR Turoni, Italy; Hopkirk et al., 1996; Burdon et al., 1999), as a bench-top or in-line device with the sensor making contact with the fruit (Sinclair, Lurol and Emery, 2007; Hertog et al., 2004a; Schotsmans and Mawson, 2005) and also for fruit hitting a stationary sensor (Imou et al., 1993; McGlone and Schaare, 1993, 1998). Acoustic impulse response technology has also been commercialised both as a bench-top as well as an in-line technology (Aweta). In previous research, acoustic firmness has been shown to be largely a measure of the mechanical stiffness based on both mechanical strength of cell wall and turgor pressure, which were affected by storage temperature and also by humidity (Hertog et al., 2004a). It has also been reported that acoustic firmness might be most sensitive for firm (unripe) fruit (Ketelaere et al., 2006).

New technologies for firmness measurement have been used either to replace the destructive penetrometer directly, i.e. looking to measure in exactly the same way as the penetrometer, or, to measure firmness or textural changes not identified by the penetrometer. In the first instance, a tight correlation with the penetrometer is required, whereas in the second instance, a tight correlation is not desired, as factors other than those measureable by penetrometer are being sought. Thus comparisons of new texture measurement methods are largely investigated by comparison with penetrometer tests and analysis of correlations (Hopkirk et al., 1996; Schotsmans and Mawson, 2005).

In this paper, two aspects of kiwifruit texture measurement are reported. Firstly, the effect of speed of penetrometer probe movement immediately before (approach speed) and during firmness measurement (measurement speed) have been quantified using a GÜSS Fruit Texture Analyser (GÜSS, South Africa). Secondly, the firmness values derived from compression, impact and acoustic impulse non-destructive measurements have been compared with a standard penetrometer measurement. Both series of experiments included measurements made at harvest and throughout cold storage and were repeated on fruit from two commercially available cultivars grown in New Zealand (*Actinidia chinensis* var. *deliciosa* 'Hayward' and *Actinidia chinensis* var. *chinensis* 'Zesy002' – marketed as Zespri® SunGold Kiwifruit, commonly called Gold3), to check for cultivar differences. Gold3 kiwifruit are structurally similar to 'Hayward' kiwifruit, but are inherently larger, with a flesh that degreens to yellow when ripe.

2. Materials and methods

2.1. Fruit and storage

Two cultivars of kiwifruit were used: 'Zesy002' (Gold3) and 'Hayward'. All fruits were harvested from vines growing in the Bay of Plenty region of New Zealand at the Te Puke Research Centre of The New Zealand Institute for Plant & Food Research Limited.

Gold3 kiwifruit were harvested on 11 May 2015 when average soluble solids content, flesh firmness and dry matter were 14.7%, 42.9 N and 18.3%, respectively. 'Hayward' kiwifruit were harvested later on 26 May 2015, when the average soluble solids content, flesh firmness and dry matter were 7.9%, 83.9 N, and 17.9%, respectively.

After harvest, fruit in ventilated plastic crates (45 L) were transferred to the Mt Albert Research Centre of Plant & Food Research, Auckland. At the end of the day of harvest, fruit were placed into polybags inside modular bulk (MB) fibreboard packs, with ~100 fruit in each pack, and the bag and pack closed. For each cultivar, four MB packs of fruit were placed into coolstores operating at 0 °C for 'Hayward' and 1 °C for Gold3.

2.2. Fruit maturity measurement

Fruit maturity data were collected for 30 fruits per cultivar. An average soluble solids content was determined for individual fruit by a combined sample of juice from the stylar and stem ends using a digital refractometer (0–50%, "pocket" PAL-1, Atago).

Fruit firmness was measured by GÜSS Fruit Texture Analyser (GÜSS FTA, model GS14, GÜSS Manufacturing Ltd, South Africa), which is a computer-controlled motorised device equipped with a 7.9 mm diameter Effegi probe. Fruit were at ~20 °C when measured. For kiwifruit, a penetrometer measurement is made after removal of skin and flesh to a depth of approximately 1 mm. The standard penetrometer measurement settings were: approach speed 20 mm s^{-1}, trigger threshold 0.49 N (0.05 kgf), measurement speed 5 mm s^{-1}, measurement distance 7.9 mm and reverse speed 30 mm s^{-1}. The maximum force was recorded automatically as the firmness value in kgf and data converted to N, where 1 kgf = 9.81 N. Firmness was measured twice at the equator of each fruit, with the two measurements taken at 90° to each other, and these values averaged to give a fruit firmness value.

The dry matter of fruit was determined by drying a 2 mm transverse slice from the middle of the fruit at 65 °C for approximately 24 h.