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Cropping effects on the loss of apple fruit firmness during storage: The relationship between texture retention and fruit dry matter concentration

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ABSTRACT

Firmness is a primary measure of apple fruit texture, the key determinant of eating quality of apples. Despite the well developed understanding of the process of firmness loss in storage, there is very limited information concerning pre-harvest and at-harvest causes of the variation in fruit quality in the market-place. The objective of the present study was to investigate the respective roles that the factors of time and intensity of crop thinning, fruit size and fruit dry matter concentration (DMC) each may have in determining fruit firmness of 'Royal Gala' apple at harvest and during storage. Loss of firmness during storage of all thinning treatments and of fruit size and DMC categories was described by a bilinear equation. Time of thinning did not influence any aspect of fruit softening during air storage at 0.5 °C. Comparing the crop loads, a lower crop load (100 fruit per tree) resulted in firmer fruit at harvest. The loss of firmness during storage associated with crop load occurred because fruit from the lowest crop load softened more rapidly during the second slow phase of softening. Fruit firmness was positively correlated with fruit size where larger fruit were slightly firmer than smaller fruit at harvest but not after storage. The softening profiles of different sized fruit were similar except for a class of extremely small fruit, which appeared to soften more rapidly during the second slow softening phase of storage. Both at-harvest and post-harvest fruit firmness were influenced by fruit DMC. Fruit firmness at harvest increased significantly as fruit DMC increased from 13% to above 16%. Despite having significantly different initial firmness, all fruit classes with DMC higher than 13% softened at a similar rate during both the initial rapid and second slow softening phases and the transition between the two phases occurred after the same time in storage. In contrast, fruit with very low DMC, less than 13%, had a greater rate of softening in the second phase. These results indicate that variation in fruit firmness at harvest and after storage is influenced by processes that affect and alter fruit DMC during fruit development. In this respect crop load control, which is used to improve fruit size, was also an important factor in altering fruit DMC, thereby affecting firmness at harvest and after storage. Furthermore, the effects of DMC on fruit firmness were independent of fruit size.

1. Introduction

Firmness is a primary measure of apple fruit texture, the key determinant of eating quality of apples, where firmer fruit are generally considered to have better quality characteristics than softer fruit (Harker et al., 1997). Many markets now require minimum quality standards of fruit firmness (FF) and soluble solids concentration (SSC) for apples, to ensure that consistently high quality fruit can be supplied to the consumers over a long period of time (Johnston et al., 2002a). New Zealand 'Royal Gala' apple fruit must have a minimum of 65 N firmness and 12% SSC after storage and on arrival into the market (Anon, 2005). Excessive post-harvest loss of fruit firmness therefore is one of the major problems affecting apple quality (Johnston et al., 2002a) and can contribute to lowering market demand by reducing consumers' acceptance of fruit and their willingness to buy (Harker et al., 2008). Harker et al. (2008) showed that after long-term controlled atmosphere storage of 'Royal Gala' apples, consumer acceptability increased as firmness increased from about 30 N to 75 N. The same general trends were evident for the cultivars 'Red Delicious', 'Golden Delicious', 'Fuji', 'Braeburn' and short-term stored 'Royal Gala'.

Some pre-harvest factors are thought to influence fruit quality and texture at harvest and after storage, including cultural practices that involve the timing and the extent of thinning (Harker et al., 1997; Johnston et al., 2002a). Fruit of 'Royal Gala' apple from lighter

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cropping trees were found to be 10% firmer than those from heavier cropping trees at harvest (Volz et al., 2004). Cmelik et al. (2006), however, did not observe any significant effect of different crop loads on FF at harvest of 'Fuji' apple. Delong et al. (2006) showed with 'Honeycrisp' apple that as crop load was increased from three to nine fruit per cm^2 trunk cross-sectional area, FF after storage decreased, regardless of pre-storage conditioning treatments and storage environment. Interestingly despite many studies having been carried out determining the effects of pre-harvest factors on fruit quality at harvest, Johnston et al. (2002a) highlighted the lack of information on their effects on fruit softening behavior during storage.

Fruit size is considered to influence the firmness and post-harvest softening of apples (Johnston et al., 2002b). Differences in fruit size at harvest typically reflect changes induced by timing and intensity of thinning to regulate crop load. It is frequently reported for apple that small fruit are firmer than large fruit, both at harvest and after storage (Marmo et al., 1985; Siddiqui and Bangerth, 1995; Harker et al., 1997). Some studies have attempted to relate FF with the biophysical properties of different sized fruit. On 'Empire' apple, Goffinet et al. (1995) only found a positive correlation of fruit size with cortical cell number but no influence of cell packing or intercellular air space. With 'Royal Gala' apple, Volz et al. (2004) found larger fruit had lower firmness, larger cells, less cell packing and more intercellular airspace than smaller fruit. Despite these differences, cell volume and cell packing showed poor association with FF for individual fruit from within a crop load and region. Koorey and Brookfield (1999) suggested that the effect of fruit size on FF arose from differences in physiological maturity of fruit of different sizes, picked on the same date. In another study, fruit size did not affect any aspect of the softening curve of apples stored at 0.5–3 °C when fruit were harvested at an early stage of maturity, but when fruit were harvested with more advanced maturity, smaller fruit tended to soften more slowly than larger fruit (Johnston et al., 2002b).

The use of fruit DMC has recently been suggested as a quality prediction tool in fruit species as diverse as apple (Palmer et al., 2010), kiwifruit, mango and avocado (Harker et al., 2009) and references therein. For 'Royal Gala' apple, Palmer et al. (2010) showed a positive relationship between consumer preference and fruit DMC. Fruit DMC also proved a more reliable predictor of total soluble solids after 12 weeks of air storage at 0.5 °C than SSC at harvest for both 'Royal Gala' and 'Scifresh' (Palmer et al., 2010). With kiwifruit, a meta-analysis of five separate consumer studies on fruit quality demonstrated that fruit of >18% DMC were significantly more liked and that the majority of consumers preferred the flavor of kiwifruit with high SSC when eating ripe, i.e. fruit with high DMC (Harker et al., 2009). The utility of DMC as a quality predictor of taste and flavor in kiwifruit is because measurements can be made before or at harvest and because DMC is principally composed of carbohydrates accumulated by the fruit, with starch being the major constituent, which breaks down to sugars during storage and ripening. With 'Royal Gala' apple fruit, predictive measurement of fruit DMC at harvest using near-infrared spectroscopy provided a very strong positive relationship with fruit SSC after storage (McGlone et al., 2003). A similar pattern to kiwifruit was evident in which SSC after storage increased as fruit DMC increased, which is not surprising given that fruit of both species have a DMC of around 15%, with 60–70% of that dry matter being in the form of sugars when fully ripe (Palmer, 2007). Consumer acceptance of apple is responsive to quality traits like SSC and titratable acidity but usually only if the FF is acceptable (Harker et al., 2008).

Only sparse and inconclusive literature implicates an influence of fruit DMC on FF at harvest or after storage. In the study by Palmer et al. (2010) with 'Royal Gala' and 'Scifresh' apples, fruit DMC was positively related to FF, although the relationship was cultivar-dependent, being quite strong for the higher DMC cultivar 'Scifresh' but weak for 'Royal Gala'. In two out of three years, the firmness of 'Cox's Orange Pippin' apples after storage was positively correlated with fruit DMC at harvest, suggesting that the accumulation of photosynthates may be important for the formation of firm fruit (Johnson et al., 1987). A survey on post-harvest loss of quality using up to 70 orchards each of four commercial apple cultivars in the Netherlands found FF at harvest was correlated with DMC of 'Elstar' in one of the two seasons surveyed, whilst no correlations were found with the cultivars 'Jonagold', 'Boskoop' and 'Cox's Orange Pippin' (De Jager and De Putter, 1999).

The aim of the present study was to investigate the respective roles that the time and intensity of crop thinning and the response variables, fruit size and fruit DMC, have in determining FF and textural properties of apple fruit during storage. A series of crop load treatments provided a matrix of fruit development conditions known to influence fruit size distribution and fruit DMC at harvest. These treatments would therefore provide a large number of individual fruit from precisely known pre-harvest origins to use in extended post-harvest time-course firmness loss studies under low temperature air storage.

2. Materials and methods

2.1. Crop load treatments to induce differences in seasonal fruit growth and fruit size at harvest

The study was conducted using fruit in a block of 16-year-old 'Imperial Gala'/'M.9' apple trees grown at The New Zealand Institute for Plant & Food Research Ltd., Hawke's Bay Research Centre, located in Havelock North, New Zealand.

Three crop load (low = 100, medium = 200 and high = 300 fruit per tree) and two thinning time treatments (30 and 60 days after full bloom (dafb)) were applied in a factorial combination together with an additional treatment of completely unthinned trees included as an 'unmodified crop' control. Treatments were set up in a randomized complete block design using 28 representative and healthy trees selected for uniform flowering. The treatments were set out as single-tree plots in four statistical blocks in which the blocks were defined by tree canopy size. An initial chemical thinning was carried out using 7.5 ppm naphthalene acetic acid + 0.05% Regulaid® at full bloom, which was followed by hand-thinning at the various times during the growing season to produce the matrix of crop load × thinning time treatments. All other aspects of crop management were conducted to standard New Zealand commercial practices for production of export quality apple fruit.

2.2. Harvest and post-harvest quality assessments

Harvest date was decided by assessing starch pattern index (SPI) and fruit background color (BGC) of the most mature fruit in the block and commenced when such fruit reached the commercial harvest indicator (SPI 1.0–1.2). All visibly mature fruit were harvested in several sequential selective picks approximately 6 days apart. From each harvest date, 10 fruit were randomly selected from the harvested fruit of every replicate tree, weighed and assessed for fruit firmness (FF), soluble solids concentration (SSC), dry matter concentration (DMC), starch pattern index (SPI) and titratable acidity (TA). Apart from the 10 fruit for harvest quality assessment, another sample of 100 fruit per tree was selected from the second pick for quality assessment after different durations of storage at 0.5 °C in air with a relative humidity of 95%. Fresh weight of individual fruit was recorded before storage for calculation of weight loss during the storage period for recalibration of stored fruit to harvest DMC. Ten fruit per tree were removed from storage initially at two-week intervals until 84 days after harvest and thereafter at