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Instrumental measurements of juiciness and freshness to sell apples with a premium value

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Juiciness and freshness play a critical role in consumers' choice of apples, and objective measurements of the traits are essential for adding a premium to fruits with high consumer demand. Juiciness and freshness were sensory evaluated by four apple-breeding experts. The score of sensory juiciness decreased with decreased instrumental measurements of water content (WC), firmness, and apoplastic solution (AS). The influence of firmness on sensory juiciness was not linear, and perception of juiciness rapidly decreased when firmness decreased below 60 N. The sensory freshness score was related to titratable acidity (TA), firmness, and the AS. A nonlinear regression model for freshness indicated that freshness was less likely to be perceived as the AS in flesh tissue decreased, and the perception of freshness rapidly decreased when firmness decreased below 60 N or TA decreased below 0.25 g 100 ml^{-1}. The firmness of fruit treated with 1-MCP hardly decreased during storage. The titratable acidity of fruit treated with 1-MCP decreased; however, the degree of the decrease was significantly lower than that of non-treated fruit. The AS immediately decreased just after harvest and was not significantly different in most cases between 1-MCP-treated and non-treated fruit during storage. Therefore, measurements of firmness and TA were useful for distinguishing 1-MCP-treated fruit from non-treated fruit and the AS is necessary to distinguish between stored fruit and that just after harvest. The performance of calibration models developed by NIR spectroscopy for TA, firmness, and AS was lower than that for soluble solids content (SSC), which is used to grade apples by NIR spectroscopy in Japanese packing houses. Therefore, it is impractical to grade fruit by freshness using calibration models. However, high correlation coefficients were obtained in the calibration model for WC. The correlation coefficient of WC was about as high as that of SSC. Therefore, apples could be graded by juiciness using the calibration model for WC with the auxiliary use of calibration models for firmness and AS.

1. Introduction

Due to the development of controlled-atmosphere (CA) storage and the use of 1-Methylcyclopropene (1-MCP) as an inhibitor of ethylene perception, fresh fruit of many apple (*Malus* × *domestica* Borkh.) cultivars, in which fruit quality had been retained for only short periods under the condition of air storage, can be marketed for additional months. Deciding which storage technique should be used is based mainly on the fruit's maturity. Maturity indicators, including starch index, firmness, and peel color, are typically monitored to assess whether apples treated with or without 1-MCP should be stored in air or CA and for what duration (Mattheis, 2008). Accurate information regarding fruit maturity becomes extremely important. However, as the storage technique has become more popular, buyers have been less willing to pay a premium for these apples with quality retention (O'Rourke, 2003). Because no difference in quality is recognized after storage in apples stored by various storage technique, warehouses cannot sell apples at a different price depending on the quality. To sell fruit with an added value, it is necessary to discriminate subtle difference in quality among fruit stored by various techniques. The evaluation of fruit

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quality is crucial for market personnel after storage, as well as at harvest.

Fruit quality, except for the occurrence of decay and physiological disorders during storage or after storage, has been evaluated mainly by attributes such as firmness, soluble solids content, and acidity, which can be measured instrumentally (Hoehn et al., 2003; Harker et al., 2008). These attributes, however, are insufficient for determining consumer preferences in apples. Studies of preference mapping have revealed that crispness and juiciness play critical roles in rating the overall liking of apples (Daillant-Spinnler et al., 1996; Zerbini et al., 1999). These attributes were not strictly determined by the measurements mentioned above such as firmness, although crispness and juiciness were both closely related to instrumental measurements of firmness (Abbott et al., 1984; Harker et al., 2002; Konopacka et al., 2003). Since sensory crispness was also closely related to sensory juiciness (Brookfield et al., 2011), the objective measurement of juiciness is essential for adding a premium to fruit in warehouses with high consumer demand.

Changes in juiciness during storage were the largest among sensory attributes regarding quality (Juhnevica et al., 2013; Mehinagic et al., 2004). Various methods of measuring juiciness instrumentally were proposed for apples. In methods previously employed mainly to determine juiciness, the release of juice was calculated according to differences in tissue weight before and after the compression of cylinders of tissue or according to the area of moistened paper once the expressed juice from the cylinders of tissue had been absorbed (Harker et al., 1997). However, in some research, the calculation of juice release correlated poorly with sensory juiciness (Harker et al., 2006; Brookfield et al., 2011). The sensory rating of juiciness increased with increasing cell size (Szczesniak and Ilker, 1988), and the amount of juice released depended on the number of fractured cells, which are characterized by cells breaking across the equator and releasing juice during chewing of the flesh tissue (Harker et al., 2002). This means that the perception of juiciness is closely related to the amount of juice contained within a cell. On the other hand, using a mathematical model for changes in texture attributes during storage, De Smedt et al. (2002) indicated that a decrease in the instrumental measurement of juiciness seemed to be accompanied by a decrease of water in the apoplast, which consists of the cell wall system and intercellular space, instead of the symplast, which consists of a network of interconnected cells, in non-mealy fruit. One reason for the poor correlation between the instrumental and sensory evaluations of juiciness is thought to be that previous instrumental measurements of juiciness did not distinguish between juice released from broken cells and that from intercellular spaces. Measurements of juiciness have never been used to compare the fruit quality of many cultivars, and the availability of measurements is uncertain for assessing storage conditions, as are cultivar-dependent differences in juiciness.

In addition to juiciness, freshness is also a decisive attribute in consumers' choice of fruit (Péneau et al., 2007; and references therein). Freshness is a sensory attribute, and instrumental measurements of freshness have not yet been developed for the apple. If objective methods for evaluating juiciness and freshness will be developed, fruit with qualities consumers demand could be ranked high in grade. Péneau et al. (2007) showed that juice release and instrumental firmness measured by physical analysis were important for freshness. To guarantee quality with freshness and juiciness before sale, it is necessary to evaluate the quality of fruit non-destructively. Near Infra-Red (NIR) spectroscopy has been examined frequently as a technique for measuring non-destructively attributes of internal quality (Nicolaï et al., 2007; Harker et al., 2008). Most previous NIR research on apples has focused on the measurement of quality attributes of soluble solids content (SSC), firmness, and acidity (McGlone et al., 2002). The practical use of NIR spectroscopy, however, has been limited for measurements of SSC (Nicolaï et al., 2007).

The first grading line with a NIR sensor was introduced in 1989 to sort peaches based on SSC in Japan (Kawano, 1998). To date, a number of packing houses in Japan have introduced a sorting machine with NIR spectroscopy and grade fruit by the SSC as assessed non-destructively (Kawakami et al., 2004). Japanese markets that deal with fruit with high sugar content at a high price in apple and packing houses wish to use the sorting machine with NIR spectroscopy more effectively to grade fruit according to differences in internal qualities besides SSC. In the latest sorting machine, the sorting rate is six fruit per second, and users can measure 10 attributes simultaneously by NIR spectroscopy using a partial least square (PLS) regression model (AIQ Vision, Shibuya Seiki Co. Ltd., Shizuoka, Japan), while the sorting tare of the initial machine was three fruit per second, and the quality attributes were measured using a multiple linear (ML) regression model. The PLS regression model performs better than the ML regression model in analyzing data with a large amount of correlation, or co-linearity, which is the case for the data of NIR spectroscopy (Nicolaï et al., 2007).

Mehinagic et al. (2004) indicated that some wavelengths correlated with juiciness in NIR measurements, although juiciness could not be predicted successfully by the spectroscopic data alone. The objectives of this study were to develop methods of measuring juiciness and freshness instrumentally and to investigate the usefulness of the non-destructive measurement of juiciness and freshness by NIR spectroscopy to grade fruit with high consumer demand after storage.

2. Materials and methods

2.1. Fruit materials

Eight apple cultivars ('Akibae,' 'Morinokagayaki,' 'Starking Delicious,' 'Golden Delicious,' 'Orin,' 'Shinano Gold,' 'Fuji,' and 'Ralls Janet') from an orchard (39°77′N, 141°14′E, 190 m altitude) at the Division of Apple Research, Institute of Fruit Tree and Tea Science, NARO, Japan; one cultivar ('Haruka') from a commercial orchard near the research institute; and one ('Oyume') from the orchards (39°35′N, 141°10′E, 90 m altitude) at the Iwate Agricultural Research Center were used in 2014 for evaluating juiciness and freshness (Table 1). The cultivars were selected to generate fruit exhibiting a wide range of sensory attributes. All trees were managed in accordance with standard orchard practices.

Apples of each cultivar were harvested five times at two- to six-day intervals, beginning with fruit just starting to mature and ending at the estimated commercial harvest date. Fruits were weighed and kept in an incubator at 20 ± 2 °C and 75 ± 15%RH until sensory evaluation. The sensory evaluation of juiciness and freshness was carried out at the last sampling date (commercial harvest date). Prior to the sensory evaluation, stored fruits were removed from the incubator and kept for more than six hours at room temperature (around 15 °C) along with those just harvested.

'Shinano Gold' and 'Fuji,' listed in Table 1, were also used in 2015 to investigate the changes in traits related to juiciness and freshness before and after harvest. Fruits of these cultivars were harvested weekly from five weeks before to one week after the commercial harvest date. Moreover, fruit harvested on the commercial harvest date were stored in a chamber controlled at 2 ± 1 °C and 90 ± 5%RH (air storage) until five months after harvest and were removed from the chamber monthly to measure the traits. Pieces of the fruits harvested at the commercial harvest date were placed in gas-tight storage containers on the day of harvest and treated with 1 $\mu l\, L^{-1}$ 1-MCP for 24 h at ambient temperature before air storage.