Apple Cultivar and Temperature at Cutting Affect Quality of Fresh Slices

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SUMMARY. The response of four apple (*Malus × domestica*) cultivars (Gala, Granny Smith, Ambrosia, and Aurora Golden GalaTM) to fresh-cut processing at core temperatures of 1, 5, 13, and 20 °C was investigated. Fruit were cut after a 24-h preconditioning at one of the four temperatures and a commercial antibrowning formulation was applied as a 7% (w/v) dip before packaging the slices and storing them for 3 weeks at 5 °C. Fruit firmness generally decreased with increasing core temperature, except for Aurora Golden GalaTM, which maintained similar firmness at all temperatures. Firmness varied among cultivars, but all except Granny Smith apples held at 13 and 20 °C, were at or above a minimum processing firmness standard of 14 lbf. Cut-edge browning of slices, in response to processing temperature, varied among the cultivars. In the extreme, 'Granny Smith' was the most responsive, showing the largest variance in surface lightness across the temperature range. 'Ambrosia' was the least responsive to temperature, showing no significant difference in L-value despite the temperature at which it was processed. 'Gala' and Aurora Golden GalaTM were intermediate in response. The visual quality rating for 'Granny Smith' at 3 weeks was poor for slices from all processing temperatures. 'Ambrosia' slices maintained acceptable quality ratings over the full test temperature range. 'Gala' slices had lower quality ratings when processed at warmer temperatures, whereas Aurora Golden GalaTM showed increased quality ratings with warmer processing temperatures. It was concluded that 'Gala' were best processed at low core temperatures, 'Ambrosia' could be processed at all tested temperatures, and Aurora Golden GalaTM produced better quality slices when fruit were at room temperature (20 °C) before slicing.

The fresh-cut apple industry has taken on momentum and has established itself as a new category in the fresh-cut fruit market segment (Clement, 2004). In the growth and development of a new sector, there is a need to improve on existing cultivars to ensure more reliable quality and shelf life (Toivonen, 2006). Much progress has been made with the development of cultivars for fresh-cut vegetables and fruit in the past several years (Gorny et al., 2000; Nicola and Fontana, 2007; Saftner et al., 2005, 2006). However, it is important to try to understand attributes of new apple selections that are important as characteristics for fresh-cut processing and shelf life (Toivonen, 2006).

Many fresh-cut processors have implemented a temperature conditioning treatment in the belief that a

warming of the fruit before cutting might reduce damage incurred during the cutting process. This practice is based on existing knowledge of the differing sensitivity of apple cultivars to bruising injury at varying temperatures (Toivonen et al., 2007). However, the effect of fruit temperature on injury response of new cultivars is not usually known at the time of commercial release. One can make an assumption that all apples behave the same way, but this approach may not always be justified. This work demonstrates the response of two new cultivars and two standard cultivars to fresh-cut processing at different cutting temperatures. The intent was to test the

null hypothesis that all cultivars respond to temperature in a similar manner and will respond to fresh-cut processing similarly when cut at differing fruit core temperatures.

Materials and methods

The four cultivars tested in this study were Ambrosia (British Columbia Ministry of Agriculture and Lands, 2007), Aurora Golden GalaTM (Hampson et al., 2005), Granny Smith, and Royal Gala. The last two cultivars are extensively used for commercial fresh-cut slicing in North America. Each of the apple cultivars was harvested at its optimal harvest date, according to the experience of staff from the breeding program at the Pacific Agri-Food Research Center, Summerland, British Columbia. Apples of each of the four cultivars were harvested into a single bulked sample, from which fruit were randomly taken and placed into four lots, and were stored for 3 months in air storage of 1 °C. The fruit were removed from cold storage on 28 Nov. 2006 ('Ambrosia') and 17 Jan. ('Gala'), 4 Feb. (Aurora Golden GalaTM), and 16 Apr. 2007 ('Granny Smith'). The four lots of each cultivar were further separated into four groups to provide replicates in each of the temperature treatment regimes. The fruit was then placed into controlled environment rooms set at 1, 5, 13, and 20 °C for 24 h. A subsample of five apples was tested for firmness and soluble solids content as described later in this section.

After 24 h at the four test temperatures, seven apples from each temperature were cut at room temperature within 1 h of removal from the treatment room. First, the whole fruit was immersed in 5 L of 100 mg·L⁻¹ chlorinated water [5.25% bleach (Javex-5, Colgate-Palmolive Canada, Toronto) in distilled water

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Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
318.3268	fl oz/ft ²	mL·m ⁻²	0.0031
3.7854	gal	L	0.2642
2.54	inch(es)	cm	0.3937
25.4	inch(es)	mm	0.0394
4.4482	lbf	N	0.2248
0.001	ppm	g·L ⁻¹	1000
1	ppm	mg·L ⁻¹	1
0.001	ppm	mL·L ⁻¹	1000
(°F - 32) ÷ 1.8	°F	°C	(1.8 × °C) + 32

at 3.7 mL·L⁻¹] for 2 min. The clean apples were then sliced using a hand-operated Food Prep bench-top corer-wedger (Ditto Dean, Rocklin, CA) fitted with an eight-slice wedging/coring head. The slices were then immersed in 3 L of 100 mg·L⁻¹ bleach solution for 2 min and then drained for 2 min. The sanitized slices were dipped in 3 L of commercial anti-browning solution (70 g·L⁻¹ Nature Seal®; Mantrose-Hauser, Westport, CT) for 2 min and then drained for 2 min. From the composite sample of slices, 14 were randomly selected for each replicate and were sealed in 20 × 25-cm zip-lock bags (measured oxygen transmission rate ≈3500 mL·m⁻² per 24 h; Lakeside Plastics, Salmon Arm, BC), resulting in four replicates per cultivar per temperature.

FIRMNESS. Firmness was measured using a handheld fruit pressure tester (Effegi, Alfonsine, Italy) fitted with an 11-mm-diameter Magness-Taylor plunger head (Magness and Taylor, 1925). A small section of skin (≈1 cm diameter) was peeled from the equatorial area of the apple with a sharp knife. The head was pushed into the apple in a smooth, consistent manner until the notch in the side of the plunger, etched at the 7-mm depth, became level with the surface of the fruit. The firmness was assessed twice, on opposite sides (sun and shade) of the fruit, and a single average value was used to represent the firmness of that apple in units of pounds-force.

SOLUBLE SOLIDS. Juice from the apple tissue was exuded from the fruit as the firmness testing plunger penetrated the tissue. This juice was collected, for each apple separately, in a clean 9-cm-diameter plastic petri plate. The soluble solids content of the juice was determined using a digital refractometer with a range of 0% to 85% and an accuracy of ± 0.2% (Refracto 30PX; Mettler Toledo Canada, Mississauga, ON).

QUALITY ASSESSMENT AFTER 3 WEEKS OF STORAGE. Lightness of the cut surface was measured on the day of cutting (day 0) and after 3 weeks of storage at 5 °C. Lightness was quantified using a Minolta chroma-meter (CR300; Minolta, Ramsey, NJ) using the *L** values of the Commission Internationale de l'Eclairage (CIE) color system (Gil et al., 1998),

measuring at three locations along each side of each slice, resulting in six measures per slice. The aperture of this particular meter head has a clear cover. The measures for all 14 slices in each bag were averaged to provide a single value for that bag. The day 0 subsample of freshly cut and dip-treated apples was measured and discarded. The change in the lightness (L-value) was calculated by subtracting the L-value on week 3 from the L-value on day 0.

The visual rating of core and flesh tissue for each slice was assessed against a rating scale chart (Kader and Cantwell, 2005). The scale was: 9 = excellent, essentially no symptoms of deterioration, 7 = good, minor symptoms of deterioration, not objectionable, 5 = fair, deterioration evident, but not serious, limit of salability, 3 = poor, serious deterioration, limit of usability, 1 = extremely poor, not usable, off-odors, fungal decay. Deterioration was defined as any of the following: increased brown discoloration, softening, water-soaked appearance, and/or tissue disintegration. The values from all the slices in each bag were averaged to give a single value for each.

EXPERIMENTAL DESIGN AND STATISTICAL ANALYSES. The design was a 4 × 4 (cultivar × temperature) randomized complete block experiment. The data were analyzed using the General Linear Models procedure

(SAS version 9; SAS Institute, Cary, NC), using orthogonal contrasts to evaluate the temperature effects. Analyses for all four measures (firmness, soluble solids, change in L-value, and quality rating) resulted in significant temperature × cultivar interactions, thus, all of the data are presented as simple effects in graphs with associated standard errors of the means to show the degree of variation for each mean.

Results and discussion

The firmness of the four cultivars of apples differed somewhat at the time of cutting (Fig. 1). 'Granny Smith' apples were generally the least firm of the four cultivars tested. The fresh-cut apple industry generally has a minimum firmness standard of 14 lbf, below which fresh-cut apple slices show increased susceptibility to browning and decay (P.M.A. Toivonen, unpublished data). The firmness values for 'Granny Smith' apples were below this standard when held at 13 and 20 °C before slicing. Firmness tended to decline with increased core temperature for all cultivars, except Aurora Golden Gala™ (Fig. 1). Because the temperature application was only 24 h in duration, just before cutting, it is not likely that the fruit would soften substantially in that period of time (Johnston et al., 2001). However, other reports indicate that fruit can increase in apparent

Fig. 1. Firmness of whole apples after a 24-h holding period at four different temperatures. All apples had been stored in air at 1 °C for 3 months before the temperature conditioning treatment was applied. Each symbol represents the mean of four replicate samples and the error bars represent SE; $(1.8 \times ^\circ\text{C}) + 32 = ^\circ\text{F}$, 1 lbf = 4.4482 N.

firmness at lower temperatures (Blanpied et al., 1978; Bourne, 1982). The surprising stability of firmness in Aurora Golden Gala™ slices regardless of conditioning is worthy of further investigation.

While there were fluctuations in soluble solids levels, they did not generally change a significant amount (Fig. 2). The exception was Aurora Golden Gala™ conditioned at 13 °C, which declined in soluble solids compared with those conditioned at the other three temperatures. Among cultivars, the soluble solids content of 'Granny Smith' was generally 1% lower than for the other three cultivars (Fig. 2).

Slice color (lightness/darkness) response was greatest in 'Granny Smith' and depended on apple temperature (Fig. 3). 'Gala' slices showed an intermediate response, with a decrease in L-value change from 1 to 5 °C and a subsequent increase from 5 to 13 °C, after which it responded similarly to 'Granny Smith'. 'Ambrosia' slices appeared to be unaffected by cutting temperature (Fig. 3), while Aurora Golden Gala™ showed a decline in L-value increase from 1 to 5 °C, after which the slices appeared not to be affected by cutting temperature. These results suggest that all four cultivars have a unique response to cutting temperature in regard to lightness change on the cut surface. It should be noted that an increase in L-value represents an increase in lightness of the cut surface on the apple slice; hence, these changes suggest a reversal of browning levels that may occur at the time of cutting. It has been reported that apple slices tend to become significantly lighter or brighter over the first week in the package and this has been attributed to the reversal of browning (Fan et al., 2006). The antibrowning dip that was applied consists of calcium ascorbate (Rupasinghe et al., 2003), and ascorbate is known to reverse browning reactions (Toivonen, 1992); hence, this apparent lightening would be expected.

Among temperatures, the highest quality score was for slices prepared from apples at 13 °C core temperature (Fig. 4). Aurora Golden Gala™, 'Granny Smith', and 'Ambrosia' showed a similar response with temperature. In contrast, 'Gala' slices performed best when cut from fruit at

lower temperatures. However, the quality of the 'Granny Smith' slices was generally at the limit of marketability (based on our quality rating scale) despite the cutting temperature (Fig. 4). Meanwhile, slices made from the other three apple cultivars were

rated good or better despite the cutting temperature. 'Gala' slices performed the best at 3 weeks storage after cutting when cut at the two lower temperatures. Much of the quality ratings in this study were determined by incidence of localized

Fig. 2. Soluble solids content of whole apples after a 24-h conditioning period at four different temperatures. All four apple cultivars had been stored in air at 1 °C for 3 months before the temperature conditioning treatment was applied. Each symbol represents the mean of four replicate samples and the error bars represent SE; $(1.8 \times ^\circ\text{C}) + 32 = ^\circ\text{F}$.

Fig. 3. Change in L-value (measured with a model CR300 chroma-meter; Minolta, Ramsey, NJ) from day of cutting to after 3 weeks in storage at 5 °C. The L-value from day 0 was subtracted from the value at week 3 and hence a higher positive value represents increased lightness relative to day 1. The data represent the lightness change for apple slices that had been conditioned for 24 h at four different temperatures, sliced, and then dipped in 7% (w/v) antibrowning formulation (Nature Seal®; Mantrose-Haueser, Westport, CT) before packaging. Each symbol represents the mean of four replicate samples and the error bars represent SE; $(1.8 \times ^\circ\text{C}) + 32 = ^\circ\text{F}$.

Fig. 4. Quality rating score for apple slices after 3 weeks in storage at 5 °C. The data represent the quality ratings (using scales developed by Kader and Cantwell, 2005) for apple slices that had been conditioned for 24 h at four different temperatures, sliced, and then dipped in 7% (w/v) antibrowning formulation (Nature Seal®; Mantrose-Hauser, Westport, CT) before packaging. Each symbol represents the mean of four replicate samples and the error bars represent SE; $(1.8 \times ^\circ\text{C}) + 32 = ^\circ\text{F}$.

“secondary browning” on the slices, a problem that relates to microbially induced browning on the cut surface (Toivonen and Brummell, 2008). Quite clearly, ‘Granny Smith’ was more susceptible to this problem than the other three cultivars. Secondary browning is affected by the degree of tissue damage that occurs at cutting (Toivonen, 2006). Previous work with Aurora Golden Gala™ has shown that warmer temperatures reduce susceptibility to tissue damage in that cultivar (Toivonen et al., 2007), and so it is not surprising to see that the quality rating for slices was higher at the warmer cutting temperature. Our results with ‘Gala’ and ‘Granny Smith’ slices show that the temperature response of fresh-cut apple is similar to intact apples of these cultivars (Johnston et al., 2001).

The results obtained in this work are limited to the response of four apple cultivars obtained from one growing season at one growing site and hence should be viewed with some caution in regard to general applicability. Many factors could modify the results obtained here, including the fruit maturity at harvest, postharvest treatments such as 1-methylcyclopropene, storage temperatures, and duration and storage

atmospheres. The intent of this report is to highlight the fact that apple cultivars can respond differently to cutting temperature and that their response should be confirmed by the processor before making decisions about pre-process handling of the fruit.

Conclusion

The advent of the fresh-cut apple industry has brought new challenges and needs for research (Toivonen, 2006). We have shown that slice quality from apple cultivars differs with core temperature, and that ‘Gala’ were best processed at low core temperatures, ‘Ambrosia’ could be processed at all tested temperatures, while Aurora Golden Gala™ produced better quality slices when fruit were at room temperature (20 °C) before slicing. These results point to the need for breeding program assessment of new apple lines for fresh-cut processing quality in addition to the potential storage quality of intact fruit.

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