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Postharvest Biology and Technology 33 (2004) 127–140
Postharvest Biology and Technology
www.elsevier.com/locate/postharvbio

Consumer evaluation and quality measurement of fresh-cut slices of ‘Fuji,’ ‘Golden Delicious,’ ‘GoldRush,’ and ‘Granny Smith’ apples

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Received 2 January 2003; accepted 14 December 2003

Abstract

We compared the eating quality of a new apple cultivar, ‘GoldRush,’ with ‘Golden Delicious’ (one of its parents), ‘Fuji,’ and ‘Granny Smith’ (the latter two often used for fresh-cut apple slices). We also compared a commercial with an in-house processing treatment, NatureSeal for apples and Produce Quality and Safety Laboratory (PQSL), respectively. Intact apples that had been stored for about 6 months were washed, processed into fresh-cut slices, stored, and then served to consumers. Both NatureSeal and PQSL treatments maintained cut-surface color values similar to values at the time of cutting. NatureSeal-treated slices were rated slightly better for texture than those receiving the PQSL treatment, but there was no significant difference in acceptability of appearance or flavor. Acceptability scores for the texture and flavor of ‘GoldRush,’ and of ‘Fuji’ when included, were higher than those of ‘Granny Smith’ and ‘Golden Delicious.’ There were small age and gender biases, with older women liking ‘GoldRush’ less and older men liking ‘Granny Smith’ less than other age groups and cultivars in one study. No instrumental measurement was a satisfactory predictor of sensory acceptability scores. ‘GoldRush’ proved to be a promising new cultivar for fresh-cut apple slices and the in-house processing solution maintained the quality of apple slices similar to that of a commercial processing treatment.

Keywords: Malus × *domestica*; Antibrowning; Cultivars; Sensory evaluation; SSC:acid ratio; Surface color; Firmness; Volatile abundance

1. Introduction

Fresh-cut apple (*Malus* × *domestica* Borkh.) slices are desired as a convenient snack for general consumers and as a component in school lunch programs. The USDA (1996) recommends that adults consume

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doi:10.1016/j.postharvbio.2003.12.008

two to three servings of fruit per day, depending on weight and activity levels; young children (ages 2–6) should have two servings of fruit. The Mayo Clinic Healthy Weight Pyramid (Mayo Clinic, 2002) recommends at least three fruit per day for adults. Fresh-cut apple slices could provide active people with a handy, low calorie way to eat fruit "on the run." Fresh-cut apple slices are also desired by food service operators as a safe, economical, and convenient way to serve fruit.

The fruit quality characteristics needed for fresh-cut slices differ from those required for the fresh market. Thus, development of fresh-cut apple products requires reconsideration of cultivar selection as well as the development of preparation and storage methods. Development of fresh-cut apple slices has been hampered by the rapid oxidative browning of apple flesh, the risk of microbial development, and physiological deterioration during transport and storage. Even slow browning cultivars will brown to some extent during the desired 3-week shelf-life.

Enzymatic browning of apple slices can be essentially eliminated by use of modified atmosphere packaging (MAP) with very low oxygen levels (Gorny, 1997); but extremely low O_2 levels, especially at the abusive temperatures to which snack-packs may be exposed, pose the risk of anaerobic respiration and consequent off-flavors (Luo and Barbosa-Canovas, 1996) and, potentially, the growth of microaerophilic human pathogens, such as *Escherichia coli* O157:H7, *Salmonella* spp., and *Listeria monocytogenes* (Buck et al., 2003; Gunes and Hotchkiss, 2002). Browning can also be delayed by reducing agents such as ascorbic, isoascorbic, or citric acid, or by inhibitors of polyphenol oxidase (PPO) such as cysteine or 4-hexylresorcinol (Siddiq et al., 1994; Buta et al., 1999). In addition, antimicrobial substances such as Ca propionate and other food preservatives (Davidson and Juneja, 1990) may delay the secondary browning that can develop on apple slices contaminated by spoilage microorganisms. Calcium salts also have been shown to maintain tissue firmness and slow decay caused by three major postharvest pathogens in apples: *Penicillium expansum*, *Botrytis cinerea*, and *Glomerella cingulata* (Conway et al., 1992).

As with any fresh-cut product, the ultimate measurement of eating quality must be made by eating. We were interested in the eating quality of several cultivars for fresh-cut slices. Initially, we were primarily interested in acceptability of the new cultivar 'GoldRush' compared to older cultivars being used in the limited fresh-cut apple slice production at the time. Later, we became interested in more fundamental questions. Soluble solids:acid ratio is widely considered important in apple flavor, so we selected cultivars with combinations of high and low perceived sweetness and acidity. 'Granny Smith' and 'Fuji' are often used for commercial fresh-cut apple slices. 'GoldRush' is a new cultivar just coming into commercial production; and 'Golden Delicious' is widely available and appears several times in the parentage of 'GoldRush.'

'Fuji,' a cross between red 'Delicious' and 'Ralls Janet,' was introduced in Japan in 1962 as a juicy, firm, crisp, fine-grained apple with a sweet, spicy flavor that has high sugar and low acid content (Brooks and Olmo, 1997; Yoshida et al., 1995). Skin color of 'Fuji' varies from yellow–green with red highlights to very red; flesh is yellowish. It is not prone to storage scald but is susceptible to watercore if harvested late. 'Golden Delicious' was a chance seedling, perhaps of 'Golden Reinette' and 'Grimes Golden,' introduced about 1914 (Baugher and Blizzard, 1987). Flavor is sweet, spicy, and moderately acidic. It is firm at harvest, with a tendency to soften in storage. 'Golden Delicious' has tender golden yellow to greenish yellow skin with a tendency to russet, yellowish white flesh, and has relatively low browning potential. 'GoldRush' was released in 1994, derived from a cross made in 1972 of 'Golden Delicious' as the seed parent with Co-op 17 (PRI 1689-110) as pollen parent (Crosby et al., 1994). The fruit is characterized by a complex, spicy flavor with high degrees of acidity and sweetness (Janick, 2001). It is firm, a low ethylene producer, and a long-storage apple. It is a late-maturing apple with yellow gold ground color, sometimes shading into orange, with yellowish flesh. The skin sometimes takes on a bronze cast and the lenticels tend to be rather prominent (authors' observations). 'Granny Smith' was introduced sometime before 1868 and is believed to be descended from French crab apples grown in Australia (Larsen, 1982; Warrington, 1994). The skin is bright green and may develop a pink blush, which is considered undesirable among US producers; flesh is white to greenish white. 'Granny Smith' apples are generally tart, crisp to crunchy, and juicy; but it lacks "flavor" other than tartness, i.e., concentrations of aromatic flavor volatiles are low. It has a low browning potential, low ethylene production, and stores well, although it is susceptible to development of superficial scald.

1.1. Objectives

- To determine consumer acceptability of apple slices from cultivars having different levels of perceived sweetness and tartness.
- To compare an in-house processing treatment to a commercial processing treatment to control browning and maintain firmness.
- To identify instrumental measurements that may predict sensory acceptability of fresh-cut apple slices.

2. Materials and methods

2.1. Apples

‘Fuji,’ ‘Golden Delicious,’ ‘GoldRush,’ and ‘Granny Smith’ apples from several sources were harvested in 2000 and 2001 at the commercial stage determined by the grower, so times of harvest varied from mid-September to early November. We decided to make our evaluations after about 5–6 months’ storage because a cultivar must store well and be available most of the year to be of interest for fresh-cut production.

2.2. Preliminary test

Processing solutions for apple, pear, and other fresh-cut products were previously developed in our laboratory (Produce Quality and Safety Laboratory, PQSL) by others (Buta et al., 1999). (Solutions designed to maintain quality of fresh-cut apple slices are referred to in this paper as processing treatments.) We decided to compare the dominant commercial processing solution in use at the time, NatureSeal for Apples (Mantrose-Haeuser Co., Westport, Conn., USA), to a formulation based on those developed in our laboratory. To verify that concentrations of potential ingredients in the PQSL processing solution were not objectionable, we ran a preliminary sensory panel with 10 staff members who were not involved in fresh-cut apple or pear research but who were familiar with apple quality and had participated often in detailed sensory evaluations of fruit.

Twenty ‘Golden Delicious’ apples purchased at a wholesale market after about 5 months’ storage were surface sanitized and halved. One half of each was cut in four slices. Each slice was dipped for 30 s in a different treatment solution (Table 1). Slices from 10 apples received treatments 1 through 4 and slices from the remaining 10 received treatments 5 through 8. The slices were then drained, the drip line of accumulated solution was blotted from the lower edge, and then each piece was put in a labeled plastic sandwich bag. The other half of the same apple was then cut into four slices and put untreated in another bag to serve as controls. The five bags (four treatments plus controls) with pieces from a single apple were stapled together. All bags were placed in an uncovered plastic bin and held at 10 °C for 19 h, then held at 23 °C for 3 h to equilibrate to ambient temperature before sensory evaluation. Substances applied to slices may diffuse into the tissues over time. We chose to evaluate taste after a very short holding time to maximize the possibility of noticeable tastes from the treatments.

Each panelist evaluated paired samples of untreated (labeled control) and treated slices (coded with random 3-digit numbers) from the same apple. Earlier tests had indicated that a single slice of fruit was sufficient for rating general quality characteristics. Each panelist tested all eight treatments in paired difference-from-control tests (Meilgaard et al., 1999), serving as a complete block in the statistical design. Apple-to-apple variation is a significant problem in tasting; and using single-slice samples allowed each panelist to taste only two apples in the treatment-control pairs, which seemed less confusing than tasting eight apples. We did not include a blind control, but assumed that the “placebo effect” would be similar for all samples. The panelists evaluated degree of difference between the labeled control and the treated sample on a 4-point scale (1 through 4 being not, slightly, moderately, and greatly different, respectively) and then rated acceptability of the treated sample on an unstructured 150-mm scale labeled *bad* to *excellent*, and later converted to scores of 0–100, respectively. On-screen ballots were prepared and data was collected using Compusense Five (Version 4.2; Compusense Inc., Guelph, Ontario, Canada).

Table 1
Treatments tested in a preliminary sensory trial of potential ingredients of the Postharvest Quality and Safety Laboratory (PQSL) processing solution, 15 February 2001, by paired comparison with untreated control slices by 10 panelists

	Treatment	Degree of difference[a]	Acceptability score[b]
1	NatureSeal for apples[c]	1.8	62
2	50 mM (0.9%) isoascorbic acid	1.9	61
3	**100 mM (1.8%) isoascorbic acid**[c]	2.1	66
4	50 mM (0.9%) isoascorbic acid + NaOH	2.4	56
5	1.0 mM 4-hexylresorcinol	2.0	69
6	**5 mM (0.1%) Ca propionate**	1.9	70
7	**10 mM (0.2%) *N*-acetylcysteine**	2.3	55
8	0.1% low viscosity carboxy-methyl cellulose	2.3	51

Ingredients in the PQSL formulation tested in 2001 are shown in bold type.
[a] Degree of difference from labeled untreated control slice of the same apple on 4-point scale, where 1: no, 2: slight, 3: moderate, and 4: very noticeable difference.
[b] Overall acceptability where 0: bad to 100: excellent.
[c] NatureSeal was applied at the label rate (∼117 mM Ca ascorbate).

2.3. Experiment 1

In 2001, we evaluated eating quality of three cultivars and compared an in-house processing treatment (PQSL) to a commercial treatment (COM). ‘GoldRush’ was furnished by the breeder and had been held in air storage at 0 °C at less than optimal relative humidity, while the ‘Golden Delicious’ and ‘Granny Smith’ apples were purchased at a wholesale produce market and had most probably been stored in CA. ‘Golden Delicious’ is readily available and is the seed parent of ‘GoldRush,’ which was our primary interest in this experiment. ‘Granny Smith’ was selected because it was being used commercially for fresh-cut apple products.

Fifteen apples of each cultivar were prepared on each of 3 consecutive days. All apples were washed in cold tap water, dried with paper toweling, and transferred to a clean room at 10 °C. All utensils and the work surfaces were sanitized with 70% ethanol. Each apple was cut longitudinally into eighths, all core tissue was removed, and three slices were immediately immersed and stirred for 1 min in PQSL and three in COM; two were left untreated. The PQSL solution was 100 mM isoascorbic acid, 5 mM Ca ascorbate, 5 mM Ca propionate, and 5 mM *N*-acetylcysteine at pH 3.0. COM was NatureSeal for Apples prepared according to the manufacturer’s directions, and contained ∼117 mM Ca ascorbate at pH 7. Both solutions were prepared with deionized water at 5 °C. One untreated control slice was reserved for immediate color and firmness measurements. The other seven slices from a single apple were then placed in a three-compartmented plastic bag prepared from standard gauge LDX 5406 film (Cryovac, Duncan, SC). The oxygen transmission rate (OTR) of the film as determined by the manufacturer at 23 °C and 1 atm was 29.16 pmol s^{-1} Pa^{-1} according to ASTM International procedure #D 3985-81 (ASTM International, 1986). At 5 °C in air, the film OTR was 11.18 pmol s^{-1} Pa^{-1} as determined following an exponential decay method for determining gas transmission rates through plastic films in a static cell (Moyls et al., 1992) with slight modification. The oxygen concentration in a static cell initially flushed with N_2 gas and stored at 5 °C in moist (∼90% RH) air was measured continuously using a noninvasive O_2 analyzer (model 101, OxySense Inc., Las Vegas, Nevada, USA). The slopes obtained from linear regressions of the test cell data (average of three samples) predicted the film OTR. Compartment sizes of the bag were ∼ 9 cm × 10 cm for the three PQSL- and for the three COM-treated slices and 3 cm × 10 cm for the untreated slice to provide similar tissue to film surface area ratios for each treatment. Bagged slices were held for 7 days at 5 °C, followed by 3 h at 23 °C before sensory testing. Gas sampling showed the internal atmosphere to be ∼17 kPa O_2 and ∼ 4 kPa CO_2 at the end of storage.

Color and firmness were measured on the untreated control slices at 23 °C at the time of cutting and on one slice from each treatment at the time of sensory evaluation. Color (L^*, a^*, and b^*; later converted

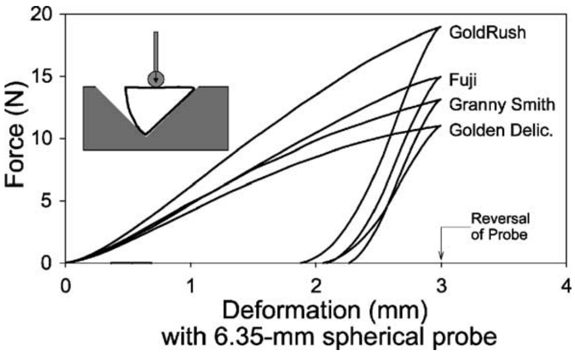

Fig. 1. Firmness measurements on fresh-cut apple slices treated with COM and stored at 5 °C for 7 days; each curve is the mean of ∼120 slices. Inset: Firmness measurement arrangement with 6.35-mm diameter spherical probe and 45° right angled slot in a steel block to hold a 1/8-apple slice. Because wedges were manually cut and therefore not precisely 45°, it was impractical to support each wedge so the upper surface was exactly horizontal, and the use of a spherical probe adjusted for the slightly imperfect angles of contact. The application of force in a direction transverse to the radial cellular orientation was not ideal for engineering measurements but was satisfactory for comparative purposes.

to L^*, C^*, H_{ab}) was measured on the cut surface of apple slices using a Minolta chroma meter (Model CR-300, Minolta, Tokyo, Japan). Firmness was measured on a Texture Analyzer (Stable Microsystems, Godalming, Surrey, UK). The slice was placed on an angled support so the upper cut surface was approximately horizontal (Fig. 1). The slice was indented with a spherical probe (6.35-mm (0.25-in.) diameter) at 1 mm s^{-1} to a depth of 3 mm. The maximum force (F_{max}), area (area, energy under the penetration curve) to the peak, and the slope (slope) of the middle 1 mm of the penetration curve were computed.

Beltsville Agricultural Research Center staff volunteers who like apples, eat them frequently, and had no knowledge of the treatments (120 consumers) evaluated a single slice from each of the six treatments. Because of apple-to-apple variation, we ensured that slices from PQSL and COM treatments tasted by a given panelist came from the same apple. The two processing treatments on the same cultivar were presented sequentially. The three cultivars were presented in random order. The same order was used for 10 panelists within a panel session, respective to the three possible ordered sequences of cultivars and the two ordered sequences of processing treatments. Each panelist evaluated all six treatments: three cultivars × two processing solutions, serving as a complete block in the statistical design. Samples were presented one at a time in individual booths under moderate incandescent lighting. Panelists were required to cleanse their palates with a bite of low-salt saltine cracker, a sip of room-temperature water, and a small time lag before every sample. The panelists rated the acceptability of appearance, flavor, and texture on unstructured 100-point scales labeled *bad* to *excellent*. Comments were solicited on the ballots. On-screen ballots were prepared and data was collected using Compusense Five (Version 4.2; Compusense Inc., Guelph, Ontario, Canada).

2.4. Experiment 2

'Fuji' was added in the second year of experimentation to provide an apple with high soluble solids content (SSC) and low acidity. 'Fuji,' 'Golden Delicious,' 'GoldRush,' and 'Granny Smith' were obtained from a single grower in southern Pennsylvania. Because the current commercial practice was to use NatureSeal for fresh-cut apple slices, we applied only NatureSeal (COM) to the slices sampled by panelists. Each apple was cut in eight slices. One slice was an untreated control used for instrumental tests immediately after cutting. Five slices were treated with COM as in Experiment (Expt.) 1. One slice was similarly treated with the PQSL processing solution which had been reformulated to contain twice as much calcium (10 mM Ca ascorbate and 10 mM Ca propionate). The remaining slice was an untreated control for instrumental tests on the day of tasting. Bags were made with two partitions, a 13 cm × 13 cm one for the COM slices and a 13 cm × 5 cm one for the PQSL and untreated control slices. Packaged slices were stored at 5 °C for 7 days.

At the time of consumer evaluation, all apple slices were equilibrated to 23 °C for 3 h. Three COM slices from each of 10 apples were pooled for sensory panels. Panelists similar to those participating in Expt. 1 (120 USDA staff, mostly different individuals from those in Expt. 1) evaluated a single slice from each of the four cultivars plus a duplicate sample of two of the cultivars, all six samples having different code numbers. For all 10 panelists within a panel session, the six samples consisted of the same two cultivar duplicates and were administered in the same order. This experimental design was balanced in the sense that it allowed each cultivar to be evaluated 18 times with samples systematically ordered so that each cultivar followed each of the other three cultivars with equal frequency to neutralize any carry-over effects. The panelists rated acceptability of appearance, flavor, texture, and overall eating quality as in Expt. 1. Comments were solicited.

At the time of sensory evaluation, color and firmness tests were made as described above on one slice from each of the three treatments on each apple. The slices used for color and texture measurements from 10 apples within a single treatment were then ground in an electric juice extractor. Soluble solids content was measured using a digital, temperature-compensated refractometer (model PR-101, Atago Co., Tokyo, Japan). Titratable acidity (TA), expressed as malic acid, was determined by titrating 10 ml juice with 1.0 M KOH to pH 8.2 (Mitcham and Kader, 1996). Aliquots of 1 ml juice were placed in glass vials and stored for later analysis of volatile abundance using a solid-phase microextraction (SPME, Supelco Co., Bellefonte, Pa.) technique and gas chromatography as described previously (Saftner, 1999). Constructing calibration curves for each volatile analyte in each apple sample is not feasible and thus total volatile abundance is reported in FID area response units of picoamps (pA) rather than absolute amounts of individual analytes.

2.5. Experiment 3

We had access to a large group of consumers of very mixed ages and backgrounds at a public field day on the grounds of the USDA Agricultural Research Center (Beltsville, Maryland, USA) on 1 June 2002. About 400 panelists of both genders and of ages from 8 to 80 evaluated slices of three cultivars. Children $<$12 years old were accepted only if it was evident that they understood the task, could discriminate, and could express their opinions; the children were closely supervised. Evaluations were done under ambient conditions in a translucent white tent. Panelists were not isolated but were strongly encouraged not to share opinions or otherwise bias other panelists.

By late May 2002, the 'Granny Smith' apples remaining after Expt. 2 showed symptoms of scald, so we substituted 'Granny Smith' apples purchased from a wholesale market. We decided that, under the conditions of an outdoor public field day, we could test only three cultivars, so we included only 'Fuji,' 'GoldRush,' and 'Granny Smith' and omitted 'Golden Delicious.' Apples of each cultivar (15 apples $\times$ 3 replicates) were prepared as for the previous experiments except that they were cut into 10 slices and all were dipped in NatureSeal solution. They were held in rigid plastic bins for 9 days at 5 °C, ventilated daily to maintain aerobic conditions. Containers were embedded in crushed ice during the serving period of about 2 h per replicate. (Ambient temperature approached 37 °C.) Paper plates (23-cm) were partitioned into three sections, each labeled with a 3-digit code, and slices of the three cultivars were placed beside their respective code number, with the positions of the cultivars randomly distributed within each of the three replicates. Different code numbers were used for each replicate. Panelists were given verbal instructions and a paper ballot with the 3-digit codes and 150-mm unstructured hedonic scales labeled *really bad* and *super good* at the ends, later digitized to 0–100, respectively. Participants were asked to indicate gender and age in decades. Instrumental tests were not made in Expt. 3.

2.6. Statistical analyses

Data were analyzed using SAS PROC MIXED (SAS, 1999). In Expt. 1, sources of variation were cultivars (3) and processing treatments (2) considered fixed and the panel sessions (12) and panelists (120) considered random. In Expt. 2, sources of variation were cultivars (4) considered fixed and the panel sessions (12) and panelists (120) considered random. For instrumental measurements, sources were cultivars (4) and processing treatments (3) and storage duration (2, at the time of cutting and at consumer evaluation). For Expt. 3, sources of variation were cultivars (3) and replicates (3). Relationships of cultivar preference relative to gender and age were examined using analysis of covariance (ANCOVA) (Littell et al., 1996). Treatment differences were tested by Tukey–Kramer, $\alpha = 0.05$. All differences mentioned were significant at $\alpha \leq 0.05$. For instrument-sensory comparisons, backward stepwise regression was used to model the relationships (SAS, 1999).

3. Results and discussion

3.1. Preliminary test

Differences of treatments from controls were only slight, although significant, and no treatment was rated unacceptable on average (Table 1). For preliminary screening, we consider roughly the upper third of the acceptability scale to be good, the center third to be mediocre, and the lower third to be unacceptable. It is important to recognize that this evaluation was preliminary and was *not* a consumer test. Our experienced panelists are generally more critical of our treatments than general consumers, and low mediocre scores indicate that a treatment probably is not acceptable but may deserve a more thorough testing. Buta et al. (1999) from our laboratory reported that a combination of 4-hexylresorcinol, *N*-acetylcysteine, isoascorbic acid, and Ca propionate extended the shelf-life of fresh-cut 'Delicious' apple slices in cold storage for 5 weeks without use of modified atmosphere packaging. However, this treatment was designed to maximize shelf-life with little consideration for physiological or sensory impact on the slices. Although 4-hexylresorcinol is derived from natural products and classified by Food and Drug Administration as GRAS (generally regarded as safe) (McEvily et al., 1992), its registration for fruit products is uncertain, so we decided not to include it in our formulations for apples. Carboxymethyl cellulose was initially tested because it had been suggested as a coating material to reduce surface drying of fresh-cut produce (Baldwin et al., 1996). However, it was scored barely acceptable in our preliminary test, was slimy to the touch, and was not in the formulations tested by Buta et al. (1999), so we did not include it in our PQSL treatments. Cysteine and its derivatives were found to inhibit PPO activity in pear (Siddiq et al., 1994), and *N*-acetylcysteine specifically is used as a dietary supplement. We decided to use 100 mM isoascorbic acid, 5 mM Ca ascorbate, 5 mM Ca propionate, and 5 mM *N*-acetylcysteine for the PQSL processing treatment in Expt. 1. Concentrations used were based on the minimal concentration necessary to maintain fresh-cut slice quality (appearance, flavor, and texture) while not adversely affecting tissue water relations and cell wall pH homeostasis.

3.2. Experiment 1

3.2.1. Processing solutions

There were no differences in performance of the processing treatments among cultivars (cultivar × treatment nonsignificant), so each main effect was considered independently (Table 2). There was no difference in appearance or flavor scores between COM

Table 2
Sensory acceptability scores[a] for appearance, flavor, and texture in Experiments 1 and 2

Effect	Sensory scores								
	Appearance			Flavor			Texture		
	Expt. 1	Expt. 2	Combined	Expt. 1	Expt. 2	Combined	Expt. 1	Expt. 2	Combined
Processing solutions									
COM	68 a	NA	NA	58 a	NA	NA	64 a	NA	NA
PQSL	67 a	NA	NA	57 a	NA	NA	61 b	NA	NA
Cultivars									
'Fuji'	NA	76 a	76 a	NA	70 a	70 a	NA	75 a	75 a
'Golden Delicious'	64 b	72 a	67 bc	49 b	56 b	51 b	56 b	49 b	52 b
'GoldRush'	65 b	58 b	63 c	63 a	69 a	65 a	71 a	74 a	72 a
'Granny Smith'	72 a	60 b	67 b	59 a	47 c	55 b	61 b	49 b	56 b

[a] Acceptability of each attribute was indicated on an unstructured 150-mm scale labeled *bad* to *excellent* and later converted to scores of 0–100, respectively. On-screen ballots were prepared and data were collected using Compusense Five (Version 4.2; Compusense Inc., Guelph, Ontario, Canada). Analyses were performed with panelist = experimental unit; 120 untrained panelists each year. NA means not available, i.e., treatment or cultivar was not used in that experiment. Within processing solutions or within cultivars, means within a column followed by the same letter were not significantly different at $\alpha = 0.05$, Tukey–Kramer means comparison.

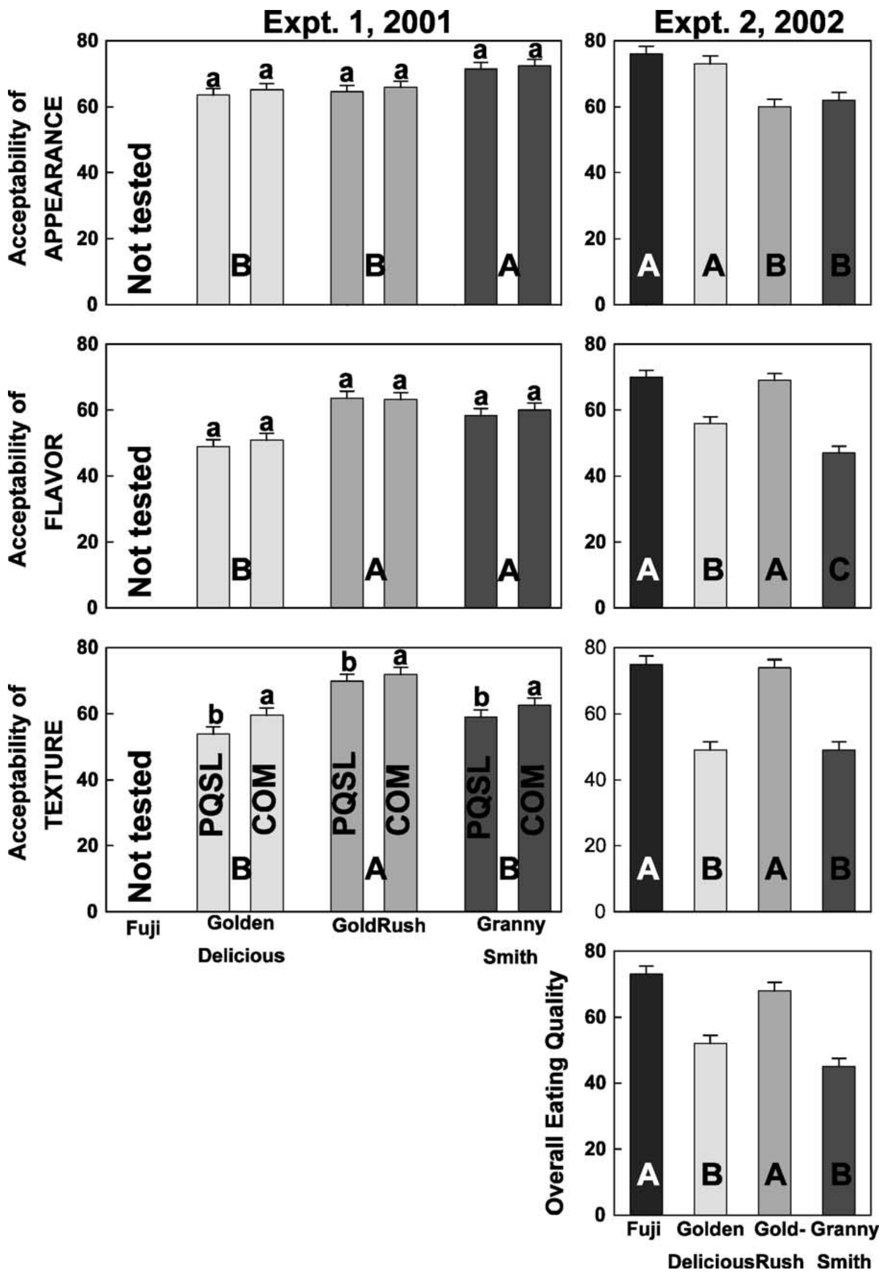

Fig. 2. Consumer sensory acceptability scores for 'Fuji,' 'Golden Delicious,' 'GoldRush,' and 'Granny Smith' apple slices treated with a commercial (COM) and an in-house (PQSL) processing solution in 2001 (left plots) or COM only in 2002 (right plots). Within a plot, cultivar means with the same upper case letter were not significantly different and, within the 2001 plots only, processing treatment means for a given cultivar (paired bars) with the same lower case letter were not significantly different.

and PQSL. There was a small difference in texture scores (Table 2, Fig. 2); but such a small difference in acceptability of texture (64 versus 61) is considered to have no practical meaning.

3.2.2. Cultivars

In Expt.1, the appearance of ‘Granny Smith’ was scored more acceptable than that of ‘Golden Delicious’ and ‘GoldRush,’ which were not different from each other (Table 2, Fig. 2). Flavors of ‘GoldRush’ and ‘Granny Smith’ were equally acceptable, although certainly different. However, the flavor of ‘Golden Delicious’ was scored significantly less acceptable (Table 2). Acceptability of the texture of ‘GoldRush’ was scored higher than that of ‘Granny Smith’ and ‘Golden Delicious’ (Table 2, Fig. 2). The numerical difference in texture scores between the higher- and lower-scored cultivars was large and clearly indicated a real preference. The acceptability of the texture of ‘GoldRush’ in 2001 was rather surprising because it had not been stored under optimal conditions.

3.3. Experiment 2

In 2002, the appearance of ‘Fuji’ and ‘Golden Delicious’ was preferred to (scored higher than) that of ‘GoldRush’ and ‘Granny Smith’ (Table 2). Because ‘Fuji’ was tested only in the second year, it is not possible to make a comparison over years, but the appearance of ‘Fuji’ seems to be well liked (Fig. 2). We did not specify whether to consider the appearance of flesh only, skin only, or both because we wanted panelists to emphasize what was important to them, not to the authors. Comments indicated that much of the difference in scores was due to differences in the skin rather than the flesh, so there would likely have been no difference in acceptability among cultivars if slices had been peeled. The skin of ‘GoldRush’ was a very intense orange–gold color, tended to have relatively large lenticels, and was slightly prone to russetting or bronzing. A few panelists commented that the orange–gold color looked artificial. The skin of ‘Golden Delicious’ was a bland, pale yellow–gold. That of ‘Granny Smith’ was light green with small whitish lenticels and some slices had a pinkish blush. ‘Fuji’ was the only red apple, and its skin was a rather light red. Markets differ in their preference for presence or absence of peel. In recent surveys, a majority of consumers preferred peels on the apple slices (Washington Apple Commission, 2000). However, people wearing orthodontic braces, the elderly, and certain ethnic groups may prefer the peel removed. Additionally, skin color varies somewhat within a cultivar depending on climatic conditions, soil fertility, and maturity at harvest. We did not test peeled slices.

Table 3
Overall eating quality scores[a] from Experiments 2 and 3 (Public Field Day 2002)

Cultivars	Expt. 2	Expt. 3
‘Fuji’	73 a	65 a
‘Golden Delicious’	52 b	NA
‘GoldRush’	68 a	71 a
‘Granny Smith’	45 b	44 b

[a] Overall acceptability was indicated on an unstructured 150-mm scale labeled *bad* to *excellent* (Expt. 2) or *really bad* to *super good* (Expt. 3) and later converted to scores of 0–100, respectively. Expt. 2 was conducted under controlled conditions in a sensory evaluation facility; participants were 120 staff of USDA. Expt. 3 was held outdoors under ambient conditions in a large white tent on 01 June 2002; outdoor temperature was 26–32 °C; the ~400 participants were from the interested public from the Washington, DC area. Means within a column followed by the same letter were not significantly different at $\alpha = 0.05$, Tukey–Kramer means comparison.

The flavor of both ‘Golden Delicious’ and ‘Granny Smith’ was scored less acceptable than that of ‘Fuji’ and ‘GoldRush.’ The differences were large enough to indicate the likelihood of a practical difference in acceptance in the market.

Acceptability of the texture (Table 2, Fig. 2) of ‘GoldRush’ and ‘Fuji’ was scored higher than that of ‘Granny Smith’ and ‘Golden Delicious.’ Again, the numerical difference between the higher- and lower-scored cultivars was large and clearly indicated a real preference.

Overall eating quality was scored higher for ‘Fuji’ and ‘GoldRush’ than for ‘Golden Delicious’ or ‘Granny Smith,’ with differences large enough to be meaningful (Table 3).

Although we did not use the PQSL solution in the sensory trials in Expt. 2, we did make instrumental measurements on PQSL- and COM-treated slices and untreated slices. Both COM and PQSL maintained cut-surface color values similar to values at the time of cutting, while untreated controls browned as indicated

Table 4
Mean instrumental values[a] on the day of sensory evaluations for apple slices treated with COM in Experiment 2

Cultivar	Color			Soluble solids content (%)	Titratable acidity (%)	SSC: acid ratio[b]	Volatile abundance[c] (pA)	Firmness		
	L^*	C^*	H_{ab}					F_{max} (N)	Area[d] (N mm)	Gradient[d] ($N\,mm^{-1}$)
'Fuji'	81.6 ab	24.3 a	99.4 ab	16.0 b	0.23 d	69.3	3283 b	14.9 b	21.3 b	5.8 b
'Golden Delicious'	82.3 a	24.2 a	100.0 a	13.5 c	0.30 c	45.5	2577 b	12.3 d	19.5 c	5.0 c
'GoldRush'	81.0 b	22.9 ab	97.2 b	17.4 a	0.72 b	24.5	5890 a	20.0 a	29.5 a	7.9 a
'Granny Smith'	81.6 ab	20.0 b	98.9 ab	15.3 b	0.80 a	19.1	1054 c	13.9 c	21.2 b	5.3 c

[a] Means within a column followed by the same letter were not significantly different at $\alpha = 0.05$, Tukey–Kramer means comparison.
[b] Ratio of soluble solids content to titratable acidity.
[c] Total volatile abundance is reported in FID area response units of picoamps (pA) rather than absolute amounts of individual analytes.
[d] Area and gradient are shown in measurement units rather than SI units to better relate to Fig. 1.

by temporal changes in L^*, C^*, and H_{ab} (Fig. 3). 'Granny Smith' showed the greatest color changes, with the color of both PQSL- and COM-treated fruit becoming somewhat less green and slightly more saturated. (Saturation represents the purity of the color: the grayer a color, the less saturated it is.) Even with the calcium level in the PQSL solution doubled in Expt. 2 compared to that in Expt. 1, the PQSL solution contained less than 20% of the calcium in the COM solution. Instrumental firmness of COM-treated slices was consistently greater than that of PQSL-treated slices, regardless of which parameter was chosen; but the differences were small and not consistently significant (Fig. 3). Although F_{max} is the measurement parameter most often reported in horticultural firmness studies, there are arguments to be made for choosing area under the curve, which approximates the energy required to penetrate the tissue, or slope of the initial portion of the curve, which engineers relate to stiffness. 'GoldRush' had the highest F_{max} and slope values, and 'Fuji' had the highest values for area (not necessarily significant), regardless of treatment (Fig. 3). 'Fuji' and 'GoldRush' received similar, high texture acceptability scores and 'Golden Delicious' and 'Granny Smith' received similar lower scores (Table 2), more similar to the ranking of cultivars by F_{max} and area than that by slope (Fig. 3 and Table 4). We will not speculate on either which is the better measurement parameter or the sensory interpretation of these three parameters from the force/deformation measurements. However, note that the order of cultivars differs among them. Slope and area separate the cultivars better than F_{max}, but F_{max} and area ranked cultivars more similarly to sensory acceptability scores than did slope in this study. None of the instrumental texture variables predicted the texture acceptability scores of our panelists well enough to be useful.

3.4. Experiment 3

'Fuji' and 'GoldRush' were liked equally well by participants in the Public Field Day 2002 trial (Table 3). Despite the apples coming from two sources and participants coming from two pools with somewhat different demographics in Expt. 2 and 3, 'Granny Smith' scored equally low in both tests. (It should be noted that the 'Granny Smith' apples used in Expt. 2 appeared to have been harvested more ma-

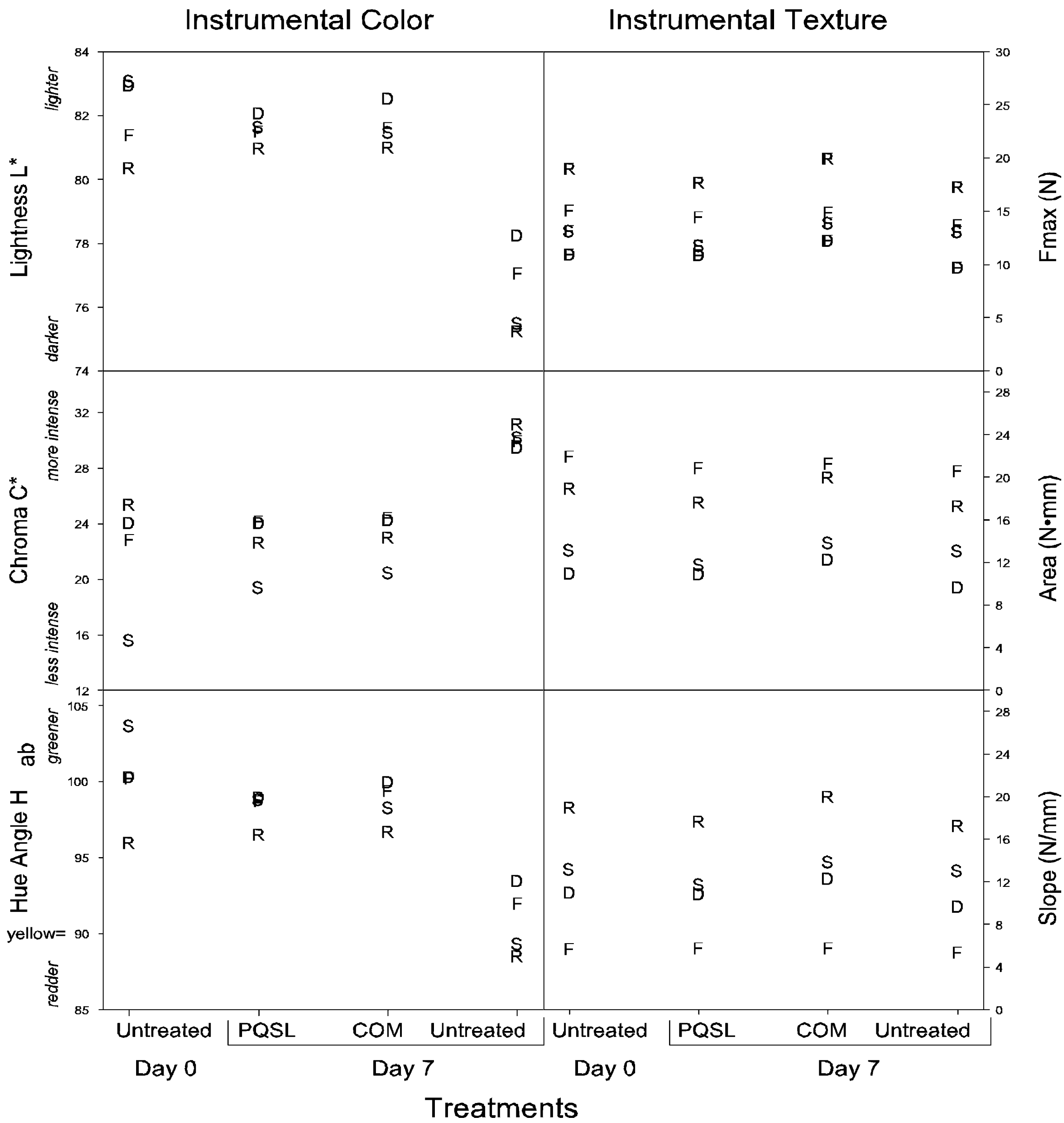

Fig. 3. Instrumental measurements of ‘Fuji’ (F), ‘Golden Delicious’ (D), ‘GoldRush’ (R), and ‘Granny Smith’ (S) apple slices at the time of preparation or on the day of consumer sensory evaluations after storage at 5 °C for 7 days (Expt. 2). Each point is the mean of 42 apples; slices from the same apples were untreated or treated with a commercial (COM) or an in-house (PQSL) processing solution.

ture than is customary on the US West Coast: many of the apples showed some blush and had higher volatile levels than is common in those purchased at wholesale markets. The ‘Granny Smith’ apples purchased for the field day trials were typical of those from the West Coast, with an entirely green peel.) We had speculated that gender and age might influence preferences, so we included gender and age on the ballots. There was a significant interaction, so each combination of gender × age was modeled separately

Table 5
Regression of overall eating quality score on age by gender and cultivar (Experiment 3)

Gender	Cultivar	Intercept[a]	Slope[a] (age effect)	$P > \|t\|$ for slope
Female	'Fuji'	104	−5.4	0.313
Female	'GoldRush'	123	−11.3	0.015
Female	'Granny Smith'	63	+0.5	0.928
Male	'Fuji'	102	−3.9	0.472
Male	'GoldRush'	102	+2.9	0.542
Male	'Granny Smith'	91	−16.8	0.003

[a] ANCOVA results: all intercepts were different from 0, $P < 0.0001$; P for slope is shown.

(Table 5). Statistically, the slope can be considered as the effect of age. Two slopes are significantly different from 0: the −11.3 slope indicates that older women tended to like 'GoldRush' less than younger women, and the −16.8 indicates that older men liked 'Granny Smith' less than younger men. Age distributions were similar for females and males.

3.5. Instrument-sensory relationships

An underlying goal of our long-term research is to better understand the relationships of instrumental measurements to sensory assessments of fruits and vegetables, with the purpose of improving instrumental quality measurements. It is often desirable to have instrumental measurements of quality because it is generally not feasible to have either consumers or trained sensory panelists evaluate fruit and vegetables in breeding programs, physiological research, or during commercial production. To that end, we compared color, chemical, and force/deformation measurements to consumers' acceptability scores for appearance, flavor, and texture, respectively, to determine how well the instruments could predict the scores.

We intended to have two cultivars with low perceived sweetness levels and two with high levels, and consumers' comments affirmed that 'Granny Smith' and 'Golden Delicious' were low and that 'Fuji' and 'GoldRush' were high (data not presented). However, instrumental measurements (Table 4) indicated that 'GoldRush' had the highest SSC, 'Granny Smith' contained as much SSC as 'Fuji,' and 'Golden Delicious' had the lowest SSC. The difference in sensory perception of sweetness probably lies in the acid contents of the four cultivars. High acidity would make 'Granny Smith' taste less sweet and low acidity would make 'Fuji' seem more sweet than the SSC levels would indicate. The SSC:acid ratio is often used to estimate ripening stage and is thought to indicate the relative perceived sweetness. However, the ranking of cultivars by SSC: acid ratio does not agree with the sensory panel's order of acceptability of flavor for the cultivars, which we expected to reflect perceived sweetness.

No instrumental variable consistently predicted acceptability scores for all cultivars. Acceptability of appearance was predicted significantly only for 'Fuji,' and the r^2 was ≤ 0.4, with chroma $\times$ L^* being the best predictor. In Fig. 4A, flavor acceptability/volatile abundance datapoints for 'Fuji,' 'Golden Delicious,' and 'GoldRush' tend to cluster because of their greater abundance of volatiles, with 'Granny Smith' clustering separately. None of the instrumental measurements predicted acceptability of flavor scores particularly well, either among all four cultivars combined ($r^2 = 0.46$) or within a single cultivar. Acceptability of flavor was predicted significantly for both 'GoldRush' and 'Granny Smith,' but at very low r^2s, 0.26 and 0.34, respectively. Regression of the texture acceptability scores on any of the instrumental texture measurements did not fit particularly well, either over all four cultivars ($r^2 = 0.44$) or within a single cultivar. In Fig. 4B, it is apparent that texture acceptability scores were similar for 'Fuji' and 'GoldRush,' but these cultivars differed considerably in F_{max} values. In addition, 'Fuji,' 'Golden Delicious,' and 'Granny Smith' had fairly similar F_{max} values, but the texture acceptability scores of 'Fuji' differed from those of the other two cultivars. None of these predictions of sensory scores from instrumental measurements is high

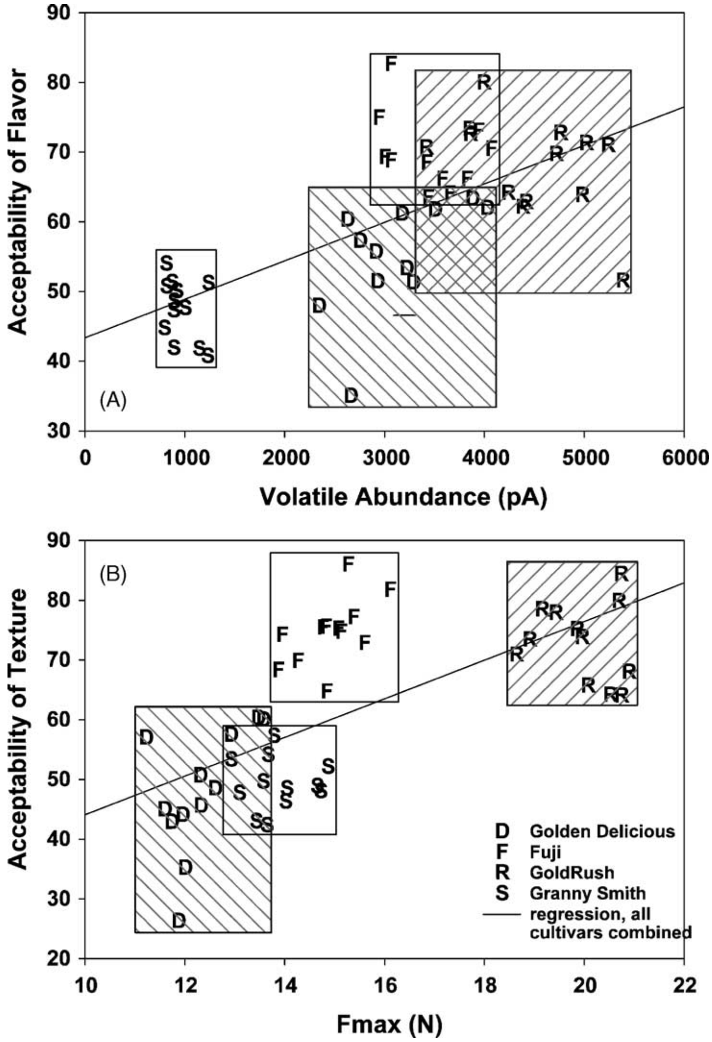

Fig. 4. (A) Relationship of flavor acceptability scores to volatile abundance in four apple cultivars (Expt. 2). (B) Relationship of texture acceptability scores to instrumental firmness measurement in four apple cultivars (Expt. 2). Boxes were drawn to enclose all scores for a given cultivar to aid in interpretation and were not based on statistical clustering.

enough to have any practical use. That is not to say that *intensity* of these attributes cannot be predicted by instrumental measurements, but that *acceptability* cannot be predicted at a useful level.

4. Conclusions

- The in-house processing solution (PQSL) was as effective as the commercial product (COM) in the control of browning.
- Consumers liked the new apple cultivar ‘GoldRush’ as well as ‘Fuji’ and better than ‘Granny Smith’ or ‘Golden Delicious’ in these studies.
- No instrumental measurement adequately predicted acceptability scores.

Acknowledgements

The authors wish to thank Eunhee Park and Willard Douglas for dedicated technical help. We also appreciate the participation of those who tasted our products, both experienced panelists and apple consumers.

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