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Correlation of Sensory Analysis with Physical Textural Data from a Computerized Penetrometer in the Washington State University Apple Breeding Program

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ADDITIONAL INDEX WORDS. crispness, hardness, Digi-Test

SUMMARY. Selecting for crispness instrumentally in fruit from apple (*Malus × domestica*) breeding programs is notoriously difficult. Most breeders rely on sensory assessment for this important characteristic. Following the 2009 harvest, we used a computerized penetrometer to assess firmness and texture of apple selections from the Washington State University's apple breeding program and 16 standard reference varieties. Data were compared with sensory data from the apple breeding team. In addition to the expected high correlations between the various firmness measures of the computerized penetrometer and the sensory firmness values, our data also show a significant correlation between the computerized penetrometer crispness value and the sensory crispness value, thus demonstrating the benefit from using this equipment rather than the industry standard Magness–Taylor penetrometer.

Crispness is one of the most important sensory attributes required by consumers in an apple (Dailliant-Spinnler et al., 1996). The majority of routine texture measures in apple use either a manual or constant rate Magness–Taylor-type penetrometer (Magness and Taylor, 1925; Molina-Delgado et al., 2009) or a non-destructive acoustic resonance technology (De Baerdemaeker, 1988).

Data from such tests have been shown to correlate well with sensory firmness, hardness, or fruit maturity; however, very little data have been shown to be indicative of the sensory attribute of crispness (Harker et al., 2002; Mann et al., 2005). Recent data from Zdunek et al. (2010) have shown that acoustic emission correlates with sensory crispness in some varieties of apple but not in others. Juiciness is inherently linked with crispness as the amount of juice released is dependent on whether the cell walls fracture or the cell-to-cell bonds break when the fruit is bitten (Barreiro et al., 1998).

Selecting for fruit quality is a major part of any apple breeding program, and breeders are constantly searching for methods to help measure these important traits. To date, sensory analysis is by far the most preferred form of testing for crispness; however, there is a limit to the number of samples a sensory panel can score without becoming fatigued and losing accuracy (Oraguzie et al., 2009; Zerbini et al., 1997).

In an attempt to find an instrumental measure of crispness that could be applied to the routine screening of the large number of fruit samples from the Washington State University's apple breeding program (WABP), data from a computerized penetrometer, the Mohr® Digi-Test (MDT-1; Mohr and Associates, Richland, WA), a new tool for measuring firmness and potentially crispness (Warner, 2007), were compared with the sensory analysis data from a small expert panel. The MDT-1 outputs are based on constant velocity measurements from an 11-mm probe extending through two of three regions of the fruit (Fig. 1). The probe can be paused briefly at the boundary between region 1 and 2 for a constant force test, which indicates the relaxation rate or creep of the apple flesh (C0). The MDT-1 samples at high frequency and produces a force profile of the measurements in region 2. A Fourier transformation of these force measurements results in a crispness value (Cn), which is representative of the tearing of the fruit as the probe goes through it and is therefore theoretically similar to the energy released during a bite (Mohr and Mohr, 2000). Rather than focusing on textural differences between the fruit from different orchards, growing systems, and harvest dates, the primary focus of this study was to determine how closely the MDT-1 data correlated to the sensory data from a wide range of different genotypes of apple and how accurately it could distinguish differences between those genotypes.

Materials and methods

EXPERIMENTAL MATERIAL. Apple samples were collected from 17

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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
25.4	inch(es)	mm	0.0394
0.4536	lb	kg	2.2046
(°F - 32) ÷ 1.8	°F	°C	(1.8 × °C) + 32

advanced selections and 16 named varieties from eight sites in central Washington in 2009. Fruit was harvested weekly as close to starch level 3 as

Fig. 1. The computerized penetrometer (Mohr® Digi-Test; Mohr and Associates, Richland, WA) divides the apple into three regions: R1, R2, and a variable R3. R1 is currently tested by manual pressure testers and extends to a depth of 0.32 inch (8.128 mm). R2 contains the bulk of edible material. R3 is the core region and is proportional to 40% of the apple diameter (Mohr and Mohr, 2000).

possible according to Cornell starch ratings (Blanpied and Silsby, 1992) up to a maximum of four picks per variety or selection. Any sample with data that fell outside the acceptable starch limits of 3 to 7 on the Cornell starch ratings at harvest was removed from the analysis. Samples were stored in air at 1 to 2 °C and either tested within 1 week of harvest or tested after 2 months of cold storage, having been warmed up to room temperature. In total, 254 samples were assessed.

INSTRUMENTAL MEASUREMENTS. Texture analysis was performed with the MDT-1 on both the sun and shade sides of each of five fruit, following peeling, from a subset of each sample harvested; any areas of sunburn were avoided. The MDT-1 was also used to weigh each fruit and to determine its diameter. MDT-1 data output includes the maximum (*M*) hardness (measured as pounds pressure from the constant force penetrometer) and the average (*A*) hardness of each region of the fruit (Fig. 1) (Mohr and Mohr, 2000), as well as E2, the force at the end of region 2, a measure of integrity of the center of the fruit.

A1 was not recorded during this experiment; data from previous years indicated this MDT-1 measurement was unlikely to be informative (J.P. Mattheis, personal communication). C0 is a measure of the relaxation rate of the fruit with a 10-lb creep force for 0.5 s at the boundary between regions 1 and 2, and Cn is based on a Fourier transformation of force measurements in region 2. The quality factor (QF) is a weighted sum of MDT-1 results determined from a calculation derived by Mohr and Mohr (2000), including M1, A2, E2, C0, and Cn values; changes in QF were advocated as a potential indicator for harvest.

SENSORY ANALYSIS. Four members of the WABP team experienced in the sensory evaluation of apples performed the assessment on a subset of five fruit from each sample harvested. Fruit was removed from cold storage and allowed to warm to room temperature. Sensory texture attributes were similar to those described by Harker et al. (2002) and are provided in Table 1 with the addition of “eating quality,” which combines all the textural attributes as well as sweetness, acidity, and aroma into one overall score. Randomized whole-fruit samples with peel were presented for analysis as part of the routine sensory testing of the WABP. Panelists took regular breaks from tasting to reduce fatigue, and water and crackers were provided to cleanse the palette. Each panelist scored crispness and hardness on an unstructured 1 to 5 scale, using ‘Gala’ as a standard score of 3 (“eating quality”

Table 1. Definition of apple sensory attributes as used by the Washington State University apple breeding program team.

Attribute	Definition
Crispness	Acoustic sensation that is detected by the ear during the fracturing of crisp foods
Hardness	Force required to completely bite through sample placed between molars
Eating quality	Overall eating quality combining textural properties with flavor

Table 2. Spearman’s ranking correlation coefficients of the computerized penetrometer (Mohr® Digi-Test; Mohr and Associates, Richland, WA) textural measurements and the sensory assessments of 16 different apple varieties and 17 selections (n = 33) from the Washington State University apple breeding program.

	Eating quality	Juiciness	Crispness	Hardness	Quality factor (QF)	C0	E2	A2	M2	M1
Cn	0.516**	0.362*	0.722****	0.529**	0.503**	−0.048	0.343*	0.312	0.378*	0.233
M1	−0.061	−0.156	0.060	0.661****	0.853****	−0.864****	0.723****	0.910****	0.818****	
M2	0.071	0.009	0.230	0.698****	0.952****	−0.620***	0.948****	0.942****		
A2	−0.017	−0.124	0.136	0.717****	0.948****	−0.769****	0.875****			
E2	0.025	0.027	0.170	0.620***	0.865****	−0.524**				
C0	0.211	0.245	0.107	−0.499**	−0.677****					
QF	0.140	0.075	0.334	0.769****						
Hardness	0.335	0.143	0.552****							
Crispness	0.749****	0.611***								
Juiciness	0.583***									

The sensory assessments of juiciness, crispness, and hardness were assessed using ‘Gala’ as a midpoint on a 5-point scale (eating quality was scored on a 9-point scale with ‘Gala’ as a standard score of 5). Using the computerized penetrometer, M1 is the maximum hardness measured as pounds pressure with an 11-mm (0.43 inch) probe through region one, the outer 0.32 inch (8.128 mm) flesh (peeled); M2 is the maximum hardness recorded in region two, from the edge of region one to the boundary of region three (where region three is 40% of the total diameter); A2 is the average firmness through region two; E2 is the firmness at the end of region two; C0 records the relaxation rate of the fruit with a 10-lb (4.54 kg) creep force for 0.5 s at the boundary between regions 1 and 2; Cn (crispness) is based on a Fourier transformation of force measurements in region 2; QF is a weighted sum of results determined by a calculation derived by Mohr and Mohr (2000) and advocated as an indicator for harvest.

*, **, ***, ****Significant at the $P \leq 0.05, 0.01, 0.001, \text{ or } 0.0001$ (two-tailed test), respectively.

was scored on a 1 to 9 scale, with 'Gala' as a standard score of 5), and the scores for each trait from all the panelists were averaged. As with the instrumental measures, the data from all picks of the same selection or variety from both at harvest and after 2 months of storage were also averaged before further analysis.

STATISTICAL ANALYSIS. Data from each set of five apples were averaged and then data from all picks of the same selection or variety at harvest and after 2 months of storage were also averaged before further analysis to give one overall value per genotype. The Spearman rank-order correlation was used to analyze the MDT-1 output with the non-parametric sensory evaluation data using the CORR procedure of SAS (version 9.2; SAS Institute, Cary, NC). The Spearman correlation coefficients indicate a measure of association based on the ranks of the non-parametric data using the formula $\theta = \frac{\sum_i ((R_i - \bar{R})(S_i - \bar{S}))}{\sqrt{\sum_i (R_i - \bar{R})^2 \sum_i (S_i - \bar{S})^2}}$,

where θ is the correlation coefficient, R_i is the rank of x_i (Cn), S_i is the rank of y (sensory crispness), $\bar{R}$ is the mean of the R_i values, and $\bar{S}$ is the mean of the S_i values. SAS software was also used to perform a linear regression (REG procedure) of the sensory crispness and Cn data; $y = a + bx$, where x and y are the variables sensory crispness and Cn, b is the slope of the regression line or the sensitivity of correlation between Cn and sensory crispness, and a is the intercept point of the regression line.

Results and discussion

TEXTURE RANGE. There was considerable range in intensity of each attribute of texture in the fruit tested both in the MDT-1 data (e.g., Cn values ranged from 97 to 321) and in the sensory analysis (e.g., sensory crispness values ranged from 2.1 to 4.4). Measurements from the sun side of the fruit were consistently less firm and crisp than from the shade side of the fruit as would be expected (Dever et al., 1995). Averaging the data resulted in values more consistent with the majority of the apple flesh. Data obtained over several seasons using just a single MDT-1 measurement from an intermediate side (between sun and shade) of samples of 5 to 10 apples have been shown to be representative of the textural

properties of the fruit (J.P. Mattheis, personal communication).

It must be noted that the range of fruit samples tested with the MDT-1

in this experiment was considerably more diverse than that of the samples from a routine quality control experiment with one or a few commercial

Fig. 2. (A) Variation of sensory crispness with the computerized penetrometer (Mohr® Digi-Test) crispness (Cn) values for 16 apple varieties and 17 selections from the Washington State University (WSU) apple breeding program (sensory crispness = $1.16108 + 0.0067Cn$, $R^2 = 0.5635$, $P < 0.0001$). Sensory crispness was measured on a 1–5 scale using 'Gala' as a standard score of 3; scores from all panelists were averaged. The computerized penetrometer Cn value is based on a Fourier transformation of force measurements in region 2 [0.32 inch (8.128 mm) in from the peeled surface through to the boundary of region 3, where region 3 is 40% of the total diameter of the fruit]. (B) Variation of sensory crispness with the computerized penetrometer maximum firmness values for the outer 0.32 inch of flesh (M1) of the 16 apple varieties and 17 selections from the WSU apple breeding program (sensory crispness = $3.12234 + 0.00102M1$, $R^2 = 0.0000$, $P = 0.9788$). ♦ = WSU apple selections, ◇ = reference varieties: 'Aurora Golden Gala' (AGG), 'Braeburn' (B), 'Chinook' (Ch), 'Crimson Crisp' (CC), 'Cripps Pink' (CP), 'Fuji' (F), 'Gala-Brookfield' (GB), 'Gala-Ultima' (GU), 'Golden Delicious' (GD), 'Honeycrisp' (HC), 'Imperial Gala' (IG), 'Jazz' (J), 'Pacific Beauty' (PB), 'Pacific Queen' (PQ), 'Pinova' (P), and 'WA 2' (W).

varieties because of the number of genotypes tested and the different orchard locations. By averaging the data from the different pick dates and combining the fresh and stored samples, some of this variation was reduced and a data set more representative of the different genotypes could be analyzed statistically. Although the size of the fruit would impact the texture of the flesh, as this would likely affect both the sensory and the instrumental measures, no analysis of this data was performed in this study and fruit size of the samples was predominantly within commercial standards.

CORRELATIONS. Spearman's ranking correlation coefficients of the MDT-1 textural measurements and the sensory assessments are shown in Table 2. As would be expected, there is a high correlation between the maximum firmness of both regions of the apple (M1 and M2), the average firmness (A2), and the firmness at the end of region 2 (E2) and these are all highly correlated with sensory hardness and the MDT-1 QF value and negatively correlated with the C0 value. The high correlation of the maximum hardness (M1) measure to sensory hardness was expected because of its similarity to a standard Magness-Taylor penetrometer; however, it is interesting to note that there is a higher correlation between the sensory hardness and the average hardness measure in region 2 (A2). This could be explained by the fact that more of the apple flesh sampled when tasting is from region 2 rather than from the outer region 1. As the apple ripens from the core outwards when it matures (Rudell et al., 2000), it is logical that this measurement should give a more accurate indication of the overall sensory hardness.

The Cn value is highly correlated to sensory crispness, which is also highly correlated to the sensory eating quality. This data set also confirms that at least for the WABP sensory panel, the measures of hardness are not as highly correlated to overall eating quality as the sensory crispness, sensory juiciness, or Cn value.

Figure 2A shows the mean values for each individual variety and selection of sensory crispness plotted against the MDT-1 Cn values; the strong relationship between these two measures is indicated by the R^2 of 0.5635 ($P < 0.0001$), following linear regression.

Figure 2B shows the same mean values of sensory crispness plotted against the MDT-1 firmness M1 value. In contrast to the standard penetrometer data reported by Harker et al. (2002), which showed an R^2 of 0.82, our data showed that the correlation with M1 is poor, indicated by the R^2 of 0 ($P = 0.9788$).

At the lower end of the crispness scale, 'Chinook' has a tendency to poor texture when grown in Washington State and 'Pacific Queen' ('Scired') in these growing conditions is hard rather than crisp, with the highest M1 value in this study. 'Honeycrisp' is the apple variety best known for its crispness, and so it is not surprising that it places at the top with 'Jazz' and 'Aurora Golden Gala', other crisp varieties. As far as the WABP material is concerned, the recently released variety 'WA 2' places close to 'Jazz' and three other WABP advanced selections form part of this high crispness group. The 'Gala' sports ('Ultima', 'Brookfield', and 'Imperial') cluster reasonably tightly toward the center of both plots.

Conclusions

Our data show that the physical measurements recorded by the MDT-1 indeed correlated with the sensory textural attributes. An R^2 value greater than 0.5 for the correlation of the Cn value with sensory crispness is particularly interesting as crispness has proved to be so difficult to measure instrumentally.

For this sample set, the MDT-1 data are likely more informative than the data from either a standard penetrometer or acoustic resonance test alone. For the preselection requirements in the WABP, the QF alone is not sufficient; however, a combination of the Cn and A2 values will be used in the future, reducing the need for some of the sensory textural analysis.

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