# Penetrometer and Taste Panel Perception of Pericarp Tenderness in *su*, *se*, and *sh₂* Sweet Corn at Three Maturities

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**Summary.** Taste panel perception and preference of pericarp tenderness in three phenotypes (*su*, *se*, and $sh_2$) of sweet corn (*Zea mays*) harvested at three different maturities were compared to the readings received from a penetrometer. Pericarp tenderness perception by taste panel correlated with penetrometer measurements when phenotypes and maturities were compared. The penetrometer showed significantly lower readings for sweet corn harvested at early maturity than those harvested at late maturity. This was also noted in the panelists' perception of tenderness, with the early and mature harvest samples being preferred over those from the late harvest. The only difference between cultivars within phenotypes was noted in $sh_2$ 'Rustler' and 'AXC904'. 'Rustler' received the greatest overall pentrometer values and lowest panel ratings; conversely, 'ACX904' had low penetrometer values and was perceived as tender and very acceptable to panelists. Correlations between penetrometer readings and panel perception of pericarp tenderness indicate that a puncture force, using a 0.118-inch (3.0 mm) probe, of greater that 0.95 g/inch² (0.147 g·cm⁻²) indicated a tough pericarp and lower than 0.70 g/inch² (0.109 g·cm⁻²) indicated a tender pericarp.

The value of sweet corn (fresh, frozen, and canning) has seen an 81% increase in the last decade. Of the three distinct sweet corn markets, fresh-market sweet corn accounts for the majority of the crop value (Lucier and Lin, 2001). As the fresh-market value increases, so does the need to determine efficient means of testing cultivars for consumer-preferred characteristics.

Fresh sweet corn quality is determined by flavor, texture, and aroma (Flora and Wiley, 1974). Although texture is generally thought to be the creaminess of the kernel, pericarp tenderness has been identified as an important factor in consumers' score of quality (Culpepper and Magoon, 1927). Tenderness has been defined as the predisposition of the pericarp to fragmentation by chewing (Huelson, 1954) and is negatively correlated to pericarp thickness (Bailey and Bailey, 1938; Ito and Brewbaker, 1981). Previous studies have determined the tenderness of the pericarp by performing bite tests, while thickness was measured using magnification and micrometer methods (Bailey and Bailey, 1938; Helm and Zuber, 1972; Ito and Brewbaker, 1981).

Although these are effective measurements, they are difficult for a grower to perform, as well as time consuming. The penetrometer has been widely used as a quick and inexpensive method in determining fruit firmness in strawberries (*Fragaria ×ananassa*), peaches (*Prunus persica*), apples (*Malus ×domestica*), and cherries (*Prunus avium*) (Hietaranata and Linna, 1999; Mitcham et al., 1998). The penetrometer was compared to four other methods for determining fruit firmness in cherries, and although the penetrometer was less expensive and time consuming than the other methods, it was also less accurate (Mitcham et al., 1998). To overcome this problem in testing fruit firmness, it was suggested that a smaller probe be used [<0.252 inch (6.4 mm)] to reduce skin stretching before the skin actually breaks (Hietaranta and Linna, 1999). The penetrometer was previously used in sweet corn to determine pericarp thickness, but not to determine pericarp tenderness (Bailey and Bailey, 1938; Culpepper and Magoon, 1927).

The objectives of our work are to determine if: 1) taste panelists are able to differentiate between cultivars of sweet corn that have been classified as tender, medial, and tough by seed companies; 2) the penetrometer could be used as an accurate method to identify pericarp tenderness as identified by taste panels and seed companies; and 3) the preferred pericarp tenderness was affected by both maturity of the sweet corn and phenotype.

## Materials and methods

**Plot establishment.** A total of nine cultivars of sweet corn were used with three cultivars per phenotype (*sugary*, *sugary enhanced*, and *shrunken-2*). *Sugary* (*su*) cultivars were comprised of 'NK199', 'Golden Cross Bantam', and 'Jubilee' (Rupp Seed, Wauseon, Ohio). *Sugary enhanced* (*se*) cultivars were 'Precious Gem', 'Brocade', and 'Lancelot' (Mesa Maize, Olathe, Colo.); and *shrunken* ($sh_2$) cultivars were 'Rustler' and 'Zenith' (Harris Moran, Modesto, Calif.) and 'ACX904' (Abbot and Cobb, Feasterville, Pa.). The *se* cultivars were planted on 28 Mar. 2003; the *su* and $sh_2$ cultivars were planted 9 May 2003. All phenotypes were isolated into different fields at least 250 ft (76.20 m) apart to prevent cross-pollination. All plots were planted in sandy loam soil at the Clemson University Coastal Research and Education Center (CREC) located in Charleston, S.C. Each cultivar was replicated four times with plots consisting of four rows, 40 ft (12.2 m) long, 3 ft (0.9 m) between rows, and 8 inches (20.3 cm) between plants. All plots were seeded with a cone planter mounted on a John Deere Flex planter (John Deere, Moline, Ill.). Plots were watered and fertigated using drip lines, following standard sweet corn practices. Recommended herbicide and pesticide regimens for South Carolina were followed.

**Harvest and penetrometer.** All plots were hand harvested at three different maturities. Full maturity was 19 d after 100% silking of the entire plot, determined from previous work done at CREC. Full maturity ears were filled with kernels to the tip and had full kernel color. Early maturity was 5 d before maturity or 14 d after 100%

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silking, where ears were not filled to the tip and full kernel color had not been achieved. Late maturity was 5 d after maturity, or 24 d after 100% silking, where the ears were completely filled and colored, and kernel denting had begun. Twenty-five ears were taken from each plot at each harvest date. Five uniform ears were selected for puncture testing. Each ear was punched four times in the center portion of the cob with an Accuforce Cadet Force gauge (model #ML5850-4; Ametek, Largo, Fla.) with a 0.118-inch circular probe. Of the remaining ears, 10 uniform ears were selected per cultivar per maturity for the taste panel. Cobs were cut into 1.5–2 inch (3.81–5.1 cm) sections (cobbettes) from the center portion using a portable band saw to prevent crushing sample kernels. Cobbettes were then frozen in liquid nitrogen (National Welders, Charleston, S.C.) within 3 h of harvest, placed in freezer bags [1 gal (3.8 L)] and then stored in a deep freezer at –30 °F (–34.4 °C).

**TASTE PANEL.** The taste panel consisted of 18 volunteers. Two groups of nine participated in orientation sessions to familiarize them with tough and tender pericarp. Panelists participated in three tasting sessions, with all sessions being held at the CREC. An incomplete block design was implemented so that panelists were randomly assigned five samples per session. Cobbettes were thawed at room temperature [71 to 73 °F (21.7 to 22.8 °C)] for 1 h prior to being blanched in unsalted, boiling water for 5 min. Cobbettes were immediately removed from water and placed in 4-fl oz (118.3 mL) Styrofoam containers with lids (Dart Container Corp., Mason, Mich.) to maintain heat until given to panelists. Panelists were asked to rate each sample on the pericarp tenderness and its acceptability using a 5.9-inch (15 cm) attribute linear scale with anchor words, where 0 inches (0 cm) represented tough and unacceptable pericarp and 5.9 inches represented tender, acceptable pericarp.

**STATISTICAL ANALYSIS.** Data were analyzed as a three-factor design with cultivar nested in phenotype, and phenotype and maturity being cross-classified. Planting field was set up as a randomized complete-block design. Taste panel analysis was an incomplete block design. Analysis of variance (ANOVA) was performed on main effects and interactions followed by pair-wise means comparison using a general linear model (SAS v.8; SAS, Cary, N.C.) (Table 1).

Penetrometer data were analyzed using a general linear model (GLM) for determining significance of main effects and interactions. Taste panel evaluation main effects and interactions were analyzed using the mixed model with panelists assigned as the random variable.

## Results and discussion

**PHENOTYPE EFFECT.** Pentrometer readings for *se* and $sh_2$ were not significantly different, while *su* was notably lower (Table 2). Panelists were able to differentiate among phenotypes with *se* receiving the greatest tenderness scores, followed by $sh_2$, and last, *su* received the lowest tenderness scores. Although panelists found phenotypes to be significantly different in tenderness, both *se* and $sh_2$ were considered acceptable.

Significant differences existed in $sh_2$ cultivars (Table 3). 'ACX904' is considerably more tender in both panel scores of tenderness and penetrometer measurements, having the greatest panel scores and lowest penetrometer values. 'Rustler' exhibited the greatest overall penetrometer values and the lowest panel score for tenderness. Panel scores and penetrometer values for $sh_2$ cultivars followed company assessment of tenderness. 'NK199' received higher penetrometer values, while 'Jubilee' receiver the lowest penetrometer values for *su* cultivars, correlating to company assessment of tenderness. *Se* cultivars, however, did not correlate with company assessments of tenderness. Panelists indicated no significant difference in the tenderness of *su* or *se* cultivars within phenotypes, but did find *su* cultivar Jubilee to be notably more acceptable than 'NK199', which was assessed "tough" by the company.

The relationship between penetrometer and panel scores within the *su* phenotype had an $R^2$ value of –0.77

**Table 1. Source of variation in the analysis of variance (ANOVA) for early, mature, and late harvested sugary, sugary enhancer, and shrunken-2 sweet corn for penetrometer measurements and panel perception of pericarp tenderness.**

| | Percent of total sums of squares[z] | | |
|---|---|---|---|
| | | Panel evaluation[y] | |
| Source of variation | Penetrometer force | Pericarp tenderness | Pericarp acceptability |
| Phenotype (P) | 27* | 6* | 11* |
| Replication (R)/Taster (T) | 1 (0.11) | 36* | 37* |
| Cultivar (phenotype) (C) | 48* | 8* | 4* |
| R × C or T × C | 3* | 21* | 22* |
| Maturity (M) | 13* | 2* | 6* |
| M × P | 1* | 1 (0.43) | 1 (0.50) |
| M × C | 4* | 3 (0.26) | 2 (0.39) |
| Error | 3 | 23 | 17 |
| $R^2$ | 0.97 | 0.77 | 0.83 |
| Coefficient of variance | 6.83 | 40.85 | 27.69 |

[z]The sum of squares for each of the factors in the ANOVA have been converted to percentages of the total sum of squares.
[y]Significance determined using the mixed procedure in SAS.
*F values significant at $P = 0.05$.

**Table 2. Statistical analysis of penetrometer values and taste panel evaluation[z] of pericarp tenderness and acceptability for fresh sweet corn phenotypes *su*, *se*, and $sh_2$ pooled over early, mature and late harvest dates[y].**

| Phenotype | Penetrometer force[x] ($g/inch^2$) | Panel evaluation[w] Tenderness | Panel evaluation[w] Acceptability |
|---|---|---|---|
| *Sugary (su)* | 0.71 b[v] | 5.9 c | 7.2 b |
| *Sugary enhancer (se)* | 1.00 a | 8.5 a | 9.7 a |
| *Shrunken-2* ($sh_2$) | 0.96 a | 7.2 b | 9.3 a |

[z]Scores >7.5 are considered tender and more acceptable.
[y]Maturity determined by number of days after 100% silking in individual plot: early = 14 d; mature = 19 d; and late = 24 d.
[x]1.00 $g/inch^2$ = 0.035 $oz/inch^2$ = 0.155 $g\cdot cm^{-2}$.
[w]Scores are cm value of panel rating using a 5.9-inch (15 cm) linear attribute scale.
[v]Means separated within columns using *t*-test least square means separation test at $P \leq 0.05$.

(Table 6), indicating that penetrometer values increased as panel rating of tenderness decreased. A similar correlation ($R^2$ = –0.94) existed between penetrometer values and the panel's acceptance of pericarp tenderness. Overall, panel perception of tenderness and acceptability were positively correlated ($R^2$ = 0.80). Relationships between penetrometer values and panel tenderness scores, as well as penetrometer and panel acceptability, within *se* were nonsignificant. The relationship between panel acceptability for *se* was similar to *su*.

Strong correlations exist between penetrometer and panel scores of tenderness ($R^2$ = –0.92) as well as penetrometer and panel acceptability ($R^2$ = –0.94) for $sh_2$. This relationship indicates that panelists were able to note differences in maturities within phenotypes. The relationship of panel acceptability to panel rating of tenderness was also stronger with $sh_2$ than with *se* or *su*.

**Maturity effect.** Notable differences existed between the penetrometer values of early, mature, and late harvest dates (Table 4). Early harvest samples received the lowest values, while those from the late harvest had the greatest values. Although penetrometer values were significantly different between early and mature samples, panelists indicated no differences in tenderness or acceptability. Late samples were considered more tough and less acceptable.

Interaction between maturity and cultivar within phenotype existed with pentrometer values (Table 5). Within *su*, 'NK199' and 'Golden Cross Bantam' received different penetrometer values at each harvest date, with early receiving the lowest values. 'Jubilee' exhibited no difference from early to mature harvest, but late harvest was considerably greater. *Se* cultivars Precious Gem and Lancelot denote no difference between mature and late harvests for pericarp firmness, but received lower values at early harvest. Conversely, 'Brocade' showed no difference between early and mature samples, but late harvest penetrometer values were significantly higher. $Sh_2$ cultivar 'Rustler' is similar, with late harvest being greater than early or mature. With 'Zenith', no *t* difference existed between mature and late harvest, although both were notably higher than early. Mature 'ACX904' was not significantly different from early or late harvest penetrometer values; however, late harvested values were greater than early. With all cultivars, within each of the three phenotypes, late harvest required greater force to break the pericarp.

**Table 3. Statistical analysis of penetrometer values and taste panel evaluation[z] of pericarp tenderness and acceptability for fresh sweet corn cultivars within phenotypes pooled over early, mature, and late harvest dates[y].**

| Phenotype | Cultivar | Company assessment[x] | Penetrometer force[w] ($g/inch^2$) | Panel evaluation[v] Tenderness | Acceptability |
|---|---|---|---|---|---|
| *Sugary (su)* | | | | | |
| | NK199 | Tough | 1.04 b[u] | 6.0 cd | 8.0 cd |
| | Golden Cross Bantam | Medial | 1.10 b | 5.3 cd | 9.6 ab |
| | Jubilee | Tender | 0.86 c | 6.4 cd | 10.4 a |
| *Sugary enhancer (se)* | | | | | |
| | Brocade | Tough | 0.70 d | 8.4 a–c | 10.0 a |
| | Precious Gem | Medial | 0.73 d | 8.7 a | 10.0 a |
| | Lancelot | Tender | 0.71 d | 8.5 ab | 9.0 a–c |
| *Shrunken-2 ($sh_2$)* | | | | | |
| | Rustler | Tough | 1.33 a | 5.0 d | 8.0 cd |
| | Zenith | Medial | 0.90 c | 6.9 bc | 9.6 ab |
| | ACX904 | Tender | 0.66 d | 9.7 a | 10.4 a |

[z]Scores >7.5 are considered tender and more acceptable.
[y]Maturity determined by number of days after 100% silking in individual plot: early = 14 d; mature = 19 d; and late = 24 d.
[x]Cultivars defined as tough, medial, or tender by seed company.
[w]1.00 $g/inch^2$ = 0.035 $oz/inch^2$ = 0.155 $g{\cdot}cm^{-2}$.
[v]Scores are cm value of panel rating using a 5.9-inch (15 cm) linear attribute scale.
[u]Means separated within columns using *t*-test least square means separation test at $P \leq 0.05$.

**Table 4. Statistical analysis of penetrometer values and taste panel evaluation[z] of pericarp tenderness and acceptability for three maturities[y] of fresh sweet corn pooled over three phenotypes (*su*, *se*, and $sh_2$).**

| Maturity | Penetrometer force[x] ($g/inch^2$) | Panel evaluation[w] Tenderness | Acceptability |
|---|---|---|---|
| Early | 0.78 c[v] | 7.8 a | 9.7 a |
| Mature | 0.90 b | 7.7 a | 9.0 a |
| Late | 0.99 a | 6.2 b | 7.4 b |

[z]Scores >7.5 are considered tender and more acceptable.
[y]Maturity determined by number of days after 100% silking in individual plot: early = 14 d; mature = 19 d; and late = 24 d.
[x]1.00 $g/inch^2$ = 0.035 $oz/inch^2$ = 0.155 $g.cm^2$.
[w]Scores are cm value of panel rating using a 5.9-inch (15 cm) linear attribute scale.
[v]Means separated within columns using *t*-test least square means separation test at $P \leq 0.05$.

Differences existed in pericarp firmness between each maturity within each phenotype (Table 5). Overall, late harvested *su* had the greatest force gauge measurements of any phenotype at any maturity. Mature *su* was comparable to mature $sh_2$ samples in firmness, yet higher than mature *se* samples, which was also true for early harvest samples. *Se* exhibited the lowest overall pericarp firmness values at any harvest for the three phenotypes.

Penetrometer and panel score correlation coefficients increased in strength with increased maturity ($R^2$ = –0.77, –0.85, –0.88) (Table 6), indicating that panelists were more likely to note differences in phenotypes and cultivars as maturity increased. This upward trend does not exist with penetrometer to panel acceptability scores or panel acceptability scores to panel tenderness ratings.

## Discussion

*Su* cultivars tend to be tougher and less acceptable than *se* or $sh_2$ cultivars. When discussing the creamy texture of the kernel, *su* cultivars should be creamier in texture because of the amount of phytoglycogen, a water-soluble starch, that they accumulate (Gonzales et al., 1976). However, with our work, the more tender and preferred phenotypes were *se* and $sh_2$, indicating that although *su* may in fact be creamier in nature, the pericarp tenderness is also important to the quality of the sweet corn. However,

**Table 5. Statistical analysis of sweet corn cultivars' penetrometer values within phenoptype and maturity[z] (early, mature, late), including a comparison with company assessment[y] of pericarp tenderness.**

| Cultivar | Company assessment | Maturity | Penetrometer force[x] (g/inch²) |
|---|---|---|---|
| | *Sugary (su)* | | |
| NK199 | Tough | Early | 0.88 g–i[w] |
| | | Mature | 1.05 f |
| | | Late | 1.17 de |
| Golden Cross Bantam | Medial | Early | 0.86 h–j |
| | | Mature | 1.21 ef |
| | | Late | 1.31 b |
| Jubilee | Tender | Early | 0.81 ij |
| | | Mature | 0.81 ij |
| | | Late | 0.94 gh |
| | *Sugary enhancer (se)* | | |
| Brocade | Tough | Early | 0.65 m |
| | | Mature | 0.66 lm |
| | | Late | 0.78 jk |
| Precious Gem | Medial | Early | 0.61 mn |
| | | Mature | 0.78 jk |
| | | Late | 0.80 jk |
| Lancelot | Tender | Early | 0.54 n |
| | | Mature | 0.78 jk |
| | | Late | 0.80 i–k |
| | *Shrunken-2 ($sh_2$)* | | |
| Rustler | Tough | Early | 1.21 cd |
| | | Mature | 1.29 bc |
| | | Late | 1.48 a |
| Zenith | Medial | Early | 0.81 ij |
| | | Mature | 0.93 gh |
| | | Late | 0.96 g |
| ACX904 | Tender | Early | 0.62 mn |
| | | Mature | 0.66 lm |
| | | Late | 0.72 kl |

[z]Maturity determined by number of days after 100% silking: early =14 d; mature = 19 d; and late = 24 d.
[y]Cultivars defined as tough, medial, or tender by seed company.
[x]1.00 g/inch² = 0.035 oz/inch² = 0.155 g·cm⁻².
[w]Means separated in columns with *t*-test least square means separation test at $P \leq 0.05$.

**Table 6. Analysis of the relationship between penetrometer values and taste panel evaluation of pericarp tenderness and acceptability for three phenotypes (*su*, *se*, and $sh_2$) of fresh sweet corn at three harvest dates (early, mature, and late).**

| Relationship | Phenotype *su* | Phenotype *se* | Phenotype $sh_2$ | Maturity Early | Maturity Mature | Maturity Late |
|---|---|---|---|---|---|---|
| Penetrometer to panel tenderness score[z] | –0.77* | –0.50 | –0.92* | –0.77* | –0.85* | –0.88* |
| Penetrometer to panel acceptability score | –0.94* | –0.63 | –0.94* | –0.63 | –0.76* | –0.71* |
| Panel tenderness to acceptability score | 0.77* | 0.78* | 0.87* | 0.87* | –0.76* | 0.78* |

[z]Maturity determined by number of days after 100% silking in individual plot: early = 14 d; mature = 19 d; and late = 24 d.
[y]Correlations ($R^2$) calculated using Pearson's correlation coefficient (n = 9).
*Significant at $P \leq 0.05$.

care needs to be taken by defining a sweet corn by pericarp tenderness. Some preferences to the *se* and $sh_2$ cultivars may be an artifact of their increased sweetness.

The most significant differences in penetrometer force readings were found between the different maturities within the three phenotypes, with the largest difference being between the early and late harvest samples. Early samples consistently had a lower puncture value than late and were also consistently more preferred. This is important to note, as it opens up the harvest window for fresh-market sweet corn, demonstrating that early sweet corn is just as preferred as mature.

$Sh_2$ cultivars were the only cultivars that showed significant difference in cultivars. The differences noted by the taste panel and by penetrometer were consistent with what the seed companies assessed as tough, medial, and tender. It is interesting to note that the tender cultivar ACX904 is a newer cultivar and does not follow the old standards of $sh_2$ sweet corn being a tough sweet corn. With the development of new, tender cultivars of $sh_2$, with higher sugar content and longer shelf life, it is becoming a stronger contender as the primary phenotype used for fresh-market sweet corn.

Our work showed that the penetrometer can be used as an indicator of pericarp tenderness. Penetrometer values greater than 0.95 g/inch² indicate a tough pericarp while a reading of less than 0.70 g/inch² indicates a tender pericarp, while intermediate values are defined as medial. Further work with taste panels and penetrometer values may be valuable to establish a more defined range for acceptable pericarp tenderness within individual phenotypes and maturities.

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