Correlation of Descriptive Analysis and Instrumental Puncture Testing of Watermelon Cultivars

J.W. Shiu, D.C. Slaughter, L.E. Boyden, and D.M. Barrett

Abstract: The textural properties of 5 seedless watermelon cultivars were assessed by descriptive analysis and the standard puncture test using a hollow probe with increased shearing properties. The use of descriptive analysis methodology was an effective means of quantifying watermelon sensory texture profiles for characterizing specific cultivars' characteristics. Of the 10 cultivars screened, 71% of the variation in the sensory attributes was measured using the 1st 2 principal components. Pairwise correlation of the hollow puncture probe and sensory parameters determined that initial slope, maximum force, and work after maximum force measurements all correlated well to the sensory attributes crisp and firm. These findings confirm that maximum force correlates well with not only firmness in watermelon, but crispness as well. The initial slope parameter also captures the sensory crispness of watermelon, but is not as practical to measure in the field as maximum force. The work after maximum force parameter is thought to reflect cellular arrangement and membrane integrity that in turn impact sensory firmness and crispness. Watermelon cultivar types were correctly predicted by puncture test measurements in heart tissue 87% of the time, although descriptive analysis was correct 54% of the time.

Keywords: descriptive analysis, puncture test, texture, watermelon

Introduction

Genetic improvement of fruit texture is a chief objective in watermelon breeding programs. However, identification of preferred fruit genotypes is complicated by the subjective nature of existing quality assessment methods. Furthermore, although it is an industry standard to use puncture tests and maximum force measurements for firmness, there are not established protocols describing exactly how these tests are applied. Breeders generally rely on a combination of personal experience and manual penetrometer measurements to assess firmness across a wide selection of cultivars; however, their aim is to breed watermelon with appealing sensory qualities.

Texture is difficult to measure in fruit because it is affected by physiological and biochemical processes that are dynamic throughout development and storage, and because of the inherent biological variability between fruit (Harker and others 1997a). Human perception of texture is difficult to measure as well. Humans vary in perceptual acuity and preferences, and there are no universal definitions for various texture words used by lay people. Nevertheless, internal fruit quality has frequently been assessed by human sensory panels despite challenges with inconsistency and logistics (Bett 2002; Barrett and others 2010).

Descriptive analysis is a method of objective sensory measurement where trained panelists collaborate to develop attributes important to the project goals and reduce inconsistency (Stone and others 2012). To date, there is little published data on watermelon texture assessed by sensory panels. Martins and others (2008) conducted consumer hedonic testing of irradiated watermelon. Pardo and others (1997) qualitatively measured consumer satisfaction of watermelon flavor, texture, and color with a verbal hedonic scale. They found consumers preferred fruit with the highest soluble solids content. Flavor, texture, and color were less important among the varieties sampled.

Instrumental puncture measurements are often cited as a tool to evaluate firmness of different watermelon cultivars, although there are no set industry standards for this methodology, making direct comparison between different bodies of research difficult (Tolla and others 2006). Furthermore, the sensory term firmness is often used synonymously with instrumental puncture test measurements, even if the correlation of these measurements to the sensory attribute is unclear. Harker and others (1997b) found that puncture, Kramer shear, and tensile tests were not sensitive enough to distinguish between the hardness of watermelon and muskmelon as perceived by a trained sensory panel. Pardo and others (1997) reported watermelon firmness measured by a penetrometer test correlated weakly to sensory texture preference ($P = 0.05$). As part of a study comparing microflora and organoleptic changes in wrapped and unwrapped sliced watermelon, Abbey and others (1988) found instrumental and subjective, sensory firmness evaluations did not correlate, rather, visual, and flavor changes were more influential. Similarly, Escribano and others (2010) found panelists better able to separate firmness of different melon cultivars than instrumental measurements, suggesting other sensory attributes contribute to perceived firmness. Dermesonlouoglou and others (2005) assessed frozen watermelon quality in part by puncture test firmness and consumer acceptance. These studies did not utilize descriptive analysis methodology, and there is very little other research published on the correlation of watermelon texture as perceived by a sensory panel to instrumental methods.

Thus, an objective texture measurement that correlates well with sensory perception would be of great assistance to watermelon breeders to differentiate germplasm with desired physical

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Table 1–Seedless watermelon cultivar descriptions and specific ripeness indicators.

Cultivar	Description	Specific ripeness indicators
Amarillo	Medium size, low firmness, yellow flesh	Pale ground spot
Fascination	Large size, high firmness	Pale yellow ground spot
Imagination	Medium-large size, medium-low firmness	Bright yellow ground spot ridges on skin blush on skin
Matrix	Large size, medium firmness	Pale ground spot
Obsession	Large size, medium firmness	Pale ground spot
Palomar	Large size, medium flesh firmness	Pale ground spot
Petite perfection	Personal size, medium flesh firmness, industry standard	Light green background color
RWT8225	Personal size, medium-high firmness	Pale ground spot
Distinction	Large size, high firmness	Pale yellow ground spot
Tri-X 313	Large size, medium flesh firmness, industry standard	Pale yellow ground spot

Note: General ripeness indicators for all cultivars include drying of flag leaf and tendril adjacent to plant stem, yellowing of the fruit ground spot, and dulling of fruit skin surface.

property differences. The goals for this study were to apply descriptive analysis to characterize and quantify the sensory texture attributes of watermelon, and to correlate the sensory and instrumental measurements to identify which puncture test parameters best relate to sensory descriptors.

Materials and Methods

Samples

Seedless, triploid watermelons were harvested in the morning of the experiments in July and August 2009 from plants grown by Syngenta Seeds Inc. (Woodland, Calif., U.S.A.). Ripeness indicators include drying of flag leaf and tendril adjacent to plant stem, yellowing of the fruit ground spot, and dulling of fruit skin surface. Specific indicators for each cultivar in Table 1 were utilized to pick fruit (Vinson and others 2010). Four 2.5-cm-thick, transverse slices were cut from the middle of each fruit. Samples for descriptive analysis were further cut into fourths for presentation to judges. Whole slices were used in analysis by instrumental hollow probe puncture tests.

Descriptive analysis

A panel of 13 judges (7 male and 6 female, ages 20 to 52) was assembled from students, staff, and community members around the Univ. of California, Davis, Calif., U.S.A. Judges indicated they enjoy consuming watermelon and most had little previous sensory experience. A generic descriptive analysis method was applied (Lawless and Heymann 2010). Prior to sample analysis, all judges attended 3 group training sessions, lasting about an hour each. This time was devoted to generation of descriptor terms for watermelon texture and flavor attributes, concept alignment of said attributes, and refinement of the rating scale system and scorecard.

Overall panel readiness was evaluated after 2 practice individual booth sessions. For these sessions, 3 watermelon cultivars were judged in duplicate at each session, presented in completely

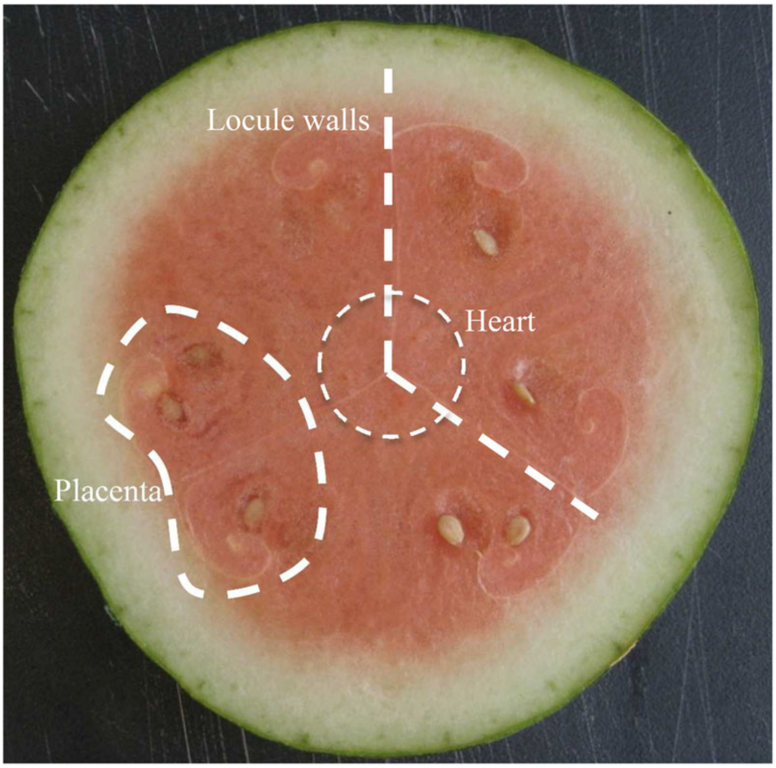

Figure 1–Anatomy of edible watermelon tissues.

Table 2–Watermelon texture and flavor attribute definitions for descriptive analysis.

Descriptor	Duration	Definition
TEXTURE		
Crisp	1st bite	Intensity of crunch/snap of 1st bite of fruit.
Firm	Early in chewing	Resistance of fruit against bite. Ranges from soft to firm.
Dense	Early in chewing	Degree flesh cells feel packed together, ranging from porous to dense.
Juicy	While chewing	Degree flesh releases water while chewing.
Melty	While chewing	Degree to which the flesh disintegrates or "melts" in the mouth without applying pressure from teeth.
Grainy	End of chewing	Degree to which the flesh feels sandy or grainy in the mouth while chewing.
Fiber leftover	End of chewing	Leftover material in mouth, like eating celery or dark leafy greens.
FLAVOR		
Sweet	While chewing	Intensity of sweet flavor/taste.
Tangy	While chewing	Intensity of sourness, but not sharp like lemon acidity. More like yogurt.
Flavor intensity	While chewing	Overall intensity of fruit flavor.

randomized Latin square design with judges and cultivars as the blocking factors. One quarter slice of watermelon was provided per sample, presented together. One sample at a time, judges ranked attribute intensity on a 15 cm continuous line scale anchored by words "low" and "high" on each end. FIZZ software (Biosystemes, Courtenon, France) acquired the data. Judges were instructed to rinse their mouths with water and take a 1-min break between samples to minimize sample interaction effects. Sessions were performed under red-colored light in individual booths to mitigate cultivar discrimination and visual quality bias by flesh and rind appearance.

Analysis of variance (ANOVA) was used to assess reproducibility across repetitions, ability to distinguish watermelon cultivars, and cultivar quality consistency. Pearson product–moment correlation coefficient of judges and attributes was calculated to assess individual judge understanding and consistent use of attribute descriptors. Attribute definitions were reviewed for judges with coefficients < -0.5.

Descriptive analysis of 10 seedless triploid watermelon cultivars (Table 1) generated a texture profile for each. Samples were presented in duplicate over 4 individual booth sessions. Principal component analysis (PCA) was used to select 5 cultivars whose texture profiles differed most from each other.

The resultant 5 watermelon cultivars (Amarillo, Imagination, Petite Perfection, RWT8225, and Distinction) were then evaluated in parallel by descriptive analysis and by the instrumental hollow puncture method described below. Samples were presented in quadruplicate over 5 sessions.

Instrumental hollow probe puncture method

The new hollow puncture probe (ID 16.5 mm, OD 20.3 mm) was designed by the authors to have the same contact area as the standard 11-mm diameter Magness-Taylor solid probe and applies the same compressive force, but increased shear force (Shiu and others 2015). In a separate evaluation by Shiu and others (2015), in comparison to the standard Magness-Taylor probe, the hollow probe exhibited promising results, in terms of its sensitivity to differentiate watermelon tissue types, and was thus selected for use in comparison to descriptive analysis.

For this analysis, the hollow probe sampled specific tissue types to evaluate if a particular area contributes to the overall watermelon texture experience as evaluated by descriptive analysis (Figure 1). Heart tissue was sampled once per slice (due to limited tissue availability), and placental and locule tissue were sampled twice per slice. Eight fruit per cultivar were sampled. The probe punctured the watermelon flesh to a depth of 8 mm at 1 mm/s penetration

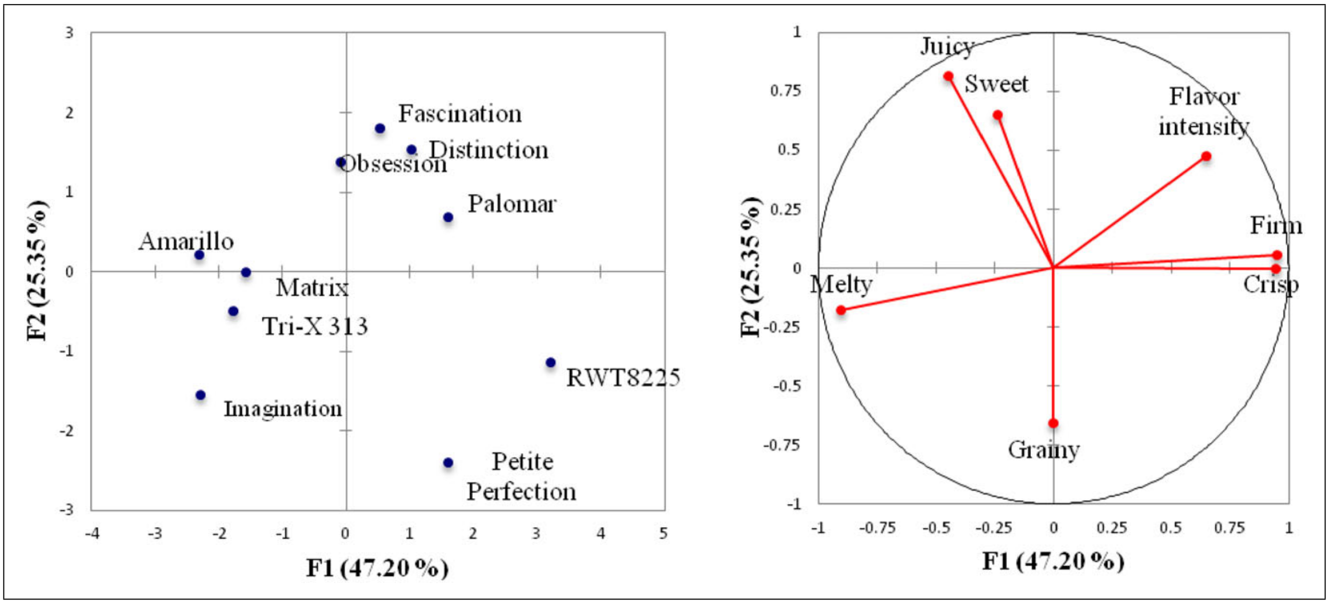

Figure 2–Principal component analysis of 7 significant descriptive analysis attribute means for 10 watermelon cultivars.

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Table 3–Descriptive analysis mean intensity ratings and standard deviations (SDs) of 10 watermelon cultivars from a 15-cm continuous line scale.

Attribute	Amarillo		Distinction		Fascination		Imagination		Matrix		Obsession		Palomar		Petite Perfection		RWT8225		Tri-X 313	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Crisp	5.6b	2.0	7.7ab	3.5	7.5ab	2.4	5.9b	2.3	6.5b	2.9	7.8ab	2.6	7.5ab	3.1	7.9ab	2.8	9.6a	2.8	6.1b	3.1
Firm	5.1bc	1.7	7.4ab	3.2	6.4abc	3.0	5.0c	2.6	4.6c	2.0	6.0bc	2.7	6.8abc	2.7	6.7abc	2.5	8.3a	2.9	4.8c	2.1
Dense	6.1a	2.5	7.7a	2.6	7.0a	2.7	5.4a	2.9	5.6a	2.9	6.0a	2.7	7.5a	3.1	7.0a	2.5	7.7a	3.3	5.8a	2.6
Juicy	9.3abc	2.2	9.8ab	2.2	10.0ab	2.4	9.3abc	2.1	9.6abc	1.9	10.5a	2.0	9.4abc	2.4	7.8c	2.1	8.3bc	2.4	9.8ab	1.9
Melty	8.3ab	3.0	6.2bc	2.9	7.3abc	2.9	8.8a	2.6	7.9abc	2.8	7.6abc	3.0	5.5c	2.7	6.7abc	2.7	6.2bc	2.9	8.5ab	2.8
Grainy	5.0c	2.6	4.7c	2.4	6.5abc	3.0	7.9a	3.1	7.7ab	3.8	5.7abc	2.8	5.2bc	2.8	7.6ab	2.6	7.1abc	3.6	5.6abc	2.9
Fiber leftover	6.6a	2.4	6.8a	3.0	7.4a	3.9	8.3a	3.0	7.5a	3.2	8.7a	2.9	7.6a	3.6	7.4a	2.2	8.7a	3.2	7.1a	2.8
Sweet	6.1b	3.0	8.2ab	3.4	9.4a	2.8	6.8a	3.2	7.6ab	3.4	8.9ab	3.5	8.0ab	3.3	9.3ab	2.4	8.9ab	2.6	7.6ab	3.2
Tangy	7.0a	3.0	5.4a	2.5	5.3a	3.2	5.2a	2.8	5.0a	3.2	5.5a	2.4	6.8a	3.7	5.0a	2.8	5.8a	2.9	6.0a	2.7
Flavor intensity	7.0b	2.6	8.2ab	2.4	9.6a	1.9	7.1b	2.9	8.1ab	2.5	8.7ab	2.6	8.7ab	2.6	8.3ab	2.4	8.5ab	2.2	7.8ab	2.4

[a–c]Means sharing a common letter group cannot be distinguished from each other.

rate with a universal testing machine (TA.XT2 Texture Analyzer, Texture Technologies Corp., Scarsdale, N.Y., U.S.A.).

Statistical analysis

Sensory attribute intensity ratings generated from descriptive analysis were assessed by ANOVA to determine reproducibility across repetitions, significance of each attribute, and cultivar quality consistency. Fixed effects were judges, replications, watermelon cultivar, and their 2-way interactions. Differences between attribute means were compared by Tukey–Kramer honest significant difference (HSD) at $\alpha = 0.05$.

PCA was performed on mean attribute intensity ratings to elucidate relationships between cultivars and attributes. Nonsignificant attributes were excluded from this analysis. Pairwise correlation coefficients between descriptive analysis and instrumental texture methods were assessed.

Quadratic discriminant analysis was performed to predict the identification of watermelon cultivar and tissue types with the hollow probe measurements and descriptive analysis results. Accuracy of prediction results is presented in confusion matrices. Stepwise selection was used to determine which measurements were entered into the model. XLSTAT (Addinsoft SARL, New York, N.Y., U.S.A.) and JMP 12.2 (SAS Inst. Inc., Cary, N.C., U.S.A.) software were used to perform all statistical analyses described.

Results and Discussion

Descriptive analysis for watermelon cultivar selection

Ten watermelon cultivars were screened by descriptive analysis in order to select a smaller subset representing a range of measurable fruit texture profiles. Ten attributes were developed to profile the fruits (Table 2). The ANOVA, with main effects of judges, products, replications, and their 2-way interactions, showed significant ($P < 0.05$) differences among most attributes. Attribute means compared by Tukey–Kramer HSD at $\alpha = 0.05$ are presented in Table 3. No cultivars were separated by the attributes dense, fiber leftover, or tangy.

PCA was applied to the mean ratings of the 10 cultivars across the significant attributes (Figure 2). The 1st 2 principal components (PCs) accounted for 72.6% of the total variation among the cultivars (PC1 = 47.2% and PC2 = 25.4%), and had Eigenvalues > 1. Attributes close together on the biplot tend to be correlated, and ones loading opposite are negatively correlated. PC1 separated cultivars mainly by the texture attributes crisp, firm, and at the opposite end, melty. Dominant PC2 attributes were juicy and sweet, although these contributed less to the overall data variation. Imagination, Petite Perfection, RWT8225, Amarillo, and Distinction demonstrated the most strongly represented sensory profiles, as determined by their squared cosines > 0.5 (Figure 2). These cultivars were selected for the hollow probe correlation experiments in the next phase of the project, due to their distinguishing sensory profiles and seasonal availability.

Amarillo was characterized by softer flesh (low in crisp, firm, and dense; high in melty) with low graininess (Figure 2 and Table 3). Imagination similarly displayed high melty scores, but with more grainy flesh. Petite Perfection had high sweetness and medium crispness. RWT8225 was profiled by high crisp, firm, and dense flesh. Distinction had significantly higher juiciness and lower grainy scores than other cultivars. Notably, these multiple comparison results and PCA loadings for firmness generally match the cultivar characteristics provided by watermelon breeders (Table 1). In addition, preference mapping combined with descriptive

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Table 4–Descriptive analysis mean intensity ratings and standard deviations (SDs) of 5 watermelon cultivars.

	Amarillo		Distinction		Imagination		Petite Perfection		RWT8225	
Attribute	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Crisp	5.9b	2.8	8.6a	2.9	6.4b	3.1	8.7a	3.1	8.0a	2.7
Firm	3.9b	2.4	6.9a	2.9	4.9b	2.8	6.7a	3.2	6.7a	2.9
Dense	5.7b	3.3	7.8a	2.8	5.5b	2.9	6.7ab	3.0	6.8ab	3.0
Juicy	8.8b	2.5	10.2a	2.2	9.4ab	2.5	8.6b	2.6	8.7b	2.6
Melty	8.4a	3.1	6.0b	2.9	7.9a	3.0	7.4ab	3.2	6.2b	3.1
Grainy	6.3b	3.2	4.1c	2.6	6.9ab	2.8	7.6ab	3.3	7.8a	2.9
Fiber leftover	5.0b	2.6	5.9b	3.1	6.4b	2.8	6.3b	3.0	8.3a	3.0
Sweet	7.1b	3.1	8.0ab	3.2	8.1ab	3.2	8.6a	2.9	7.7ab	2.8
Tangy	6.0a	3.1	5.4a	2.9	5.0a	3.0	5.0a	2.6	5.2a	2.6
Flavor intensity	7.2a	2.8	7.6a	2.9	7.9a	2.9	8.5a	2.5	7.3a	2.6

Means sharing a common letter group cannot be distinguished from each other.

analysis may also be a powerful tool for marketers to brand watermelons to have specific desirable attributes and increase sales.

Descriptive analysis for 5 selected watermelon cultivars

Sensory characterization of the 5 selected watermelon cultivars (Amarillo, Distinction, Imagination, Petite Perfection, and RWT8225) was performed by descriptive analysis. This dataset was used to correlate to the instrumental hollow probe puncture method data.

The ANOVA showed significant ($P < 0.05$) differences among attribute intensities except flavor intensity and tangy. Attribute means multiple comparisons are presented in Table 4. PCA was applied to the mean ratings across the 8 significant attributes (Figure 3). The 1st 2 PCs accounted for 81.9% of the total variation among the cultivars (PC1 = 53.16%, PC2 = 28.73%). The squared cosines for PC1 were largest for the attributes crisp, firm, dense, and melty. Cultivars were mainly separated by these attributes in this PC. The attributes grainy, fiber leftover, and juicy separated cultivars along PC2. Overall, the dominant attributes are similar to those determined for the initial 10 cultivar screening. Crisp, firm, and conversely melty were all found to account for the most variation in both cases. The same cultivars were separated most strongly by the same PCs. This supports the fact that both the fruit quality and judges were fairly consistent across both panels.

Pairwise comparison of descriptive analysis measurements indicate that the sensory attributes crisp and firm were strongly correlated to each other ($r = 0.99$; Table 5). Dense and crisp (0.88) and dense and firm (0.90) were slightly less well correlated. Whether the relationship between crisp and firm is correlated or causative is unclear. Melty was negatively correlated to crisp (−0.89), firm (−0.95), and dense (−0.94). Sweet and flavor intensity were also strongly correlated (0.98). It may be prudent to evaluate these descriptors that do not appear to contribute further distinguishing power between the tested cultivars. Removal from the descriptive analysis may expedite the judging process.

Assessment of instrumental hollow probe puncture method

Ten instrumental parameters were measured from the hollow probe puncture test applied to the 5 selected watermelon cultivars. The ANOVA showed significant ($P < 0.05$) differences for maximum force (MF), work before MF, work after MF, and number of peaks (# peaks). Parameter means and their groupings are presented in Table 6.

PCA was applied to the mean measurements across the significant parameters (Figure 4). The1st 2 PCs accounted for 81.9% of the total variation among the cultivars, although distribution was primarily along PC1 (PC1 = 73.4%, PC2 = 28.73%). The squared cosines for PC1 were largest for maximum force, work

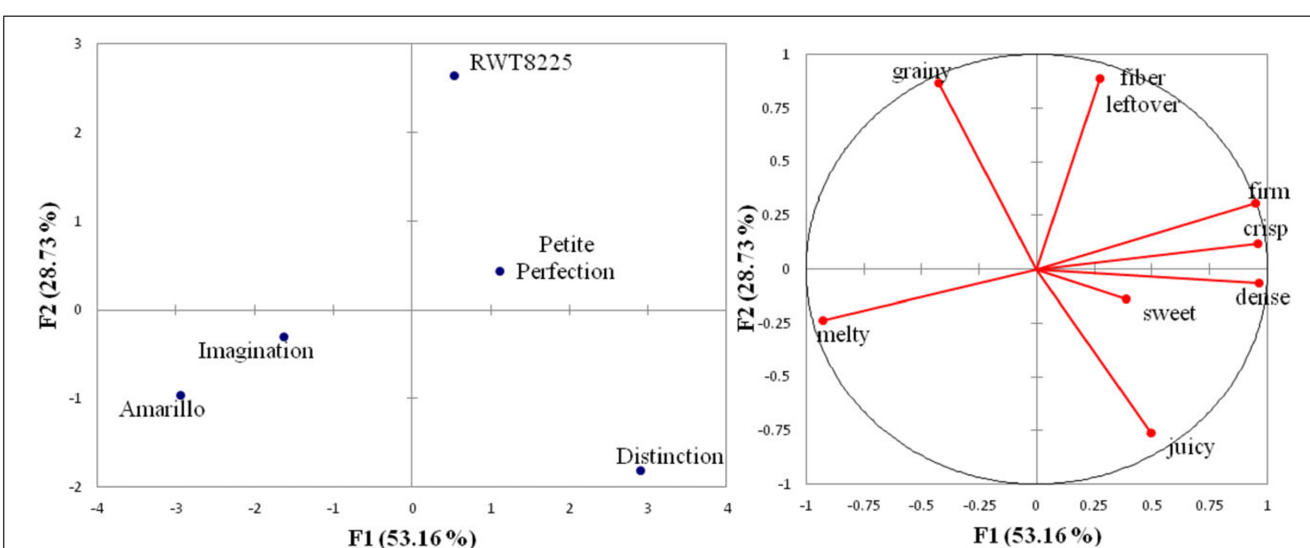

Figure 3–Principal component analysis of 8 significant descriptive analysis attribute means for 5 watermelon cultivars.

Table 5–Pairwise correlation *r* values of descriptive analysis attribute intensity scores of 5 watermelon cultivars.

	Flavor intensity	Tangy	Sweet	Fiber leftover	Grainy	Melty	Juicy	Dense	Firm
Crisp	0.72	−0.59	0.85	0.45	0.07	−0.89*	−0.16	0.88*	0.99**
Firm	0.64	−0.59	0.79	0.49	0.00	−0.95*	−0.04	0.90*	–
Dense	0.43	−0.25	0.57	0.15	−0.40	−0.94*	0.20	–	–
Sweet	0.98**	−0.81	–	–	–	–	–	–	–

*$P < 0.05$. **$P < 0.01$. ***$P < 0.001$.

Table 6–Hollow probe puncture test measurements and standard deviations (SDs) for 5 watermelon cultivars.

	Amarillo		Distinction		Imagination		Petite Perfection		RWT8225	
Parameter	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Initial slope (N/mm)	7.3a	3.5	8.2a	2.6	6.9a	2.9	8.6a	5.2	8.9a	4.7
BY force (N)	7.0ab	3.4	8.4a	3.6	6.0b	2.3	6.9ab	3.7	8.7a	3.7
BY deformation (mm)	1.1a	0.6	1.1a	0.5	0.9a	0.5	0.9a	0.4	1.1a	0.5
BY slope N/mm)	8.6ab	4.1	9.1ab	3.1	8.0b	3.0	10.4ab	5.0	10.6a	4.6
BY work (N·mm)	3.7ab	4.2	4.3a	3.3	2.5b	1.7	2.8ab	2.4	4.1ab	2.6
Max force (N)	12.5c	3.0	15.3b	3.6	12.6c	2.6	17.8a	4.5	18.2a	5.6
Work bef MF (N·mm)	42.3c	21.6	54.0abc	22.1	48.9bc	23.7	66.2a	32.3	61.6ab	29.3
MF deformation (mm)	5.0a	2.1	5.3a	1.9	5.5a	2.2	5.7a	2.0	5.3a	1.9
Work after MF (N·mm)	75.7b	18.6	91.7a	23.3	75.6b	15.6	104.5a	27.2	104.3a	28.4
# Peaks	38.7b	10.2	39.9b	9.3	41.7b	10.2	50.5a	8.1	41.4b	9.2

Means sharing a common letter group cannot be distinguished from each other. BY, bioyield; MF, maximum force.

before MF, and work after MF. Amarillo, Imagination, Petite Perfection, and RWT8225 were mainly separated by these attributes in this PC. Only # peaks separated Distinction along PC2.

Pairwise correlation of hollow probe puncture measurements indicate correlations between initial slope and bioyield slope (0.96), maximum force (0.99), work before maximum force (0.89), and work after maximum force (1.00; Table 7). Bioyield slope was also correlated to maximum force (0.98) and work after maximum force (0.95). Maximum force was also strongly correlated to work after maximum force (0.99).

Correlation of descriptive analysis to hollow probe puncture method

PCA was performed to determine whether instrumental parameters could be related to the descriptive analysis sensory attributes (Figure 5). Pairwise correlation results showed the sensory terms crisp and firm correlated well with the texture measurements initial slope, maximum force, and work after maximum force (Table 8). The sensory attribute dense positively correlated to bioyield force (0.93) and work after maximum force (0.89). Melty negatively correlated to work after maximum force (−0.91). Grainy negatively correlated to bioyield work (−0.89). Several flavor sensory attributes also correlated to instrumental measurements. Tangy correlated to bioyield deformation (0.94), whereas sweet (0.94) and flavor intensity (0.90) correlated to work before maximum force. The remaining sensory attributes were not significantly correlated. Sensory attributes juicy and fiber leftover were not very well described by PCs 1 and 2 as determined by squared cosine values. Melty and grainy were well described, but did not positively correlate with any puncture test measurements. Puncture

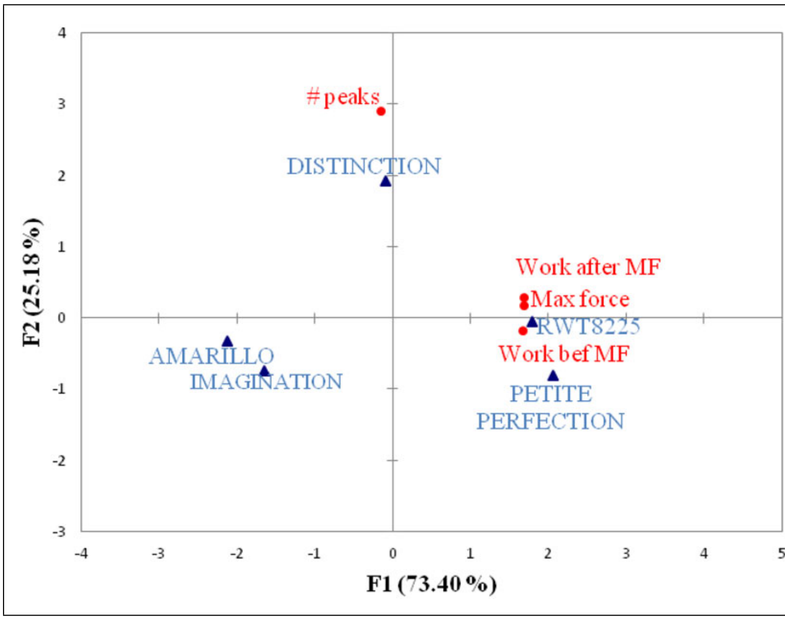

Figure 4–Principal component analysis biplot of the significant parameter means from the hollow probe puncture test of 5 watermelon cultivars. MF = maximum force.

Table 7–Pairwise correlation *r* values of hollow probe puncture test parameters on 5 watermelon cultivars.

	# Peaks	Work MF	MF deformation	Work bef. MF	Maximum force	BY work	BY slope	BY deformation	BY force
Initial slope	0.78	1.00***	−0.17	0.89*	0.99**	0.08	0.96**	−0.45	0.78
BY slope	0.88	0.95*	−0.13	0.86	0.98**	−0.07	–	–	–
Maximum force	0.8	0.99**	−0.26	0.83	–	–	–	–	–

BY = bioyield; MF = maximum force.
*P <0.05. **P < 0.01. ***P < 0.001.

Table 8–Pairwise correlation *r* values of hollow puncture probe (instrumental) and descriptive analysis (sensory) parameters.

	Instrumental									
Sensory	Initial slope	BY force	BY deformation	BY slope	BY work	Maximum force	Work before MF	MF Deformation	Work after MF	# Peaks
Crisp	0.98**	0.72	−0.56	0.91*	0.01	0.95*	0.89*	−0.11	0.97**	0.78
Firm	0.95*	0.75	−0.56	0.85	0.05	0.92*	0.81	−0.22	0.96**	0.69
Dense	0.87	0.93*	−0.16	0.71	0.47	0.81	0.69	−0.35	0.89*	0.39
Melty	−0.87	−0.87	0.37	−0.75	−0.29	−0.86	−0.61	0.50	−0.91*	−0.46
Grainy	0.09	−0.48	−0.67	0.31	−0.89*	0.19	0.20	0.33	0.04	0.66
Sweet	0.79	0.30	−0.71	0.75	−0.36	0.73	0.94*	0.41	0.74	0.87
Tangy	−0.45	0.08	0.94*	−0.42	0.68	−0.42	−0.58	−0.39	−0.41	−0.70

BY = bioyield; MF = maximum force.
*P < 0.05. **P < 0.01. ***P < 0.001.

test measurements of BY deformation, BY work, BY force, work before MF, MF deformation, work after MF, and # peaks were also well described, but did not correlate with any sensory attributes.

Maximum force values determined by puncture test measurements are frequently used as a destructive measure of firmness in various commodities (Sugiyama and others 1998; Chauvin and others 2010). The findings of this study confirm that maximum force correlates well with not only firmness in watermelon, but crispness as well. This is positive in that the measurement of maximum force is already an industry standard and easy to measure, so confirmation of its use as a measure of firmness has much practical promise. It also suggests that maximum force may be an appropriate instrumental measurement for crispness, although more thorough studies would be informative. For instance, in a sensory and instrumental assessment of apple texture, Costa and others (2011) found firmness correlated positively to # peaks and # peaks/mm and negatively to acoustic material properties. Crispness exhibited the inverse correlation. Although some sensory attributes may be positively correlated, it is important to note the underlying mechanisms may differ and not be captured by the scope of the study.

In addition to maximum force, measurements of initial slope and work after maximum force also correlated well to both the firm and crisp sensory attributes (Table 8). This suggests the material properties that contribute to crisp and firm are very similar. Mohsenin (1986) and Bourne (2002) related initial slope to the stiffness of a material under load. The initial slope reflects the initial resistance of the tissue to the applied force of the probe, that is, the greater the resistance, the greater the initial slope. This is very similar to the definition for the sensory attribute "firm" developed by the panelists, which was the resistance of fruit to bite

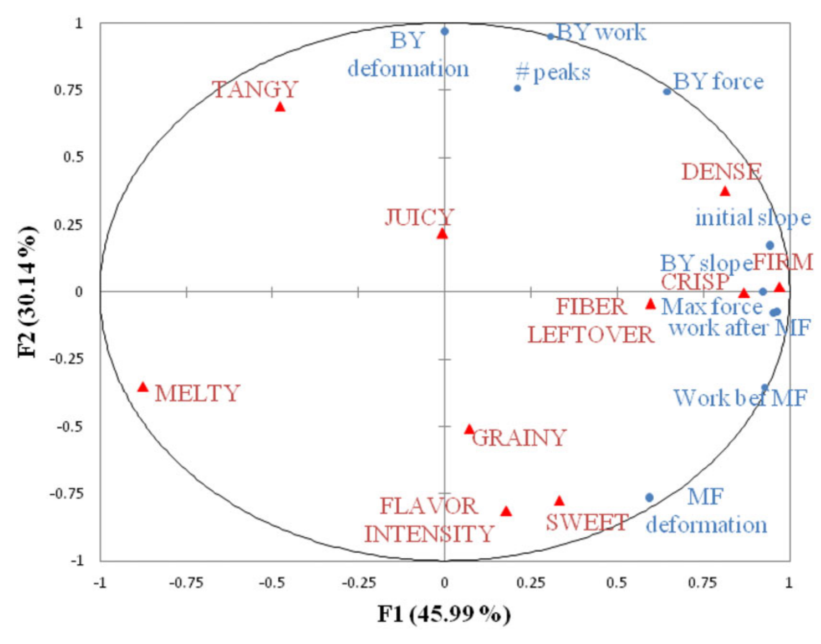

Figure 5–Principal component analysis of descriptive analysis attribute and hollow probe puncture measurement means. BY = bioyield; MF = maximum force.

Table 9–Confusion matrices of watermelon cultivar identification by hollow probe measurements of heart, placenta, locule (A to C), and by descriptive analysis (D).

	Predicted					
Actual	Amarillo	Distinction	Imagination	Petite Perfection	RWT8225	% correct
A. Heart tissue						
Amarillo	**7**	0	1	0	0	88
Distinction	0	**8**	0	0	0	100
Imagination	0	0	**8**	0	0	100
Petite Perfection	1	1	0	**9**	1	75
RWT8225	2	0	1	1	**6**	60
						83
B. Placental tissue						
Amarillo	**9**	0	5	0	1	60
Distinction	0	**11**	2	0	3	69
Imagination	4	1	**10**	0	1	63
Petite Perfection	0	0	2	**19**	3	79
RWT8225	1	1	2	3	**11**	61
						67
C. Locule tissue						
Amarillo	**11**	1	3	1	0	69
Distinction	3	**5**	5	2	1	31
Imagination	5	0	**9**	1	1	56
Petite Perfection	1	0	9	**12**	2	50
RWT8225	1	3	4	4	**8**	40
						49
D. Descriptive analysis						
Amarillo	**33**	9	3	2	3	66
Distinction	13	**21**	4	8	4	42
Imagination	10	6	**30**	20	10	39
Petite Perfection	4	6	15	**50**	1	66
RWT8225	5	8	5	3	**31**	60
						54

Note: Correct identifications are along the diagonal in bold.

(Table 2). This suggests the perceived resistance of the fruit to panelists is similar to the initial resistance described by the instrumental measurement of initial slope. In addition, crisp was defined by the panel as the intensity of the crunch or snap of the 1st bite of fruit. The crunch or snap was described as the degree of give in the tissue before cell rupture, the greater the give, the lower the crispness. The resistance measured by the initial slope is a combination of compression of intracellular spaces and cell membrane integrity and turgor, which appears to be interpreted as the resistance before cell rupture described by sensory crispness and sensory firmness.

Work after maximum force, which is the amount of work done on a tissue after maximum force is reached, also correlated well to crisp (0.97) and firm (0.96). This measurement was also positively correlated strongly with initial slope (1.00) and maximum force (0.99). At maximum force, the tissue under load reaches maximum compression and cell membranes are at maximum strain before rupture. After cell rupture, the tissue behaves plastically, continuing to deform without increase in applied load. It is hypothesized that the higher the initial resistance of the tissue to deformation (as measured by initial slope) and higher the maximum force, the greater the force will be when it reaches plasticity and thus the greater work after maximum force. This may account for the strong correlations seen between these 3 measurements. In onions, Gonzalez and others (2010) found a strong positive correlation between cell membrane intactness and initial slope, but only weak correlation to work after maximum force. After maximum force, the onions did not appear to maintain resistance as much as watermelon in this study, which may account for the weak correlation. The application of cell imaging methods would help determine the extent that cellular arrangement and membrane integrity contribute to firmness and crispness in different watermelon cultivars.

Despite the promising performance of the number of peaks measurement in the comparison of the Magness–Taylor solid and hollow puncture probes (Shiu and others 2015), this measurement did not correlate to any sensory attributes (Table 8). Although number of peaks may correlate to passage of the probe through cell layers, and be an effective means to distinguish cultivars and tissues, it remains unclear what the measurement quantifies in terms of sensory parameters. It may be that the sensory panel did not consider the concept of multiple "crunches" in a bite, and thus did not assess the watermelons for anything equivalent to number of peaks in this study. Perhaps if the concept of multiple failures was suggested, a sensory measure of number of peaks would have developed. Overall, the maximum force measurement was efficient and reflected firm and crisp sensory attributes, although initial slope and work after maximum force measurements may also be informative.

Classification of watermelon cultivars by descriptive analysis and puncture test methods

Quadratic discriminant analysis was performed to predict the identification of watermelon cultivar by hollow probe puncture test parameters and descriptive analysis attributes. For heart tissue, maximum force, BY force, BY deformation, work after MF, and # peaks were entered into the model. Placental tissue used maximum force, work before MF, MF deformation, and # peaks. Maximum force, BY force, and # peaks were used in the model with locule tissue.

Using heart tissue measurements, watermelon cultivars were correctly predicted 83% of the time (Wilks' Lambda $P = 0.247$;

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Table 9). However cultivars were correctly classified only 67% of the time if placental tissue was used ($P = 0.200$), and only 49% of the time with locule tissue ($P = 0.453$). Amarillo and Imagination were practically indistinguishable, suggesting that their placental tissue characteristics are quite similar. Overall, these findings suggest that the texture differences of the heart tissue are greatest as measured by the hollow probe and provide the greatest ability to discriminate watermelon cultivars.

For descriptive analysis, the attributes crisp, firm, juicy, melty, grainy, and fiber leftover were entered into the model. Discriminant analysis of watermelon cultivars using descriptive analysis sensory data resulted in 54% overall correct classifications ($P = 0.471$; Table 9). Amarillo was correctly predicted 66% of the time, Distinction 60%, Imagination 42%, Petite Perfection 39%, and RWT8225 66%. In comparison, cultivar prediction by hollow probe puncture test parameters in the heart and placental tissue was generally better. These results are encouraging, indicating that this relatively rapid instrumental method could be comparable to use of a sensory panel for sorting cultivars by texture properties. This could also be a useful tool developed for quality assurance or breeding efforts where throughput is especially critical.

Conclusions

Descriptive analysis methodology effectively quantified and separated watermelon cultivar sensory texture profiles. Of the 10 cultivars screened, the sensory attributes measured captured 73% of variation in the data using the 1st 2 principal components. Crisp and firm were most distinguishable between cultivars. Pairwise correlation of the hollow puncture probe and sensory parameters determined that initial slope, maximum force, and work after maximum force measurements were all well correlated to sensory attributes crisp and firm as well. This is positive in that the measurement of maximum force is already an industry standard, so confirmation of its use as a measure of sensory firmness and perhaps crispness has much practical promise. Initial slope also captures sensory crispness of watermelon, but is not as practical to measure in the field as maximum force. Watermelon cultivar types were correctly predicted by puncture test measurements in heart tissue 87% of the time, although descriptive analysis was correct 54% of the time. Application of the puncture test to heart tissue may be adequately representative of texture differences across cultivars. This sampling strategy could be quite beneficial for breeding efforts and perhaps quality assessment. Future work with preference mapping would be an excellent way to identify the sensory attributes most important to consumers, and in turn use that information for improved marketing and breeding efforts.

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