Title: Optimizing texture assessment for muscadine grape breeding

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Abstract

Muscadine grapes (*Vitis rotundifolia* Michx.) are enjoyed as a specialty crop in the southeast United States, but consumer acceptance is hindered by their thick skins and soft gummy flesh. Improved textural quality of muscadine grapes has been major objective of breeding programs and may contribute to market expansion. Multiple methods have been developed to assess textural quality in muscadine, including descriptive sensory panels, instrumental texture analysis, and breeders' field ratings, but few attempts have been made to compare the results of these methods in consideration of perceived consumer preferences. The objective of the present study is to improve selection efficiency for improved texture in muscadine breeding programs by correlating texture data from six precise instrumental analysis methods with ten interpretable descriptive sensory panel characteristics and three low-cost breeders' field ratings across seven texturally diverse muscadine genotypes and a table grape check in 2019 and 2020. The muscadine genotypes differed significantly for most instrumental and sensory attributes measured and many significant correlations were identified between the sensory and instrumental measurements. Findings suggest that a single generalized breeder's rating for overall texture quality combined with instrumental texture assessment using a 2 mm puncture probe to estimate work to rupture, skin elasticity, and skin thickness would provide a sufficient estimation of most descriptive sensory panel characteristics including awareness of skins, crispness, detachability, hardness, and visual separation of skins from flesh, which are all important attributes in determining consumer acceptance.

Introduction

Muscadine grape (*Vitis rotundifolia* Michx.) is a singular North American member of the economically important grape genus, *Vitis,* often sold as a fresh market table-grape. Although muscadine is a specialty crop, it possesses an ardent following in its native region and presents a well-adapted, disease-resistant option for fruit producers in the humid, temperate region of the southeastern United States. As a fruit, muscadines are often noted for their unique flavor and challenging texture profile. Indeed, even most table-type muscadine cultivars have a thick, leathery exocarp that slips easily (commonly referred to as 'slipskin') from a gummy, mucilaginous mesocarp (Conner, 2013; Olien, 1990). This texture starkly contrasts with the thin, tender exocarp and meaty mesocarp that is observed among preferred table-type *Vitis vinifera* cultivars (Sato et al., 1997). Consumer panelists have indicated that the overall 'liking' of a muscadine cultivar is heavily influenced by both skin thickness and pulp texture, and that even panelists familiar with muscadines would prefer thinner skins (Brown et al., 2016). Moreover, variation in muscadine texture may be associated with postharvest quality and storability. Barchenger et al. (2015) observed that the force required to penetrate the skin of a muscadine reduced over time in cold storage, but that the rate of this reduction varied significantly between genotypes. Conner (2012) reported similar findings, noting that 'Supreme' maintained exceptional firmness in storage compared to other genotypes.

Despite evidence that muscadine fruit texture influences both storability and consumer acceptance, little is known about relationships between human-perceived texture qualities and objective measurements of texture-related attributes through lab instrumentation. To begin this comparison, food texture must first be defined as "all the mechanical, geometrical, surface and body attributes of a product perceptible by means of kinesthetic and somesthetic receptors, and (where appropriate) visual and auditory receptors from first bite to final swallowing" (ISO 5492:2008). The key assumption of this definition is that any textural attribute must be human-perceptible. Thus, investigators of grape texture have often relied on either randomly sampled consumer panels (Brown et al., 2016) or trained and standardized descriptive sensory panels (Cliff et al., 1996; Felts et al., 2018) to gather texture data that is conforms to human perception. However, consumer panels are highly subjective and trained sensory panels are costly to implement for regular screening of breeding materials, so for some, lab instruments like the Stable Micro Systems TA.XT Texture Analyzer Analyzer (Texture Technologies Corporation, Hamilton, MA) have presented an effective alternative to panel-based texture analyses (Conner, 2013; Rolle et al., 2012).

The objective of the present study is to expand on the work of others like Brown et al. (2016), who compared instrumental and consumer sensory data collected from a large selection of twenty-two muscadine genotypes. To build on this work, this study implements a more comprehensive array of Texture Analyzer metrics and probes with ten descriptive sensory panel attributes among seven diverse muscadine grape genotypes. Based on these correlations, a robust strategy has been developed for routine screening of muscadine texture profiles through cost-effective instrumentation. Finally, the proposed strategy was deployed in a sample of twenty genotypes representing a wide range of textures present in the University of Arkansas muscadine breeding program.

Materials and Methods

Plant Materials and Harvest

Three advanced selections from the University of Arkansas breeding program (AM-9, AM-135, and AM-195), one breeding selection from the North Carolina State University muscadine breeding program (NC67015-26), and three commercially available muscadine cultivars (‘Carlos’, ‘Ison’, and ‘Tara’) were used for sensory and texture analysis in 2019 and 2020 on the basis of their diverse texture characteristics and availability of ripe fruit. Ten 500 g clamshells of each cultivar were harvested from the University of Arkansas Fruit Research Station (FRS) in Clarksville, AR on September 11, 2019, and September 16, 2020. Additionally, ten 500 g clamshells of the bunch-grape cultivar, ‘Red Globe’, were purchased on September 10, 2019 and September 15, 2020 to provide a check representing ideal table-grape texture qualities for reference during the analysis. Collectively, twenty additional genotypes were harvested on two separate days from FRS in 2020 to implement large scale screening of texture profiles. One 500 g clamshell of AM-64, AM-70, AM-77, AM-131, AM-205, AM-210, ‘Ison’, ‘Nesbitt’, and ‘Summit’ were harvested on September 21, 2020. One 500 g clamshell of AM-26, AM-92, AM-132, AM-134, AM-148, AM-158, AM-182, AM-193, AM-194, AM-211, and AM-213 were harvested on September 28, 2020.

Randomization

After harvest, fruit was transported from FRS to the Department of Food Science in Fayetteville, Arkansas. Fruit from each genotype was be mixed and re-sorted into seven 500 g clamshells which were randomly assigned to the five analytical texture analysis methods and sensory analysis (two clamshells). During randomization berries that were immature, overripe, or that displayed obvious deformity, wet stem scar, or other damage were discarded.

Descriptive Sensory Analysis

Descriptive sensory analyses of the AM-9, AM-135, AM-195, NC67015-26, ‘Carlos’, ‘Ison’, ‘Tara’, and ‘Red Globe’ were conducted at the Sensory Research and Consumer Center in the Food Science Department at the University of Arkansas on September 12, 2019 and September 17, 2020. The descriptive panelists developed a fresh market muscadine lexicon of sensory terms in 2017 (Felts et al., 2018). This lexicon, with slight modifications to the “thickness of skins” attribute (Table 1), was be implemented for sensory analysis. The panelists (n=9 in 2019; n=6 in 2020) used a modified Sensory Spectrum® method, an objective method for describing the intensity of attributes in products using references for the attributes. The descriptive panel evaluated each sample for 10 texture attributes (Table 1) using a 15-point scale (0=less of an attribute, 15=more of an attribute). The descriptive sensory evaluation was performed in duplicate in 2019 and triplicate in 2020 with randomized presentation order of each of the eight muscadine genotypes within each replication.

Breeders’ Ratings

Mason Chizk, Margaret Worthington, and Renee Threlfall performed ratings for all 28 breeding selections and check cultivars for skin texture, flesh texture, and overall texture desirability on a 1-9 scale, with 1 = thick skin, soft, mucilaginous flesh, or undesirable texture, and 9 = thin, crisp skins, firm, meaty, non-slipskin flesh, or desirable overall texture, respectively.

Texture Analyzer Instrumental Analysis

All instrumental analyses were performed using a TA.XTPlus Texture Analyzer (Texture Technologies Corporation, Hamilton, MA) with a 5 kg load cell. The specific specifications used with each protocol are recorded in Table 2 for reference and repeatability. Fifteen randomly selected berries were used for each genotype of each analysis, except for the Kramer shear cell (KSC), which consisted of three runs per genotype and six berries per run.

Penetration. Fruit firmness was measured by penetration using a 2 mm flat cylindrical probe. Penetrations were made on the equatorial plane of each berry with the stem scar facing the right-hand side at a probe speed of 1 mm.sec^{-1} (Table 2). Berry skin break force (N) was calculated as the force required to rupture the berry skin. Elasticity was calculated as the distance (mm) the berry was compressed before the skin was ruptured. Skin firmness was calculated as skin break force (N) / elasticity (mm) following Felts et al. (2018). Berry penetration work (mJ) was calculated as the area under the curve from zero to the point of berry maximum force following Conner (2013).

Skin and flesh analysis. To evaluate skin and flesh properties individually, a small circular section of skin was carefully removed from the equatorial surface of each berry with the stem scar facing the right-hand side using a razor blade. The removed sections of skin were trimmed of any excess flesh clinging to the interior surface and probed using a 2 mm flat cylindrical probe. The distance traveled from first contact to the work surface was recorded as skin thickness. The exposed flesh of the entire berry was probed using an 8 mm flat cylindrical probe. The probe traveled 3 mm at a speed of 0.5 mm.sec^{-1} after first contact, and the peak force was recorded as flesh firmness.

Compression. Compression tests were performed using a 10 mm flat cylindrical probe and was conducted on the equatorial plane of each berry with the stem scar facing the right-hand side at a probe speed of 1 mm.sec^{-1} (Table 2). After the probe contacts the berry surface, it traveled halfway to the work surface, achieving a strain of 50%. Peak force (N) and compression work (mJ) were recorded as compression firmness and compression work, respectively.

Single blade. Tests were performed using a knife blade attachment with a 45-degree chisel end. Compressions were conducted on the equatorial plane of each berry with the stem scar facing the right-hand side at a probe speed of 1 mm.sec^{-1} (Table 2). After the probe contacted the berry surface, it traveled halfway to the work surface, achieving 50% strain. Peak force (N) and compression work (mJ) were recorded as knife firmness and knife work, respectively.

Kramer shear cell. Kramer shear tests were performed using a Kramer shear cell (KSC) (TA-91). The box at the cell base was filled with six berries. The sample was then be macerated in two cycles with a probe speed of 1 mm.sec^{-1} (Table 2). While the first maceration cycle of the Kramer shear cell yielded data representative of compressing and shearing a berry, the berries of smaller genotypes were extruded through the slots in the base, resulting in a load cell overload during the second cycle. Due to this complication, the second cycle measurement was discarded for the two smallest muscadine genotypes, ‘Carlos’ and NC67AO15-26.

Statistical Analysis

Instrumental and breeders' ratings were analyzed using PROC GLM in SAS 9.4 (SAS Institute Inc., Cary, NC) with genotype as a fixed effect. Sensory texture data were also analyzed using PROC GLM with genotype considered as a fixed effect and panelist and genotype x panelist interaction considered as random effects. The panelist factor was also nested within year since panelists changed from year to year. In all analyses, year and year interactions were also considered as random effects. Mean separations for significant factors were estimated using Fisher's F-protected Least Significant Difference. PROC CORR was used to conduct Pearson correlations between the instrumental, sensory, and breeders' ratings data. A principal component analysis (PCA) was conducted using SAS 9.4. Multiple linear regression analyses were performed using PROC REG.

Large Scale Texture Screening

Texture analyzer puncture probe, skin thickness, and breeders' ratings were also conducted on the same day as harvest for the last twenty genotypes harvested following previously described protocols. Descriptive sensory attributes for each genotype were predicted using linear regression models constructed from previous analyses.

Results and Discussion

Descriptive Sensory Analysis and Breeder's Ratings

The descriptive sensory panel and breeder's rating results differed significantly ($p < 0.05$) for all attributes measured within 2019 and 2020 analyses of variance (ANOVA), except moisture release and detachability. However, due to a pervasively significant genotype by year interaction, only crispness, moisture release, and visual separation of skins reflected consistent genotypic differences in an across-years analysis. Differences in ratings ($p < 0.05$) also existed between panelists who participated in the sensory analysis, but there were no detectable differences between breeders for the breeder's ratings. The *V. vinifera* check, 'Red Globe', was a frequent, yet anticipated outlier for most attributes measured and thus, was not included in ANOVA or correlation analyses.

The mean breeder's ratings between skin texture, flesh texture, and overall desirability in 2019 and 2020 were highly correlated ($p < 0.01$), with AM-135 consistently ranking as the most texturally desirable grape for all three ratings. Both AM-135 and AM-195 approach the breeders' ratings of 'Red Globe', indicating that they may be promising for table use. In spite of these improved muscadines genotypes, 'Red Globe' greatly exceeded breeders' ratings of all others, indicated that all of the muscadines observed are quite gummy in comparison. For all three breeder attributes, 'Carlos' and NC67AO15-16 performed similarly and were rated significantly lower than all other genotypes for flesh texture and overall desirability. Interestingly, the results of all breeder's rating methods were consistently most correlated ($p < 0.01$) with work to rupture using the 2mm puncture probe, although they were also consistently correlated with six other instrumental methods.

Among the five sensory panel attributes for which genotypic differences were observed across years ($p < 0.10$), visual separation displayed the widest ranges of variation between muscadine genotypes according the 15-point scale, suggesting that genetic diversity for the degree slip-skin qualities exists among the observed germplasm. The genotypic means of visual separation was also strongly correlated to detachability ($p < 0.01$), with AM-135 and AM-195 both having skins that were significantly less prone to separation (0.05) than the other five muscadine genotypes. Even so, the detachability and visual separation scores of these genotypes were twice as large as those of 'Red Globe', suggesting that despite the wide range of skin adherence, all muscadines measured are much more slip-skin than the bunch-grape check, 'Red Globe'. Detachability and visual separation were also both positively correlated with 2mm probe rupture force ($p < 0.01$) and negatively correlated with flesh firmness (total work from 8mm probe) ($p < 0.01$), indicating that genotypes with softer, gummier flesh tend to slip from skins more easily.

Mean seed separation was similar between most genotypes, including 'Red Globe', with the processing-type, NC67A016, being the only notable exception, having seeds that were at least 25% more resistant to separation than all other genotypes. Among the muscadine genotypes, AM-9 had the largest mean seed size while AM-135 had the lowest, although significant genotypic differences were not detected for this trait. AM-195 and 'Red Globe' both had about one less seed on average than 50% of the genotypes measured. However, seed number was heavily influenced by year, as evidenced by a significant genotype by year interaction and a nearly two-fold increase in seed number from 2019 to 2020 for most genotypes. For berry crispness, hardness, and awareness of skins, the genotypic means of 'Red Globe' were at least

30% lower than all muscadine genotypes, indicating that these characteristics represent a large gap between muscadines and bunch-grapes. However, both processing-types, ‘Carlos’ and NC67AO15-16, did have lower mean hardness and crispness ratings than all other muscadine genotypes. The genotypic means of crispness and hardness were generally correlated ($p < 0.01$) with one another, suggesting either that the sensory panel had difficulty distinguishing these two traits, or that crisp genotypes also tended to be hard. AM-9 and AM-195 were the hardest and the crispest genotypes, respectively. Both hardness and crispness reflected strongly positive correlations with skin thickness, compression rupture force, and KSC cycle 1 peak force ($p < 0.05$). Ignoring ‘Red Globe’, few significant differences existed between mean ratings for awareness of skins, but AM-135 did have significantly lower ratings compared to all other muscadine genotypes except for AM-195, suggesting that this genotype may be particularly well-suited for table use or parental stock for improved texture. This is somewhat surprising though, as this genotype also had one of the hardest berries with one of the thickest skins, potentially suggesting that firm flesh texture has more to do with awareness of skins than skin qualities directly.

TA.XT Texture Analysis

Penetration (2mm) and Flesh Analysis (8mm): For all attributes measured by the 2 mm puncture probe, muscadine genotypic means were much larger than those of ‘Red Globe’. However, the skin thickness of the store-bought ‘Red Globe’ check was disproportionately affected by year, being twice as thick in 2020, possibly resulting from different sources of fruit in each year. The thinnest-skinned muscadine, NC67AO15-16, had skin that was about 20% thinner than the thickest-skinned AM-9, but 30% thicker than ‘Red Globe’. Despite being the thinnest skinned muscadine, NC67AO15-16 had the largest rupture force, skin peak force, elasticity, work to rupture, and skin work. In contrast, AM-195 had the softest skins, as indicated by mean values for both skin peak force and skin work. AM-135 had the lowest rupture force and elasticity, being only 68% and 72% of genotypic mean values for NC67AO15-16, respectively. AM-135 had particularly low rupture force across years, being significantly lower than all other genotypes ($p < 0.05$). Penetration elasticity held a tight negative correlation ($p < 0.01$) with all breeders’ ratings across both years and in 2019 a positive correlation ($p < 0.01$) with visual separation and detachability. Skin thickness was positively correlated with berry hardness and moisture release ($p < 0.01$). Additionally, the flesh work analysis conducted with the 8 mm probe demonstrated that AM-195 had flesh that was significantly more firm than all other genotypes ($p < 0.05$), while ‘Carlos’ and NC67AO15-16 had the softest flesh.

Compression (7.62cm) and Single Blade (45° chisel) Analysis: The means of attributes measured in the compression and single blade analysis were redundantly similar, as further evidenced by multiple high correlations with one another ($p < 0.001$). For this reason, the results of the single-blade analysis were excluded from the correlation analysis and will be discussed together. In both analyses, ‘Carlos’ consistently demonstrated the lowest rupture force, maximum force, elasticity. Total work, which was weakly correlated ($p < 0.05$) with crispness, was consistently highest for AM-9 and AM-195. The genotypic means of peak force and rupture force were more significantly correlated ($p < 0.01$) with crispness and hardness, indicating that the sensory panel’s interpretation these traits was comparable the instrumental compression technique.

Kramer Shear Cell Analysis: Using the methods previously described,

Conclusion

Using the methodological framework provided, any textural sensory attribute, excluding fibrousness, could be sufficiently be predicted by at least one instrumental attribute. Additionally, an apparent relationship between breeder's ratings and the sensory attributes of awareness of skins, seed separation, and detachability suggests that breeders may adequately assess these characteristics without need for sensory panels or instrumental techniques. However, the extremely tight correlation between breeders' ratings suggests that either using one generalized breeders' rating for texture may be necessary, or else specific breeders' ratings must be more explicitly defined or standardized to avoid any redundancy in the data. In future research, through modifying these breeders' ratings, it may even be possible to strengthen the weak correlation that exists between the flesh ratings and flesh firmness attributes measured by the 8mm probe. Accurate prediction of hardness and crispness may not be possible using breeders' ratings alone. Because these two highly correlated traits are thought to be important to shaping consumer opinion, it may be necessary to screen for hardness and crispness with the 2 mm puncture probe (skin thickness or rupture force), with which they were most highly correlated ($r = 0.77$-0.88).

Lastly, among the germplasm surveyed, the slip-skin nature of muscadines, which parallels the sensory attributes of detachability and visual separation, could be most accurately assessed using the 2mm puncture probe as well. Both characteristics appear to be linked with skin characteristics and are highly correlated ($p < 0.01$) with the rupture force and skin toughness (skin peak force) as determined by the 2mm probe. Of all muscadine genotype included, AM-135 appears to have characteristics that are most desirable for table use. This genotype was easily punctured by the 2mm probe, had flesh that was firm, and had skin that was soft. Among the muscadine genotypes examined, AM-135 was also demonstrated the lowest ratings for awareness of skins across years, despite having relatively thick skins. These qualities contrast heavily with those of 'Carlos' and NC67AO15-16, which appear to be much more suited to processing than table-use.

In summary, for a more holistic characterization of fruit texture in muscadine breeding programs, direct evidence supports the adoption of a combined approach that utilizes a single breeder rating for texture quality and an instrumental protocol that implements the 2 mm puncture probe to estimate work to rupture, rupture force, and skin thickness. This approach would appear to provide an adequate prediction of sensory characteristics including awareness of skins, crispness, detachability, hardness, and visual separation. No accurate estimation of fibrousness was observed among the TA.XT attachments and protocols described, however this particular attribute is not of critical importance to the UA breeding program, but may be a topic of future investigation. Furthermore, additional work may be done to develop a more predictive method for assessing seed separation, which is most strongly correlated to breeders' ratings. It may be possible to develop a more tailored breeders' field rating for this attribute that measures the time required to separate seeds from the flesh.

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Table 1. 2019-2020 Lexicon Muscadine Grapes for Texture (each panelist receives 5 berries).

Term	Definition	Technique	Reference
Appearance (pulp of one berry cut in half)			
Visual separation	Detachability of pulp from skin of berry	Squeeze half of berry and observe the extent of which the pulp detaches from the skin. (None=*does not detach* to Much=*completely detaches*)	None=0 Much=15.0
Amount of seeds	Number of seeds in the whole berry	Count the number of seeds in the whole berry.	Number of seeds
Seed size	Visual size of the seeds	Observe the seeds and determine the overall size. (Small to Large)	Photo reference of size A=12 (5.3 x 8.5 mm) B=7 (4.9 x 7.1 mm) C=3 (3.9 x 6.1 mm)
Texture (whole berry for 4 berries)			
Berry hardness	Force required to compress the sample.	Place the sample in the mouth. Compress or bite through the sample one time with molars or incisors. (Soft to Hard)	Cream Cheese[1] 1.0 Egg White 2.5 Am Cheese 4.5 Beef Frank 5.5 Olive 7.0 Peanut 9.5 Almond 11.0
Berry crispness	Unique, strong, clean, and acute sound produced in first bite of the food with incisors and open lips.	Place the sample in the mouth. Compress or bite through the sample one time with molars or incisors. Evaluate the sound intensity produced at the first bite. (None=*not crisp* to Much=*extremely crisp*)	Ripe Banana[2] 0.0 Granny Smith Apple 7.5 Carrot 15.0

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[1] Philadelphia cream cheese, cut into ½" cubes (Kraft, Chicago, IL); Egg White, jumbo eggs, boiled for 5 minutes, cut into ½" cubes; American cheese, cut into ½" cubes (Boars Head, Brooklyn, NY); Hebrew National beef frank, boiled for 5 minutes and cut into ½" slices (ConAgra Foods, Indianapolis, IN); Great Value queen olives, with pimentos removed (Walmart, Bentonville, AR); Planters peanuts, whole pieces (Kraft, Chicago, IL); Almonds were not used for this evaluation

[2] Ripe banana, cut into ½" cubes; Granny smith apple, peeled and cut into ½" cubes; Carrot, peeled and cut into ½" cubes

Table 1. Continued.

Moisture release	Amount of wetness or moistness felt in the mouth after one bite or chew.	Compress the sample with molars one time only. (Dry to Wet)	Banana[3] Carrot Mushroom Snap Beans Cucumber Apple Honeydew Orange (Chew refs 5 times)	1.0 2.0 4.0 7.0 8.0 10.0 12.0 15.0
Awareness of skins	How aware are you of the skins during mastication of the sample?	Place sample in mouth and chew 3-5 times. Can also be evaluated in first bite stage. (None=*cannot tell skins are there* to Much=*extremely aware of skins*)	Baked Beans[4] Medium Lima Beans Edamame	4.0 8.0 15.0
Detachability	Ease with which the pulp separates from the skin of the berries	Place the sample in the mouth. Compress or bite through the sample one time with molars or incisors. Evaluate the ease that the pulp separates from the skin. (None=*does not detach* to Much=*completely detaches*)	None=0.0 Much=15.0	
Fibrousness between teeth	Amount of grinding of fibers required to chew through the sample (not including skins)	Place sample between molars and chew 3-5 times. Evaluate during chewing, but ignore the skin. (None=*not fibrous at all* to Much=*extremely fibrous*)	Apple[5] Apricot Salami Celery Toasted Oats Bacon Beef Jerky	2.0 5.0 7.0 9.0 10.0 12.0 20.0

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[3] Ripe banana, cut into ½" cubes; Carrot, peeled and cut into ½" cubes; Button mushrooms, destemmed and cut into ½" cubes; Snap beans were not used for this evaluation; Cucumber, peeled, deseeded, and cut into ½" cubes; Pink lady apple, peeled and cut into ½" cubes; Honeydew, peeled and cut into ½" cubes; Dole mandarin orange piece (Dole Foods, Westlake Village, CA)

[4] Bush's baked beans (Bush Brothers and Company, Knoxville, TN); Medium lima beans; Edamame in pods

[5] Pink lady apple, peeled and cut into ½" cubes; Mariani apricots, sliced in half (Mariani, Vacaville, CA); Hard salami, cut into ½" cubes (Boars Head, Brooklyn, NY); Celery, cut into ½" pieces; Oats, toasted for 5 minutes at 350 F; Bacon and beef jerky were not used for this evaluation

Table 1. Continued.

Seed separation	The ease with which the seeds separate from the pulp of the berry	Manipulate the pulp in the mouth for ease to separate seeds from pulp. (None=*hard to separate seeds from pulp* to Much=*seeds easily separate from pulp*)	None=0.0 Much=15.0

Table 2. Analysis of variance for descriptive sensory attributes of seven muscadine cultivars harvested at Clarksville, AR in 2019 and 2020.

SOV	Awareness of Skins			Crispness			Detachability			Fibrousness			Hardness		
	DF	MS		DF	MS		DF	MS		DF	MS		DF	MS	
Year	1	1.96		1	4.28		1	7.30		1	51.12		1	0.00	
Rep	2	3.45		2	6.12		2	1.46		2	0.01		2	0.94	
Genotype	6	19.83	†	6	18.50	*	6	81.11		6	32.17		6	9.08	†
G*Y	6	5.81	†	6	3.00		6	57.93	**	6	30.46	**	6	2.59	**
Panelist(Year)	13	19.52	**	13	37.45	**	13	31.39	**	13	18.72	**	13	12.48	**
G*Panelist(Year)	78	2.85	†	78	3.40		78	7.77	**	78	4.40	**	78	0.71	
Residual	145	2.09		145	3.43		145	2.07		145	1.59		145	1.00	

†, *, **, Significant at 0.10, 0.05, and 0.01 probability levels, respectively.

Table 2. Continued.

SOV	Moisture Release			Seed Number			Seed Separation			Seed Size			Visual Separation		
	DF	MS		DF	MS		DF	MS		DF	MS		DF	MS	
Year	1	0.15		1	448.45		1	207.89		1	91.48		1	12.84	
Rep	2	1.18		2	1.84		2	5.61		2	4.87		2	1.15	
Genotype	6	8.57	**	6	18.20		6	120.26		6	5.80		6	165.29	**
G*Y	6	0.69		6	11.88	**	6	43.08	**	6	9.86	**	6	8.68	
Panelist(Year)	13	10.92	**	13	17.96	**	13	77.88	**	13	14.33	**	13	36.95	**
G*Panelist(Year)	78	2.23	*	78	1.96		78	12.20	†	78	1.67		78	8.91	**
Residual	145	1.52		145	2.21		145	8.98		145	1.48		145	5.52	

†, *, **, Significant at 0.10, 0.05, and 0.01 probability levels, respectively.

Table 3. Analysis of variance for TA.XT texture analysis for seven muscadine genotypes collected from Clarksville, AR in 2019 and 2020

TA.XT Attachment	Attribute Measured	Year MS (DF=1)	Genotype MS (DF=6)		G*Y (DF=6)		Error MS	Error DF
7.62cm cylinder	Work to Rupture	72815	31382	*	5548.88	*	2363.04	195
	Work to 50% Strain	194226	82833	*	15048.47	**	2438.11	195
	Elasticity	88	36	†	10.67	**	2.83	195
	% Strain to Rupture	751	179		150.09	*	52.30	195
	Max Force	2849	2001	**	236.05		132.82	195
	Distance Traveled	25	53	**	1.17	**	0.36	195
	Rupture Force	1692	1547	**	181.27		137.61	195
8mm probe	Flesh Firmness	0	4	†	0.93	**	0.15	196
	Total Work	204	14	**	1.32		0.74	196
45° chisel	Work to Rupture	28333	31844	*	5185.05	**	1286.97	196
	Work to 50% Strain	13967	42626	**	3514.58	*	1466.78	196
	Elasticity	72	59	†	15.18	**	2.46	196
	% Strain to Rupture	767	250		231.05	**	45.24	196
	Max Force	281	1360	*	199.92	**	47.27	196
	Distance Traveled	509	46	**	1.46	*	0.61	196
	Rupture Force	323	1321	*	216.56	**	50.36	196
Kramer Shear Cell	Cycle 1: Work	3801597	2493720	**	229863.68		124061.62	27
	Cycle 1: Max Force	168	4407		1599.14		1003.41	28
2mm probe	Work to Rupture	1376	969	**	21.03		38.15	196
	Elasticity	17	22	**	1.13		0.83	196
	Rupture Force	10	37	**	3.51		2.41	196
	Skin Work	5	24	*	3.43	**	1.02	196
	Skin Thickness	0	1	*	0.10		0.15	196
	Skin Hardness	3812	315	*	42.73	**	12.41	196

†, *, **, Significant at 0.10, 0.05, and 0.01 probability levels, respectively.

Table 4. Least square means of breeders' ratings for grape genotypes across 2019 and 2020.

	Overall	Flesh	Skin
	---------------------------0-9 scale---------------------------		
AM-135	7.17 A	6.33 A	7.17 A
AM-195	6.83 A	5.83 AB	7.00 A
AM-9	4.67 B	4.83 AB	4.50 BC
Carlos	2.33 C	2.50 C	2.83 CD
Ison	5.00 B	4.50 B	5.33 AB
NC67A015	2.50 C	2.50 C	2.33 D
Tara	5.50 AB	5.00 AB	5.33 AB
Red Globe	8.67	7.83	9.00

Letter groupings assigned using Fisher's LSD for $p < 0.05$. 'Red Globe' excluded from post-ANOVA mean separations due to expected bias.

Table 5. Least square means of descriptive sensory attributes for grape genotypes across 2019 and 2020.

	Texture Attributes							Visual Attributes		
	Awareness of Skins	Crispness	Detachability	Fibrousness	Hardness	Moisture Release	Seed Separation	Visual Separation	Seed Size	Seed Number
	---------------------------0-15 scale---------------------------							-0-15 scale-	------mm------	-----#-----
AM-135	11.99 C	6.73 AB	9.98 ns	4.92 ns	6.75 ABC	11.91 AB	10.99 ns	9.38 B	3.82 ns	4.72 ns
AM-195	12.19 BC	7.35 A	9.82 ns	4.63 ns	7.20 AB	11.54 ABC	10.74 ns	8.24 B	3.88 ns	3.79 ns
AM-9	13.65 A	7.18 A	13.16 ns	4.54 ns	7.57 A	12.02 A	10.62 ns	12.90 A	4.56 ns	4.57 ns
Carlos	13.52 AB	5.37 C	12.72 ns	6.16 ns	6.22 C	11.03 C	9.24 ns	13.07 A	4.38 ns	6.09 ns
Ison	13.72 A	6.62 AB	13.07 ns	5.53 ns	6.60 BC	11.85 ABC	8.24 ns	13.09 A	4.87 ns	5.41 ns
NC67A015	13.68 A	5.88 BC	13.28 ns	6.95 ns	6.21 C	11.09 BC	5.98 ns	13.71 A	4.24 ns	4.61 ns
Tara	13.37 AB	6.05 BC	12.17 ns	4.44 ns	6.50 B	12.35 A	10.58 ns	13.02 A	3.91 ns	4.87 ns
Red Globe	4.51	2.84	5.22	2.43	4.20	11.26	11.53	3.69	3.76	3.78

Letter groupings assigned using Fisher's LSD for $p < 0.05$. 'Red Globe' excluded from post-ANOVA mean separations due to expected bias.

Table 6. Least square means of TA.XT texture attributes for grape genotypes across 2019 and 2020.

	7.62cm cylinder probe														Kramer Shear Cell			
	Work to Rupture		Total Work		Elasticity		Distance Traveled		Peak Force		Rupture Force		Percent Strain to Rupture		Cycle 1: Total Work		Cycle 1: Peak Force	
	mJ				mm				N				%		mJ		N	
AM-135	88.17	BC	145.87	A	7.91	AB	12.18	B	32.21	AB	27.52	BC	32.77	ns	3370.64	AB	203.76	ns
AM-195	93.02	B	188.02	A	7.69	AB	12.66	AB	35.60	A	28.29	BC	30.63	ns	3325.37	AB	208.57	ns
AM-9	148.25	A	171.21	A	9.65	A	13.11	A	40.08	A	39.08	A	37.11	ns	3832.55	A	222.39	ns
Carlos	45.55	C	45.50	C	6.57	B	10.16	C	17.23	C	17.23	D	32.70	ns	1917.56	C	154.44	ns
Ison	100.22	B	125.29	AB	8.14	AB	12.37	B	31.60	AB	30.57	AB	33.23	ns	3217.28	AB	220.60	ns
NC67A015	61.47	BC	63.33	BC	7.04	B	9.76	C	21.26	C	21.21	CD	36.45	ns	2273.57	C	163.43	ns
Tara	91.29	BC	130.02	AB	9.16	A	12.77	AB	24.57	BC	22.36	BCD	36.28	ns	3095.18	B	206.38	ns
Red Globe	66.10		81.52		10.17		11.06		18.86		13.66		47.36	ns	1098.47		61.88	

Letter groupings assigned using Fisher's LSD for $p < 0.05$. 'Red Globe' omitted from post-ANOVA mean separations due to expected bias. Means from 45° chisel probe omitted due to high correlation with 7.62cm cylinder probe.

Table 6. Continued.

	8mm probe				2mm probe											
	Peak Force		Total Work		Work to Rupture		Total Work (Skin)		Elasticity		Skin Thickness		Rupture Force		Peak Force (Skin)	
	N		mJ		mJ				mm				N			
AM-135	1.81	AB	3.46	B	17.33	C	5.74	BC	6.04	C	1.37	AB	6.82	D	25.42	BCD
AM-195	2.09	A	4.22	A	25.56	B	4.63	C	6.30	C	1.30	ABC	9.38	AB	21.30	D
AM-9	1.39	BC	2.87	BC	27.32	B	6.05	B	7.12	B	1.44	A	9.36	AB	27.19	ABC
Carlos	1.03	C	2.10	D	33.18	A	6.52	AB	8.11	A	1.13	BC	9.61	AB	28.73	AB
Ison	1.29	BC	2.78	BCD	24.48	B	5.89	B	7.01	B	1.41	A	8.66	BC	27.91	ABC
NC67A015	1.24	BC	2.51	CD	34.03	A	7.50	A	8.38	A	1.12	C	10.02	A	31.15	A
Tara	1.45	BC	3.07	BC	24.73	B	5.39	BC	7.28	B	1.44	A	8.02	C	24.12	CD
Red Globe	1.73		3.58		6.32		0.92		6.82		0.82		2.46		7.47	

Letter groupings assigned using Fisher's LSD for $p < 0.05$. 'Red Globe' omitted from post-ANOVA mean separations due to expected bias. Means from 45° chisel probe omitted due to high correlation with 7.62cm cylinder probe.

Table 7. Pearson correlations (r scores) of sensory attributes (columns only), breeders' ratings (columns and rows), and TA.XT attributes (rows only) for seven muscadine genotypes and 'Red Globe' in 2019 and 2020.

Attachment	Method	Breeders' Rating (whole)	Breeders' Rating (flesh)	Breeders' Rating (skin)	Awareness of Skin	Crispness	Detachability	Fibrousness	Hardness	Moisture Release	Seed Separation	Visual Separation
N/A	Breeders' Rating (whole)	1.00	0.99 *	0.99 *	-0.73 *	-0.27	-0.86 *	-0.63	-0.31	-0.07	0.77 *	-0.88 *
	Breeders' Rating (flesh)	0.99 *	1.00 *	0.98 *	-0.76 *	-0.30	-0.85 *	-0.63	-0.31	-0.09	0.80 *	-0.87 *
	Breeders' Rating (skin)	0.99 *	0.98 *	1.00 *	-0.76 *	-0.31	-0.88 *	-0.56	-0.35	-0.13	0.77 *	-0.90 *
2mm probe	Work to Rupture	-0.92 *	-0.94 *	-0.93 *	0.87 *	0.57	0.90 *	0.52	0.57	0.24	-0.67 *	0.85 *
	Elasticity	-0.86 *	-0.83 *	-0.85 *	0.33	-0.22	0.53	0.52	-0.16	-0.18	-0.73 *	0.66
	Rupture Force	-0.79 *	-0.81 *	-0.81 *	0.94 *	0.77 *	0.90 *	0.38	0.77 *	0.38	-0.57	0.79 *
	Skin: Work	-0.83 *	-0.85 *	-0.86 *	0.94 *	0.68 *	0.94 *	0.38	0.65	0.41	-0.67 *	0.89 *
	Skin: Thickness	-0.17	-0.18	-0.22	0.77 *	0.88 *	0.63	-0.15	0.78 *	0.90 *	0.02	0.55
	Skin: Peak Force	-0.83 *	-0.84 *	-0.85 *	0.95 *	0.70 *	0.96 *	0.38	0.67 *	0.45	-0.66	0.90 *
7.62cm cylinder	Total Work	0.47	0.46	0.42	0.18	0.68 *	-0.01	-0.55	0.65	0.53	0.50	-0.19
	Work to Rupture	0.19	0.25	0.13	0.26	0.58	0.24	-0.51	0.65	0.57	0.31	0.12
	Elasticity	0.65	0.72 *	0.61	-0.57	-0.34	-0.51	-0.65	-0.29	0.13	0.61	-0.43
	Percent Rupture	0.41	0.48	0.40	-0.82 *	-0.84 *	-0.64	-0.35	-0.75 *	-0.45	0.24	-0.48
	Peak Force	0.23	0.24	0.18	0.35	0.78 *	0.23	-0.44	0.82 *	0.50	0.27	0.01
	Distance Traveled	0.47	0.48	0.43	0.15	0.54	0.00	-0.52	0.49	0.70 *	0.59	-0.09
	Rupture Force	-0.05	-0.02	-0.10	0.54	0.83 *	0.50	-0.31	0.88 *	0.57	0.06	0.30
8mm probe	Peak Force	0.83 *	0.79 *	0.81 *	-0.45	0.10	-0.66	-0.57	0.06	-0.06	0.62	-0.79 *
	Total Work	0.86 *	0.82 *	0.84 *	-0.47	0.07	-0.68 *	-0.62	0.02	-0.02	0.63	-0.79 *
Kramer Shear Cell	Cycle 1: Total Work	-0.03	-0.04	-0.09	0.67 *	0.93 *	0.52	-0.29	0.88 *	0.78 *	0.10	0.37
	Cycle 1: Peak Force	-0.26	-0.29	-0.31	0.84 *	0.96 *	0.70 *	-0.09	0.87 *	0.81 *	-0.11	0.57

* Indicates significance at $p < 0.05$

APPENDICES

Appendix A. Analysis of variance 25 unique TA.XT attributes measured with 5 attachments in 2019 and 2020.

TA.XT Attachment		2019			2020		
		MS	Err MS		MS	Err MS	
7.62cm cylinder	Work to Rupture	29748.84	2877.85	*	7138.16	1853.48	*
	Total Work	78709.75	2987.96	*	18885.17	1893.86	*
	Elasticity	33.18	2.53	*	13.03	3.13	*
	% Rupture	234.45	44.48	*	92.98	60.03	
	Peak Force	1648.43	166.76	*	581.97	99.22	*
	Distance Traveled	32.85	0.30	*	20.87	0.43	*
	Rupture Force	1223.45	164.01	*	501.94	111.47	*
8mm probe	Peak Force	3.98	0.15	*	0.87	0.15	*
	Total Work	7.75	0.32	*	7.66	1.16	*
45° chisel	Work to Rupture	23141.71	1357.13	*	13887.14	1216.82	*
	Total Work	26782.81	1309.12	*	19357.38	1624.43	*
	Elasticity	49.24	1.45	*	24.98	3.47	*
	% Rupture	222.93	25.94	*	258.44	64.54	*
	Peak Force	791.62	46.81	*	768.35	47.72	*
	Distance Traveled	29.09	0.67	*	17.90	0.54	*
	Rupture Force	776.64	49.35	*	761.34	51.38	*
Kramer Shear Cell	Cycle 1: Work	1164513.20	87460.14	*	1673855.88	158048.71	*
	Cycle 1: Peak Force	3080.44	650.30	*	2926.01	1356.52	
2mm probe	Work to Rupture	494.68	28.69	*	495.68	47.61	*
	Total Work	495.06	28.68	*	495.63	47.56	*
	Elasticity	12.57	0.56	*	10.79	1.11	*
	Rupture Force	16.57	1.37	*	23.55	3.44	*
	Skin: Work	12.05	0.78	*	15.61	1.25	*
	Skin: Thickness	0.41	0.05	*	0.27	0.25	
	Skin: Peak Force	254.61	20.68	*	102.94	4.13	*

* Significant at $p < 0.05$

Appendix B (a). Analysis of variance of sensory descriptive texture attributes among seven muscadine breeding lines and cultivars grown in Clarksville, AR in 2019.

SOV	Awareness of Skins			Crispness			Detachability			Fibrousness			Hardness		
	DF	MS		DF	MS		DF	MS		DF	MS		DF	MS	
Rep	1	0.21		1	0.08		1	0.11		1	0.56		1	0.45	
Genotype	6	7.08	**	6	10.18	**	6	129.75	**	6	6.58	**	6	5.32	**
Panelist	8	16.64	**	8	18.86	**	8	34.23	**	8	5.62	**	8	11.28	**
Genotype*Panelist	48	1.58	**	48	2.97	*	48	10.37	**	48	1.12	†	48	0.43	
Residual	62	0.59		62	1.87		62	2.85		62	0.79		62	1.19	

†, *, **, Significant at 0.10, 0.05, and 0.01 probability levels, respectively.

Appendix B (a). Continued

SOV	Moisture Release			Seed Number			Seed Separation			Seed Size			Visual Separation		
	DF	MS		DF	MS		DF	MS		DF	MS		DF	MS	
Rep	1	0.59		1	1.58		1	0.20		1	9.01		1	0.00	
Genotype	6	4.30		6	3.36	**	6	32.61	*	6	11.68	**	6	112.70	**
Panelist	8	10.34	**	8	1.38	*	8	81.64	**	8	22.60	**	8	46.73	**
Genotype*Panelist	48	2.24		48	0.57		48	10.44		48	1.82		48	10.22	
Residual	62	1.79		62	0.56		62	9.94		62	2.44		62	7.63	

†, *, **, Significant at 0.10, 0.05, and 0.01 probability levels, respectively.

Appendix B (b). Analysis of variance of sensory descriptive texture attributes among seven muscadine breeding lines and cultivars grown in Clarksville, AR in 2020

SOV	Awareness of Skins			Crispness			Detachability			Fibrousness			Hardness		
	DF	MS		DF	MS		DF	MS		DF	MS		DF	MS	
Rep	2	3.69		2	6.21		2	1.49		2	0.49		2	0.90	
Genotype	6	18.86	**	6	11.36	*	6	6.29		6	57.30	**	6	6.38	**
Panelist	5	24.13	**	5	67.20	**	5	26.83	**	5	39.68	**	5	14.40	**
Genotype*Panelist	30	4.88	†	30	4.09		30	3.62	**	30	9.63	**	30	1.16	
Residual	82	3.24		82	4.65		82	1.50		82	2.20		82	0.87	

†, *, **, Significant at 0.10, 0.05, and 0.01 probability levels, respectively.

Appendix B (b). Continued

SOV	Moisture Release			Seed Number			Seed Separation			Seed Size			Visual Separation		
	DF	MS		DF	MS		DF	MS		DF	MS		DF	MS	
Rep	2	3.82		2	1.05		2	8.13		2	0.88		2	2.86	
Genotype	6	4.98	†	6	27.31	**	6	133.23	**	6	3.78	*	6	60.07	**
Panelist	5	11.85	**	5	44.48	**	5	71.87	**	5	1.09		5	21.31	*
Genotype*Panelist	30	2.20	*	30	4.17		30	15.01	*	30	1.44	*	30	6.82	*
Residual	82	1.25		82	3.48		82	8.30		82	0.76		82	3.96	

†, *, **, Significant at 0.10, 0.05, and 0.01 probability levels, respectively.