Instrumental Textural Analysis of Muscadine Grape Germplasm

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Abstract. Twenty-six muscadine grape (*Vitis rotundifolia* Michx.) cultivars and selections were evaluated for a range of skin and flesh texture attributes. Two *Vitis vinifera* L. and one *Vitis labruscana* Bailey table grape cultivars were included for comparison. Penetration tests using a flat cylindrical probe were used to assess whole berry texture. Ideal whole berry texture is firm and easily broken down during mastication, which was measured as small berry deformation at first peak and berry maximum force, respectively. Muscadine berry deformation at first peak ranged from 4.35 to 7.82 mm and berry maximum force ranged from 5.7 to 13.9 N. *V. vinifera* table grape berries were firmer (3.14 to 3.19 mm berry deformation at first peak) and more tender (4.0 to 4.9 N berry maximum force) than muscadine berries. Berry penetration work was strongly correlated with both berry deformation at first peak and berry maximum force and ranged from 13.0 to 54.1 mJ in the muscadine germplasm. Penetration tests of muscadine berry flesh revealed a range of flesh firmness from very soft (0.65 N) to firm (3.06 N) but none was as firm as the *V. vinifera* berry flesh (3.9 N). Penetration tests of muscadine berry skins revealed newer selections bred for table use had relatively tender skins with a skin break force of 12.1 N, which was not different from *V. vinifera* samples. Berry penetration work and flesh maximum force were determined to be the most useful characteristics for routine screening of breeding program material.

The genus *Vitis* L. contains two subgenera, *Euvitis* Planch. (bunch grapes) and *Muscadinia* Planch. (muscadine grapes). The muscadine grape is the only commonly cultivated member of the *Muscadinia* subgenus. Muscadines are native to the southern United States and have been cultivated for over 400 years (Lane, 1997). Muscadines grow in regions where winter temperatures remain above –12 °C. The muscadine grape differs from the familiar bunch grape (*Vitis labrusca* L., *V. vinifera*, and their various hybrids) by the presence of smaller clusters, unbranched tendrils, and berries with thick skins and a unique fruity aroma. In addition, muscadine berries often abscise from the cluster when ripe and are picked as single berries and sold in plastic containers much like other berries.

Although they enjoy popularity within their region of adaptation, muscadine grapes are not well known outside of the southeastern United States. To increase consumption of fresh market muscadines, they need to be successfully introduced to consumers unfamiliar with the fruit.

Consumer acceptance of muscadine fruit has likely been hampered by the relatively tough skins and soft flesh of muscadine berries. These traits are especially pronounced in comparison with *V. vinifera* table grapes, which have been selected for their tender skins and a crisp pulp. Consumers in the southern United States are less troubled by these attributes and either discard the skins or consume the skins of

the more tender-skinned cultivars. However, to successfully market muscadines to consumers only familiar with *V. vinifera* table grapes, new muscadine cultivars with textural attributes more akin to *V. vinifera* table grapes will likely need to be developed.

Texture is one of the most important quality characteristics of fresh-market grapes (Sato et al., 1997). Texture includes all physical characteristics sensed by touch, which are related to deformation under applied force, and can be measured objectively in terms of force, distance, and time (Letaief et al., 2008). Sensory attributes such as skin friability, skin thickness, and flesh firmness have been proposed to characterize commercial table grape cultivars (Cliffet et al., 1996). Recently, mechanical investigation into grape texture has been recommended to replace sensory panel studies because mechanical tests can be conducted under controlled laboratory conditions making them more stable than sensory tests and easier to carry out (Rolle et al., 2011). The mechanically measured variables most often used to define texture are force and deformation (distance), and various machines have been designed to carry out these tests (Sato and Yamada, 2003). Berry texture characteristics are most commonly investigated through the use of a universal testing machine that produces force deformation curves (Rolle et al., 2012).

A crisp pulp is particularly desired among consumers of table grapes, and this trait is often associated by consumers with freshness of the product. Crispness may be defined as the sensual experience of eating a food item that fails in a brittle manner under a relatively low force (Vincent, 2004). This is in contrast to “jelly,” which has low work to fracture

(brittle) but is so soft that it deforms a long way before fracture, and “tough,” which has higher work to fracture but is soft and deforms easily. The difficulty in mastication of *V. labruscana* grape flesh may contribute to its comparatively small consumption as a table grape in comparison with *V. vinifera* (Bourne, 1979). Sato et al. (1997) showed differences in grape berry texture as measured by flesh puncture tests using a texture analyzer. Difficulty of mastication of the flesh in sensory tests was found to be highly correlated to deformation at first peak (distance traveled by the probe between contact with the sample and first breakdown of the sample). Flesh firmness in the sensory test was best described by the maximum force reached before sample breakdown. *V. vinifera* cultivars with a crisp flesh had a small deformation at first peak and large maximum force. *V. labruscana* cultivars had a wide range of flesh textures varying from tough (large deformation at first peak and maximum force) to tender (small deformation at first peak and maximum force) (Sato et al., 1997). Further tests indicated that *V. vinifera* table grape cultivars had lower deformation at first peak and higher maximum force scores than did wine-use or dual-purpose cultivars (Sato and Yamada, 2003).

Textural analysis of the skins of grape berries has been done in both wine grape and table grape *V. vinifera* cultivars (Rolle et al., 2012). Berry skin break force and energy can be used to differentiate wine grape varieties (Giacosa et al., 2012; Rio Segade et al., 2008). Rolle et al. (2011) found that the textural profile attributes of hardness, gumminess, and chewiness were best described by skin break force, skin break energy, and modulus of elasticity in white table grape cultivars. Skin break force was particularly useful in differentiating among *V. vinifera* table grape cultivars and ranged from 0.329 N to 0.585 N (Rolle et al., 2012). Ideal grape skins will be highly friable but with sufficient toughness to protect the berry from pathogens, harvest damage, and splitting and cracking on the vine. Puncture tests have also been shown to be helpful in predicting the anthocyanin extractability of grape skins in ‘Nebbiolo’ and ‘Brachetto’ berries (Rolle et al., 2008).

Textural analysis of muscadine grapes has been limited. Walker et al. (2001) used a flat 2-mm cylindrical probe to penetrate unpeeled ‘Fry’ muscadine berry halves to evaluate fruit firmness in different berry maturity classes and during storage. Firmness was found to decline with increasing maturity and storage times. Development of improved texture in muscadine grapes has been hampered by the lack of a standardized protocol for textural analysis. Our objectives were to express muscadine grape texture by instrumental analysis and to evaluate berry texture in a wide range of muscadine germplasm.

Materials and Methods

Plant material. Muscadine and the *V. labruscana* cultivar Blue Lake berries were

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sampled in 2012 from vines grown at the University of Georgia (UGA)–Tifton Campus located in Tift County, GA. (lat. 33°53'7.69" N, long. 83°25'20.30" W). Muscadine clones used in this work were a mixture of historical and new cultivars, as well as advanced selections from the UGA breeding program and represented a wide range of skin and flesh texture and a mixture of table and juice germplasm. All vines were trained to a single wire trellis with two cordons per vine and spaced 3 m between plants within the row and 4.5 m between rows. Vines were irrigated through a single line with a 3.6-L·h⁻¹ drip emitter located 30 cm from each side of the vine. Diseases and insects were controlled according to commercial guidelines (Poling et al., 2003). All muscadine and the 'Blue Lake' samples were collected at their ripening time by removing entire clusters by hand from vines. To avoid creating detachment tears, berries were separated from bunches by cutting the stems so that the pedicel remained attached to the berry. Samples were brought indoors to equilibrate to room temperature (22 °C). 'Sugraone' and 'Midnight Beauty' *V. vinifera* berries were purchased from a local supermarket.

Muscadine berries were density-sorted by floating them in sodium chloride brine solutions of 8% to 11% (Lanier and Morris, 1979). Fruit was placed into 8% brine and berries that floated were removed, rinsed with tap water, dried, and designated as density grade 1. This procedure was repeated with 9%, 10%, and 11% brine to give density grades 2, 3, and 4, respectively. The effect of density grade on texture characteristics was investigated using all four density grades of 'Triumph' muscadine berries, but all other experiments only used density grade 2 berries.

Textural analysis. An Universal Testing Machine TaxT2i Texture Analyzer (Stable Micro System, Godalming, Surrey, U.K.) equipped with a 25-kg load cell was used. Sample size was 20 berries for each clone examined. Force and distance values were read directly from the electronic keyboard controlling the analyzer. Probe type and speed and trigger set points for each test are indicated in Table 1. Tests were carried out on the harvest day for all samples except for *V. vinifera* samples, which were tested on the day of purchase.

The shape and size of the probe greatly influences the results of a texture analysis (Rolle et al., 2012). Berry puncture tests have been conducted using needle (Letaief et al., 2008), rounded (Maury et al., 2009), or cylindrical (Walker et al., 2001) probes. Needle

probes are typically used to decrease the effect of flesh texture and provide an estimate of skin hardness. Initial testing with a needle probe produced much less variation between muscadine genotypes than could be achieved with a cylindrical probe (data not shown). Because we were more concerned with overall texture of the grape, rather than just skin hardness, a flat cylindrical probe was used for all subsequent tests.

Whole berry penetration tests measuring berry deformation at first peak and berry maximum force were conducted by placing single berries on an aluminum stage with a 1-cm conical depression to stabilize the berry. Penetrations were made on the equatorial plane of the berry. The probe speed was 1 mm·sec⁻¹ until the probe made contact with the berry surface triggering the probe set point. Thereafter, the probe continued downward at 1 mm·sec⁻¹ for 9 mm, which was the minimum distance that allowed the probe to break the skin of the largest berries. Once the skin breaks, the analyzer records the distance traveled from first contact to the break point (berry deformation at first peak) and the maximum force achieved (berry maximum force). Berry penetration work is expressed as the area under the curve from zero to berry maximum force and is estimated as the triangular area: (berry deformation at first peak × berry maximum force)/2 (Sato et al., 1997).

Flesh texture measurements have been conducted by puncturing slices of flesh (Sato et al., 1997) and by removing the berry skin and puncturing the flesh on the whole berry (Rolle et al., 2012). As a result of the gelatinous nature of the pulp of many muscadine samples, it was not practical to remove slices of the flesh. Flesh texture was examined by carefully removing the skin of the berry on the equatorial plane of the berry with a razor blade revealing a 1-cm circular area of flesh. Berries were placed onto the aluminum stage with the probe centered above the flesh opening. The machine was set to record the maximum force (flesh maximum force) encountered from the time the probe contacted the flesh surface until it had traveled 3 mm. Probe distance traveled was short enough that no contact was made between the probe and the seeds.

Skin texture was examined by removing an ≈1-cm² section of skin from the berry at the equatorial plane. Adhering flesh was carefully removed using a razor blade and the skin was placed, with the epidermis facing upward toward the probe, on a 1-mm thick polypropylene stage into which a 6-mm hole had been drilled. The hole in the stage was centered directly below the probe so that the probe

could break through the berry skin and continue downward through the hole. The skin was manually anchored to the polypropylene stage during the test. Skin break force was the maximum force achieved as the probe traveled downward for 5 mm, punching a hole through the skin.

Other analysis. Brix was measured for each berry after textural analysis. Berry juice was collected and Brix was determined using a digital refractometer (PAL-1; Spectrum Technologies Inc., Plainfield, IL). Berry firmness was determined using a separate sample of 20 berries with a FirmTech2 fruit firmness tester (BioWorks Inc., Wamego, KS). The FirmTech2 compresses individual fruit with a load cell, and firmness is estimated by the slope of the force-deformation curve produced between the minimum and maximum force applied (Timm et al., 1996). The minimum force was set at 50 g and maximum force was set at 350 g and the amount of pressure in grams required to compress fruit by 1 mm is determined from the resulting force-deformation curve.

Statistical analysis. Berry, flesh, and skin texture characteristics and berry firmness and soluble solids content were examined using analysis of variance and means were separated with Fisher's protected least significant difference test ($P < 0.05$). Associations among texture characteristics, skin diameter, berry firmness, and cultivar release year of muscadine cultivars were determined using Pearson product moment correlation coefficients of the mean values of cultivars. Statistical analysis was performed using SigmaPlot 12.3 statistical software.

Results and Discussion

'Triumph' berries were density-separated into four grades using a sodium chloride solution. The fifth grade was not used because berries in this grade were clearly overripe, noticeably soft, and had begun to deteriorate. Soluble solids content provides a good marker for berry maturation and was highest in grade 4, medium level in grade 3, and at similar levels in grades 1 and 2 (Table 2). Overall soluble solids content of the various grades were similar to those found by Walker et al. (2001) in density-separated 'Fry' berries. No differences were found among density-graded fruit for berry deformation at first peak, berry penetration work, or flesh maximum force (Table 2). Berry maximum force was significantly lower in density grade 4 as compared with the less mature density grades. Walker et al. (2001) also found berry maximum force to decline with increasing density grade of 'Fry' muscadine berries. Skin break force declined from density grade 1 to grades 2 and 3 and then increased to similar levels in density grade 4. It is unclear why skin break force increased in density grade 4, especially considering berry maximum force declined in this grade, suggesting a more tender skin. However, when using a flat cylinder plunger, force values are a combination of compression (flesh under the plunger) and shearing values, which may explain some of

Table 1. Operational parameters for the TaxT2i textural analyzer used to perform the muscadine berry textural analysis.

Test	Probe type	Test speed (mm·sec ⁻¹)	Probe trigger point (N)	Probe end point (mm)
Berry deformation at first peak	2-mm flat cylinder	1	0.07	9
Berry maximum force	2-mm flat cylinder	1	0.07	9
Flesh maximum force	5-mm flat cylinder	0.5	0.07	3
Skin break force	5-mm flat cylinder	0.5	0.07	5

the variance observed. From veraison to ripeness, an increase was seen in berry skin hardness and thickness in *V. vinifera* Nebbiolo grapes with a steady value or slight decrease close to maturity (Rolle et al., 2012). Other tests have found that grape skin is more influenced by terrior than the ripeness level of the grape (Maury et al., 2009). Taken together, these data seem to indicate that overall grape ripeness plays an inconsistent and perhaps minor role in grape skin texture, at least until grapes begin to soften with senescence.

Maturity levels of muscadine grapes found in commercial shipments varies among years with density grades 1 to 3 being the most common (Walker et al., 2001). Although muscadines in large commercial vineyards are often picked relatively immature so that

berries have acceptable firmness to the retailer, we found density grade 1 ‘Triumph’ berries were noticeably hard and immature and were not considered acceptable for consumption. Density grades 2 and 3 did not differ from each other in any textural characteristics, and density grade 2 was chosen for further experimentation because the majority of harvested fruit fell into this grade.

There was a large amount of variation for most texture characteristics both within the muscadine germplasm examined and between muscadine and the *Euvitis* cultivars (Table 3). Table 3 indicates the release or selection year of each of the muscadine cultivars and includes three cultivars that were selected from native vines. These dates provide insight into how muscadine textural attributes have

changed with several decades of breeding. Product use of muscadine cultivars has also evolved over time. Most early cultivars could probably be best labeled as dual-use cultivars in that the same cultivars were processed for juice as were used for fresh consumption. Cultivars studied here released after 1970 generally represent table grape cultivars except for ‘Noble’ and ‘Carlos’, which are the leading muscadine juice cultivars. UGA breeding selections represent the most advanced of the germplasm studied and have been selected for tender skins and firm flesh. ‘Blue Lake’ was included as a *V. labruscana* reference, which has a slip skin and a gelatinous pulp. ‘Midnight Beauty’ and ‘Sugraone’ were included as *V. vinifera* table grape references with crisp flesh.

A nearly 2-fold difference was found in the muscadine germplasm for berry deformation at first peak, which ranged from 4.35 to 7.82 mm (Table 3). The three *Euvitis* cultivars had lower berry deformation at first peak values ranging from 2.85 to 3.19 mm. Much of the muscadine germplasm had nearly twice the berry deformation at first peak of the *V. vinifera* cultivars. Firm fruit with a tender skin will have a smaller berry deformation at first peak than will softer fruit or fruit with a tougher skin. Indeed, berry deformation at first peak was negatively correlated with flesh

Table 2. Effect of density grade of ‘Triumph’ muscadines on berry texture and soluble solids content.

Density grade ^a	Berry deformation at first peak (mm)	Berry maximum force (N)	Berry penetration work (mJ)	Flesh maximum force (N)	Skin break force (N)	Soluble solids (%)
1	6.50	10.7 a ^b	35.1	1.92	19.1 a	13.5 a
2	6.87	10.7 a	37.1	1.84	17.0 b	13.9 a
3	6.59	10.3 a	34.2	2.08	16.1 b	15.8 b
4	6.78	9.6 b	33.0	1.94	19.0 a	17.8 c
Significance	NS	<i>P</i> < 0.001	NS	NS	<i>P</i> < 0.001	<i>P</i> < 0.001

^a1, 2, 3, 4, float in 8, 9, 10, and 11% brine, respectively.

^bMeans within a column separated by analysis of variance with mean separation by Fisher’s protected least significant difference, *P* < 0.05.

NS = nonsignificant.

Table 3. Berry texture attributes of grape cultivars and selections.

Clone	Species	Release year ^a	Berry deformation at first peak (mm)	Berry maximum force (N)	Berry penetration work (mJ)	Flesh maximum force (N)	Skin break force (N)	Berry firmness (g·mm ⁻¹)
Flowers	<i>V. rotundifolia</i>	WS	4.99	10.9	27.2	1.16	19.0	—
Scuppermong	<i>V. rotundifolia</i>	WS	6.92	12.0	41.5	0.65	38.2	261
Thomas	<i>V. rotundifolia</i>	WS	5.30	10.4	27.6	0.81	21.3	—
Yuga	<i>V. rotundifolia</i>	1934	6.04	9.6	29.0	0.75	15.2	—
Dawn	<i>V. rotundifolia</i>	1938	6.04	10.6	32.0	0.85	16.2	—
Albermarle	<i>V. rotundifolia</i>	1962	6.14	12.9	39.4	0.93	26.9	340
Southland	<i>V. rotundifolia</i>	1967	6.50	13.3	43.1	1.36	27.8	302
Cowart	<i>V. rotundifolia</i>	1968	7.23	12.4	44.6	0.86	17.6	275
Carlos	<i>V. rotundifolia</i>	1970	6.81	10.9	37.1	0.74	28.2	—
Fry	<i>V. rotundifolia</i>	1970	5.89	11.8	35.2	1.16	23.1	377
Noble	<i>V. rotundifolia</i>	1973	5.03	9.8	24.5	1.19	26.0	332
Triumph	<i>V. rotundifolia</i>	1980	6.90	10.7	36.7	1.88	18.1	352
Granny Val	<i>V. rotundifolia</i>	1983	6.08	11.7	35.9	1.11	23.3	356
Nesbitt	<i>V. rotundifolia</i>	1985	6.79	13.9	47.2	1.00	21.7	280
Supreme	<i>V. rotundifolia</i>	1988	6.45	11.3	35.3	1.44	18.7	307
Late Fry	<i>V. rotundifolia</i>	1993	7.82	13.8	54.1	1.65	23.6	297
Scarlett	<i>V. rotundifolia</i>	1997	5.92	11.7	34.6	1.20	14.6	—
Ga. 15-19-2	<i>V. rotundifolia</i>	1998	5.03	10.5	26.5	2.33	12.1	—
Ga. 1-1-48	<i>V. rotundifolia</i>	2004	5.93	9.2	27.6	1.24	12.5	360
Ga. 4-3-147	<i>V. rotundifolia</i>	2007	5.40	9.7	26.5	1.51	13.0	—
Ga. 6-2-101	<i>V. rotundifolia</i>	2008	6.62	10.3	34.2	1.89	17.6	313
Ga. 6-2-192	<i>V. rotundifolia</i>	2008	5.89	8.0	23.7	1.27	15.6	344
Ga. 6-2-46	<i>V. rotundifolia</i>	2008	5.85	8.3	24.3	1.46	15.6	331
Lane	<i>V. rotundifolia</i>	2011	4.35	9.5	20.6	3.06	14.8	402
Ga. 10-1-269	<i>V. rotundifolia</i>	2012	4.39	5.7	13.0	1.62	14.6	278
Ga. 10-1-3	<i>V. rotundifolia</i>	2012	4.60	7.6	17.8	2.44	14.5	—
Ga. 10-1-633	<i>V. rotundifolia</i>	2012	4.72	7.8	18.5	2.63	14.8	—
Blue Lake	<i>V. labruscana</i>	1960	2.85	3.2	4.6	0.99	8.9	—
Midnight Beauty	<i>V. vinifera</i>	1998	3.14	4.0	6.3	3.90	10.3	188
Sugraone	<i>V. vinifera</i>	1972	3.19	4.9	7.9	3.96	9.5	190
Significance			<i>P</i> < 0.001	<i>P</i> < 0.001	<i>P</i> < 0.001	<i>P</i> < 0.001	<i>P</i> < 0.001	<i>P</i> < 0.001
Fisher’s protected least significant difference			0.51	0.79	3.81	0.36	6.6	41.1
<i>V. rotundifolia</i> minimum			4.35	5.7	13.0	0.65	12.1	261
<i>V. rotundifolia</i> maximum			7.82	13.9	54.1	3.06	38.2	402

^aYear the clone was released as a cultivar. Dates in bold indicate unreleased selections where the year is the year the selection was made.

WS = wild selection.

maximum force and positively correlated with skin break force (Table 4).

Berry maximum force ranged from 5.7 to 13.9 N in the muscadine germplasm. This parameter was positively correlated with the skin break force (Table 4) as expected. However, berry maximum force was also negatively correlated with flesh maximum force, indicating that a firmer underlying flesh does not measurably increase the force required to penetrate the berry and may instead facilitate the ability of the probe to break the skin. Alternatively, firmer flesh may be associated with more friable skin in this germplasm. Regardless of the cause, the result is encouraging because there does not seem to be an impediment to developing cultivars with both firmer flesh and more tender skins. The lowest berry maximum force was found among seedlings of progeny Ga. 10-1, which is a cross of 'Supreme' to a UGA

selection with a friable skin and firm flesh. *Eu vitis* cultivars all had lower berry maximum force values than muscadine germplasm, and most advanced muscadine selections had nearly twice the berry maximum force as the *V. vinifera* cultivars (Table 3).

Berry penetration work is calculated using the measured values of berry deformation at first peak and berry maximum force and is therefore highly correlated with both of these characteristics (Table 4). Berry penetration work was also positively correlated with skin break force and negatively correlated with flesh maximum force. The highest values for berry penetration work were found in muscadine cultivars like 'Late Fry', 'Nesbitt', 'Scuppernong', and 'Coward' that are known for their tough skins and soft pulps (Table 3). Berry penetration work had more than a 4-fold range of variation among muscadine germplasm varying from 13.0 to 54.1 mJ.

Eu vitis cultivars had approximately half the berry penetration work of the lowest berry penetration work of the muscadine germplasm, and 'Blue Lake' had less than one-tenth the berry penetration work of the highest muscadine.

A firm crisp flesh is an important characteristic in the consumer acceptance of *V. vinifera* table grapes. Traditional muscadine cultivars have a soft gelatinous pulp with a slip skin that is more similar to *V. labruscana* grapes. Newer muscadine cultivars have tended to have a more firm flesh with more of a plum-like flesh texture. Flesh maximum force varied from 0.65 to 3.06 N in the muscadine germplasm (Table 3). Flesh maximum force was highest in the cultivar Lane, which was selected for its firm flesh texture (Conner, 2013). The smallest flesh maximum force occurred in 'Scuppernong' and 'Thomas', cultivars which originated as wild selections. 'Blue Lake' had a very soft pulp and a flesh maximum force of 0.99 N, whereas the *V. vinifera* cultivars had firmer flesh, ≈ 3.9 N, than all of the muscadine germplasm. A firmer berry flesh will prevent the probe from traveling as far before the skin breaks, leading to lower values of berry deformation at first peak, berry maximum force, and berry penetration work, all of which are negatively correlated with flesh maximum force (Table 4). Flesh maximum force was also negatively correlated with skin break force. It is not clear why firm flesh would lead to lower skin break force values, but it may be attributable in part

Table 4. Correlations among muscadine berry texture characteristics (texture analyzer) and berry firmness (FirmTech2).

	Berry deformation at first peak	Berry maximum force	Berry penetration work	Flesh maximum force	Skin break force
Berry maximum force	0.717**				
Berry penetration work	0.909**	0.931**			
Flesh maximum force	-0.509**	-0.412*	-0.466*		
Skin break force	0.455**	0.562**	0.570**	-0.502**	
Berry firmness	NS	NS	NS	0.504*	NS

Significant at * $P \leq 0.05$, ** $P \leq 0.01$.

NS = nonsignificant.

Fig. 1. Flesh maximum force (N) vs. berry penetration work (mJ) for muscadine and *Eu vitis* germplasm. Data points represent the average of 20 berries measured for each trait.

to the presence of several clones specifically selected to combine friable skins and firm flesh.

Sections of berry skins were excised from the berries to measure the skin break force without having the variation of the underlying flesh. Skin break force varied over 3-fold in the muscadine germplasm ranging from 12.1 to 38.2 N. The highest values for skin break force occurred in the wild selection 'Scuppermong' and in the juice cultivars Carlos and Noble. The popular fresh-market cultivar Fry also had a relatively high skin break force, leading many consumers to eat only the pulp of this and other muscadine cultivars and discard the skins. *Euvitis* cultivars had skin break force values of ≈ 9 to 10 N, which was not different from the lowest skin break force that occurred in muscadine germplasm. Thus, if flesh maximum force can be increased in muscadine germplasm and paired with already occurring low skin break force, the resultant berry might approach *V. vinifera* table grapes in palatability of berry texture.

Berry firmness was measured by a Firm-Tech2 machine, which approximates the firmness that would be felt when squeezing berries between the thumb and index finger and is a quick, non-destructive measure of berry quality (Rodriguez et al., 2011). Berry firmness in muscadine germplasm varied from 261 to 402 g·mm⁻¹ (Table 3). Berry firmness in *V. vinifera* cultivars was ≈ 190 g·mm⁻¹, but measured berries had been stored an unknown amount of time before purchase and likely lost some firmness during this time period. Berry firmness was positively correlated with flesh maximum force (Table 4) supporting the idea that selecting for a firmer flesh will produce a firmer feeling berry, which is more desirable in the marketplace.

The muscadine germplasm evaluated displayed a wide range of variation for the textural characteristics studied. Breeding programs will need to measure a large number of selections to select the most desirable phenotypes, so measurement protocols need to be as efficient as possible. Skin break force requires a large amount of sample manipulation to remove the flesh from the skin and was

both time-consuming and somewhat subjective because firm flesh samples lack a clear delineation between flesh and skin. For these reasons, skin break force was ruled out for routine germplasm screening and replaced with berry penetration work, which is highly correlated with both berry deformation at first peak and berry maximum force. Berry penetration work also showed good separation both within the muscadine germplasm and between the *Euvitis* and muscadine samples. The second characteristic chosen was flesh maximum force. This characteristic is useful in separating samples with soft flesh from those with firm flesh as was indicated by the wide separation between the *V. labruscana* and *V. vinifera* samples and was positively correlated with berry firmness.

Plotting berry penetration work and flesh maximum force provides a good means of visually classifying the muscadine germplasm (Fig. 1). Muscadine clones ranged from those with tough skins and soft pulps such as 'Scuppermong', 'Carlos', 'Nesbitt', and 'Southland' to those with more tender skins and firmer pulps such as 'Lane', Ga. 10-1-633, Ga. 10-1-3, and Ga. 15-19-2. Continued selection in breeding programs for friable skins and firm flesh should increase consumer acceptance of muscadines, but sensory analysis and tasting panels should be conducted to validate these assumptions.

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