HortScience 49(10):1315–1323. 2014.

# Effect of Field Fungicide Applications on Storability, Physicochemical, and Nutraceutical Content of Muscadine Grape (*Vitis rotundifolia* Michx.) Genotypes

**Derek W. Barchenger[1] and John R. Clark**
*316 Plant Science, Department of Horticulture, University of Arkansas, Fayetteville, AR 72703*

**Renee T. Threlfall, Luke R. Howard, and Cindi R. Brownmiller**
*2650 N. Young Avenue, Institute of Food Science and Engineering, University of Arkansas, Fayetteville, AR 72704*

*Additional index words.* antioxidants, fresh-market grapes, muscadine, nutraceuticals, storage

***Abstract.*** **A major limiting factor in fresh-market muscadine grape (*Vitis rotundifolia* Michx.) commercialization is fruit deterioration during storage. Research on table grapes has shown that field fungicide applications increase storability, but little is known of their effect on muscadines. The effect of field applications of fungicides on physicochemical attributes during postharvest storage and nutraceutical content at date of harvest was evaluated on five muscadine cultivars (Nesbitt, Southern Jewel, Summit, Supreme, and Tara) and four breeding selections from the University of Arkansas Fruit Breeding Program in 2012 and 2013. There were two field treatments (no fungicide and fungicide). For the fungicide treatment, alternating applications of two fungicides were applied to the vine at 14-day intervals during berry maturation. Fruit was harvested and physicochemical attributes including berry volume, titratable acidity (TA), pH, soluble solids (%), color (L, chroma, and hue), firmness (force to penetrate berry skins and flesh), storage weight loss (%), and unmarketable fruit (%) were evaluated every 7 days for 3 weeks. Whole muscadine berries were analyzed for nutraceutical content only for the date of harvest. As a result of less decay, less weight loss, and greater firmness during storage, AM 27, 'Southern Jewel', and 'Supreme' had the highest potential for postharvest storage, whereas AM 01, AM 15, and 'Tara' had the least potential. Nutraceutical content varied by genotypes; overall AM 27 had the highest nutraceutical content [sum of anthocyanins, total phenolics, flavonols, resveratrol, and oxygen radical absorbane capacity (ORAC)], whereas 'Supreme' and AM 28 had the lowest. Total anthocyanins were only found in the black genotypes and total phenolics and resveratrol were unaffected by fungicide treatment. Total ellagitannins varied among the fungicide treatments. Total flavonols were generally greater in the no fungicide treatments, whereas ORAC was generally greater with fungicide treatments. Year of study and genotype were determined to be major contributors as sources of variation. Although field fungicide applications did not affect all postharvest attributes and nutraceutical components, differences among genotypes and fungicide treatments did occur.**

Native to the southeastern United States, the muscadine grape (*Vitis rotundifolia* Michx.) is commonly grown for its unique flavor, high nutraceutical content, and pest and disease resistance, which is often a limiting factor in the production of bunch grapes (*Vitis* spp.) (Conner, 2009; Silva et al., 1994; Striegler et al., 2005; Walker et al., 2001). This native grape is currently grown in small commercial vineyards and home plantings, ranging from North Carolina and Florida to eastern Oklahoma and Texas. The recent recognition that the muscadine berries are important sources of beneficial antioxidants has increased consumer demand (Perkins-Veazie et al., 2012; Striegler et al., 2005). Additionally, alternative crops, including muscadines, are being explored by growers in the South as a means of increasing profits or diversifying farm operations (Conner, 2009). Three of the major limiting factors on fresh-market production of muscadines are uneven ripening, short harvest season, and high perishability of the fruit (James et al., 1999; Morris, 1980; Perkins-Veazie et al., 2012).

Many variables contribute to muscadine storability, including berry maturity, texture (crispness), weight loss, decay, shriveling, browning, leakage, and amount of dry stem scars. Muscadines harvested at physiologically ripe maturity have been shown to successfully store for 2 to 3 weeks (Perkins-Veazie et al., 2012; Takeda et al., 1982). To maintain adequate quality, muscadines should be stored from 1 to 5 °C with 85% to 95% relative humidity (RH) (Lutz, 1938; Silva et al., 1994; Takeda et al., 1983; Walker et al., 2001). The use of sulfur dioxide storage treatment on the quality of bunch grapes is cultivar-specific and with muscadines not reliably beneficial (Ballinger and Nesbitt, 1982a, 1982b; Conner and Maclean, 2012; James et al., 1997, 1999; Lane, 1978; Lane and Flora, 1980; MacLean et al., 2009; Morris et al., 1992; Smit et al., 1971).

Although it is well known that fungicide applications benefit other fruits and vegetables, including other *Vitis* species, little is known about the effect of field fungicide applications on storability and nutraceutical content of muscadines (Smith, 2013). It has been shown that field fungicide applications improved the shelf life of 'Doreen', 'Hunt', 'Magnolia', 'Nevermiss', and 'Summit' muscadine grapes, but 'Cowart' was unaffected (Lane, 1978; Smith and Magee, 2002). Additionally, fungicide pre-storage treatment was ineffective in managing decay during storage, although microbial spoilage was the major factor contributing to postharvest deterioration (Takeda et al., 1982). Field fungicide applications have been shown to increase resveratrol concentrations in *V. vinifera* wine grapes but reduce resveratrol concentrations in muscadines (Jeandet et al., 1995; Magee et al., 2002). The effects of field fungicide applications on other nutraceutical compounds in muscadines are unknown.

Muscadine grapes contain phenolic acids, flavonols, anthocyanins, ellagic acid, and numerous ellagic-acid derivatives (Boyle and Hsu, 1990; Huang et al., 2009; Lee et al., 2005; Pastrana-Bonilla et al., 2003; Stringer et al., 2009; Talcott and Lee, 2002). Ellagic acid and other antioxidants have been shown to demonstrate anticarcinogenic activity in the colon, lungs, and liver as well as a reduction of birth defects in rats and mice and two forms of colon cancer in humans (Ector, 2001; Yi et al., 2005). Polyphenolic concentrations usually increase in muscadines as fruit ripens (Lee et al., 2005) and are higher in wine than in unfermented juices extracted from berries with identical fruit pressing procedures (Musingo et al., 2001; Talcott and Lee, 2002). Research has shown that muscadine grapes possess one of the highest antioxidant levels among fruit crops (Greenspan et al., 2005). Some of these components of muscadines have been shown to have anticancer, antimutagen, and anti-inflammatory properties and to reduce levels of glucose, insulin, and glycated hemoglobin in people with diabetes (Banini et al., 2006; Bralley et al., 2007; God et al., 2007; Greenspan et al., 2005; Yi et al., 2005).

Since the implementation of a muscadine breeding program at the University of

Received for publication 5 June 2014. Accepted for publication 1 July 2014.

[1]To whom reprint requests should be addressed; e-mail dwbarche@nmsu.edu.

Arkansas in 2005, selections have been made based on flower type, fruit size, time of ripening, hardiness, improved texture, and dry stem scar. Although increased crispiness and a greater percentage of dry stem scars have been observed, it is unknown whether there has been a true improvement in postharvest quality of muscadines. Nutraceutical levels in muscadines vary among genotypes (breeding selections and cultivars) (Marshall et al., 2012), but no information has been collected on the nutraceutical content of the University of Arkansas breeding selections.

The objectives of this study were to determine the effect of field applications of fungicides on the storage performance, physicochemical attributes, and nutraceutical concentrations of muscadine grapes and to develop a postharvest evaluation protocol for Arkansas muscadine genotypes for potential commercial use.

## Materials and Methods

Vines of nine muscadine genotypes used for the study were grown at the University of Arkansas Fruit Research Station, Clarksville, AR (lat. 35°31′58″ N and long. 93°24′12″ W). Vines were of varying ages within each genotype, most of the cultivars were ≈6 years old, whereas many of the selections were from younger vines 3 to 4 years old. The vines were grown in Linker fine sandy loam, in USDA hardiness zone 7a, where average annual minimum temperatures reach –15 to 17.7 °C. Vines were spaced 6.1 m apart and rows were spaced 3.0 m apart. A single-wire trellis was used, and vines were trained to a bilateral cordon. The vines were dormant-pruned annually in February using spur pruning with spurs retained of two to four buds in length. Weeds were controlled with pre- and post-emergence herbicides as needed, and vines did not have any stress from weed competition. Vines were irrigated by drip irrigation as needed, beginning in early June (prior months received adequate rainfall) and continuing through the harvest period. Vines received nitrogen fertilization in March of each year at a rate of ≈70 kg·ha$^{-1}$. No insecticides or other pest control compounds were applied to the vines other than those vines that received the fungicide treatments. The vines used in the study had full crops produced each year, and no crop reduction resulting from winter injury or other limitation occurred. Thus, the vines produced fruit under representative conditions. Daily maximum and minimum temperatures along with rainfall were recorded at the research location to characterize the environment the vines were subjected to and potential differences among years.

The vines of nine muscadine cultivars and selections were used for fungicide treatments. Each genotype had a single vine treated with fungicide, whereas the other did not receive fungicide applications (berries from the fungicide-treated vines were referred to as fungicide-treated berries and berries from the no fungicide-treated vines were referred to as no fungicide-treated berries). A rotation of systemic field fungicide applications of Abound® [azoxystrobin: methyl (*E*)-2-{2-[6-(2-cyanophenoxy) pyrimidin-4-yloxy] phenyl}-3-methoxyacrylate*] (Syngenta, Basel, Switzerland) and Rally® [myclobutanil: a-butyl-a-(4-chlorophenyl)-1H-1,2,4,triazole-1-propanenitrile] (Dow AgroSciences, Indianapolis, IN) (a sterol inhibitor) were applied with a backpack sprayer every 14 d beginning when the fruit was ≈3 to 5 mm in diameter and after ≈400 growing degree units were accumulated beginning 1 Jan.

The muscadines were once-over hand-harvested. Harvest date/maturity was based on soluble solids (SS) of 18% to 22% in 2012 and 15% to 18% in 2013 (as a result of differences in summer temperature and precipitation), ease of release from the pedicel, and berry color. Both fungicide-treated and non-fungicide-treated vines within the same genotype were harvested on the same day. Fruit was harvested either early in the morning or late in the afternoon and transported to the University of Arkansas Institute of Food Science and Engineering, Fayetteville, AR, in an air-conditioned car on the same day. The fruit was stored at 2 °C on arrival.

Berries were then hand-sorted to remove any split, shriveled, or decayed fruit before packaging to simulate commercial standards. Only sound berries, showing no signs of unmarketability, were used for this study. The fruit was packaged into hinged standard vented clamshells (18.4 cm × 12.1 cm × 8.9 cm) (H116; FormTex Plastics Corporation, Houston, TX) and placed in cold storage at 2 °C with 85% to 89% RH. From the randomly selected fruit from each vine, six vented clamshell containers were filled to ≈500 g.

Three of these clamshells were used as storage replications for each treatment and genotype. Total clamshell weight was determined at date of harvest, and percent weight loss was calculated as percent weight decrease from this initial value. Weight loss and percent unmarketable fruit were evaluated on the storage clamshells every 7 d for up to 21 d. Storage performance was evaluated by removing all the fruit from each clamshell and counting the number of fruit that showed signs of unmarketability, which included individual or a combination of characteristics of browning, softness, mold, rot, leakage, splitting, and shriveling (Conner, 2013; Conner and Maclean, 2012; Perkins-Veazie et al., 2012). Both the unmarketable and marketable berries were returned to the appropriate clamshell each week, and storage measurements were discontinued once the percent unmarketable in all three clamshells reached 50% or after 3 weeks of storage. Each week during storage, berries exhibiting fungal growth were sent to the University of Arkansas Cooperative Extension Service Plant Health Clinic, Fayetteville, AR, for disease diagnostics. Reports from the Clinic were provided on the fungal species isolated.

The remaining three clamshells were used as replications for physicochemical analyses. For physicochemical measurements, every 7 d three berries were removed from each of the three clamshells and used to measure berry volume, chroma, hue, L*, SS, TA, pH, and firmness of the skin and flesh. Physicochemical measurements were discontinued once the percent unmarketable in all three clamshells reached 50% or after 3 weeks of storage.

The physicochemical procedures used were modeled from previously reported protocols (Conner, 2013; Conner and Maclean, 2012; Striegler et al., 2005; Threlfall et al., 2007; Walker et al., 2001).

Titratable acidity and pH were measured by an 877 Titrino Plus (Metrohm AG, Herisau Switzerland) with an automated titrimeter and electrode standardized to pH 2.0, 4.0, 7.0, and 10.0 buffers. Titratable acidity was determined using 6 g of juice diluted with 50 mL of deionized, degassed water by titration of 0.1 N sodium hydroxide to an endpoint of pH 8.2 with results expressed as percent tartaric acid. Soluble solids were measured using a Bausch and Lomb, Inc. Abbe Mark II refractometer (Rochester, NY). Soluble solids, TA, and pH were measured from the juice of the whole berries strained through cheesecloth to remove any solids.

Exterior skin color measurements were determined on each of the three berries every 7 d using a Chroma Meter CR 300 series (Konica Minolta Holdings Inc., Ramsey, NJ). The Commission Internationale de l'Eclairage Laboratory transmission "L*" value indicates how dark or light the skin is with 0 being black and 100 being white. Hue angle describes color in angles from 0° to 360°: 0° = red; 90° = yellow; 180° = green; 270° = blue; and 360° = back to red. Chroma is the aspect of color by which the skin color appears different from gray of the same lightness and corresponds to intensity of the perceived color.

Firmness, or the maximum force to penetrate skin and flesh tissues, was determined using the three whole berries per replication. A TA-XT2 Texture Analyzer (Stable Micro Systems, Haslemere, U.K.) with a 2-mm-diameter probe was used to penetrate the skin and mesocarp tissues (flesh) to a depth of 10 mm in each berry at a rate of 10 mm·s$^{-1}$. Measurements are expressed as force in Newtons (N), and the data were analyzed using Texture Expert Version 1.17 (Texture Technologies Corp., Scarsdale, NY).

Three randomly selected berries from each physicochemical replication of each treatment were used from the harvest date sample to measure nutraceuticals including ORAC and levels of total phenolics, total anthocyanins, total ellagitannins, total flavonols, and resveratrol by methods previously described in Cho et al. (2004, 2005), Hager et al. (2008), and Prior et al. (2003).

The storage experiment was designed as a split plot with three replications of each genotype and fungicide treatment. The split was storage (Weeks 0, 1, 2, and 3). The nutraceutical component was a complete randomized design with three replications of

each genotype and treatment (these measurements were only done on the harvest date, not during storage). As a result of differences in year, likely the result of extreme differences in weather, the data were analyzed separately for each year of the study. A single vine was used as an experimental unit.

The data were analyzed by analysis of variance (ANOVA) using JMP® (Version 11.0; SAS Institute Inc., Cary, NC). Tukey's honest significant difference and Student's *t* test were used for mean separations ($P$ = 0.05). Associations among all dependent variables were determined using multivariate pairwise correlation coefficients of the mean values using JMP (Version 11.0; SAS Institute Inc.).

## Results and Discussion

Substantial differences were observed in minimum and maximum temperatures as well as for precipitation among the years of the study (Table 1). During the growing and harvest seasons (April through September), differences of mean temperatures up to 5 °C warmer and approximately half as much precipitation were observed in 2012 compared with 2013 (Table 1). These extreme differences in weather among years of the study offered some important insight on the significance of environment on postharvest storage and composition of muscadine grapes.

The postharvest fruit diseases present were identified as black rot [*Guignardia* (*Phyllosticta*) *bidwellii* (*ampelicida*) Ellis.], myrothecium leaf spot (*Myrothecium* sp./spp.), and botrytis fruit rot (*Botrytis* sp./spp.), confirming previous reports by Lane (1978), Smit et al. (1971), and Takeda et al. (1983). Generally, fruit diseases were not a major cause of unmarketability for either fungicide or no fungicide treatments, until 3 weeks of storage. The primary factors involved in unmarketable fruit were browning (especially in bronze genotypes), leakage from torn or wet stem scars, and shriveling, which was consistent with similar work reported by Perkins-Veazie et al. (2012). Occasionally an unknown species of fruit fly (*Drosophila* sp.) was present, but only in fruit with wet or torn stem scars and did not contribute to unmarketable berries.

A major cause of unmarketability in the bronze berries was browning during storage (especially no fungicide-treated AM 01 in 2013) (Fig. 1), likely caused by chilling injury (CI). The abiotic disorder of CI is common in many horticultural crops, including bananas (*Musa* × *paradisiaca* L.), citrus (*Citrus* spp.), sweetpotatoes (*Ipomoea batatas* L.), and tomatoes (*Solanum lycopersicum* L.) (Wang, 1990). CI can increase susceptibility to decay by providing a favorable medium for the growth of pathogens (Wang, 1990). The primary symptom of CI identified in this study was brown discoloration of the skin, pulp, and vascular strands of fruit (Himelrick, 2003; Wang, 1990). Table grapes (*V. vinifera*) were successfully stored at –1 °C without showing symptoms of CI (Burg, 2004). However, CI has been reported in muscadines stored at or below 1.7 °C (Himelrick, 2003; Smittle, 1990) but is uncommon in muscadine grapes stored at 2 to 3 °C. It was unexpected to find possible symptoms of CI on the muscadine berries studied, because they were stored above the previously reported threshold of 1.7 °C (Himelrick, 2003; Smittle, 1990). This illustrates that CI susceptibility might be genotype-specific and creates the potential for opportunities of improvement through tolerance selection in breeding programs.

Leakage and shriveling are common problems in muscadines during storage and are managed by removing berries with wet stem scars before storage and maintaining high RH during storage (Perkins-Veazie et al., 2012; Smit et al., 1971). It has been shown that use of plastic film packaging of lemons (*Citrus limon* L.) and bell peppers (*Capsicum annuum* L.) prevents water loss, resulting in less leakage and shriveling (Ben-Yehoshua et al., 1983). Conversely, muscadines stored in polyethylene bags had less weight loss, but this did not prevent leakage and shriveling as a result of the juice retention of the bags (Walker et al., 2001).

The ANOVA for each year indicated a three-way interaction of fungicide treatment, genotype, and week of storage for percent unmarketable berries ($P < 0.0001$) and two-way interactions of genotype by fungicide treatment ($P < 0.0001$) and fungicide treatment by week of storage ($P$ = 0.0143 in 2012 and $P < 0.0001$ in 2013) for percent berry weight loss. As expected, both percent berry weight loss and percent unmarketable berries increased during storage and varied among genotypes (Figs. 1 and 2), and these results were consistent with other studies (Ballinger and Nesbitt, 1982a; James et al., 1997, 1999; Lutz, 1938; Silva et al., 1994; Takeda et al., 1983). Overall percent unmarketable berries were greater in 2013 (Fig. 1), whereas the percent weight loss was greater in 2012 (Fig. 2). These differences were potentially the result of the unusually hot and dry conditions of the 2012 growing season (Table 1), which resulted in less fungal growth on the berries but contributed to lower quality berries (leaked and shriveled). After 3 weeks of storage, AM 15 fungicide-treated berries in 2012 and 'Nesbitt' no fungicide-treated fruit in 2012 had the greatest weight loss (7.1% and 6.5%, respectively), whereas 'Nesbitt' and 'Southern Jewel' from all treatments in 2013 each had the least weight loss (2.2%) (Fig. 2). AM 01 no fungicide-treated berries in 2013 and 'Nesbitt' fungicide-treated fruit in 2012 had the greatest amount of unmarketable berries after 3 weeks of storage (94.9% and 81.7%, respectively), whereas AM 04 fungicide- and no fungicide-treated berries in 2013 and 'Summit' fungicide-treated berries in 2012 had the least amount of unmarketable berries after 3 weeks (12.6% and 14.5%, respectively) (Fig. 1). Overall, berries from fungicide treatments had less unmarketable berries, but treatment had much less effect on weight loss (Fig. 1), corroborating findings by Lane (1978).

Data for force to penetrate the berry skin and flesh also had a three-way interaction for fungicide treatment, genotype, and week of storage ($P < 0.0001$). Force to penetrate muscadine skin and flesh has been shown to be a useful characteristic to assess berry crispiness and texture as well as berry maturity (Conner, 2013); however, use of force to determine storability of muscadine grapes has shown results with no clear trend (Silva et al., 1994; Walker et al., 2001). It has been reported that muscadines require a force up to 13.9 N to penetrate the mesocarp at harvest, which is nearly twice that of *V. vinifera* cultivars (Conner, 2013). After 3 weeks of storage, fungicide- and no fungicide-treated berries of 'Tara' had the lowest force (3.2 and 3.3 N in 2012 and 5.45 and 4.8 N in 2013, respectively), whereas fungicide- and no fungicide-treated berries of AM 04 had the highest (7.8 and 7.7 N in 2012 and 9.8 and 9.5 N in 2013, respectively) (Fig. 3). Similar to the findings of Conner (2013), it was determined that 'Nesbitt' was among the most firm cultivars. Berries stored in 2013 were generally firmer than the berries stored in 2012 (Fig. 3), further showing the significance of environmental influences on storage quality with heat stress likely contributing to less firm berries. Generally, berry firmness

Table 1. Average monthly maximum and minimum temperatures (°C) and total precipitation (mm) recorded at the Fruit Research Station; Clarksville, AR (lat. 35°31′58″ N and long. 93°24′12″ W) (2012 and 2013).

| | Maximum temp (°C) | | Minimum temp (°C) | | Precipitation (mm) | |
|---|---|---|---|---|---|---|
| Month | 2012 | 2013 | 2012 | 2013 | 2012 | 2013 |
| January | 11.4 | 9.1 | 0.1 | –0.7 | 111.84 | 98.85 |
| February | 11.8 | 9.9 | 2.5 | –0.2 | 65.50 | 70.63 |
| March | 21.4 | 2.8 | 9.8 | 2.0 | 198.73 | 130.30 |
| April | 23.08 | 19.5 | 11.5 | 8.7 | 81.86 | 119.37 |
| May | 26.6 | 23.9 | 16.3 | 13.6 | 18.88 | 163.07 |
| June | 32.9 | 29.8 | 19.4 | 19.0 | 14.36 | 54.61 |
| July | 36.5 | 31.4 | 22.7 | 19.9 | 40.56 | 100.35 |
| August | 33.9 | 30.4 | 20.9 | 20.9 | 62.47 | 178.82 |
| September | 28.4 | 30.2 | 17.4 | 17.9 | 158.19 | 57.91 |
| October | 20.2 | 20.9 | 9.2 | 10.4 | 127.21 | 106.18 |
| November | 16.2 | 12.6 | 4.4 | 2.3 | 23.56 | 103.14 |
| December | 11.8 | 6.8 | 1.9 | –1.6 | 3.23 | 64.51 |

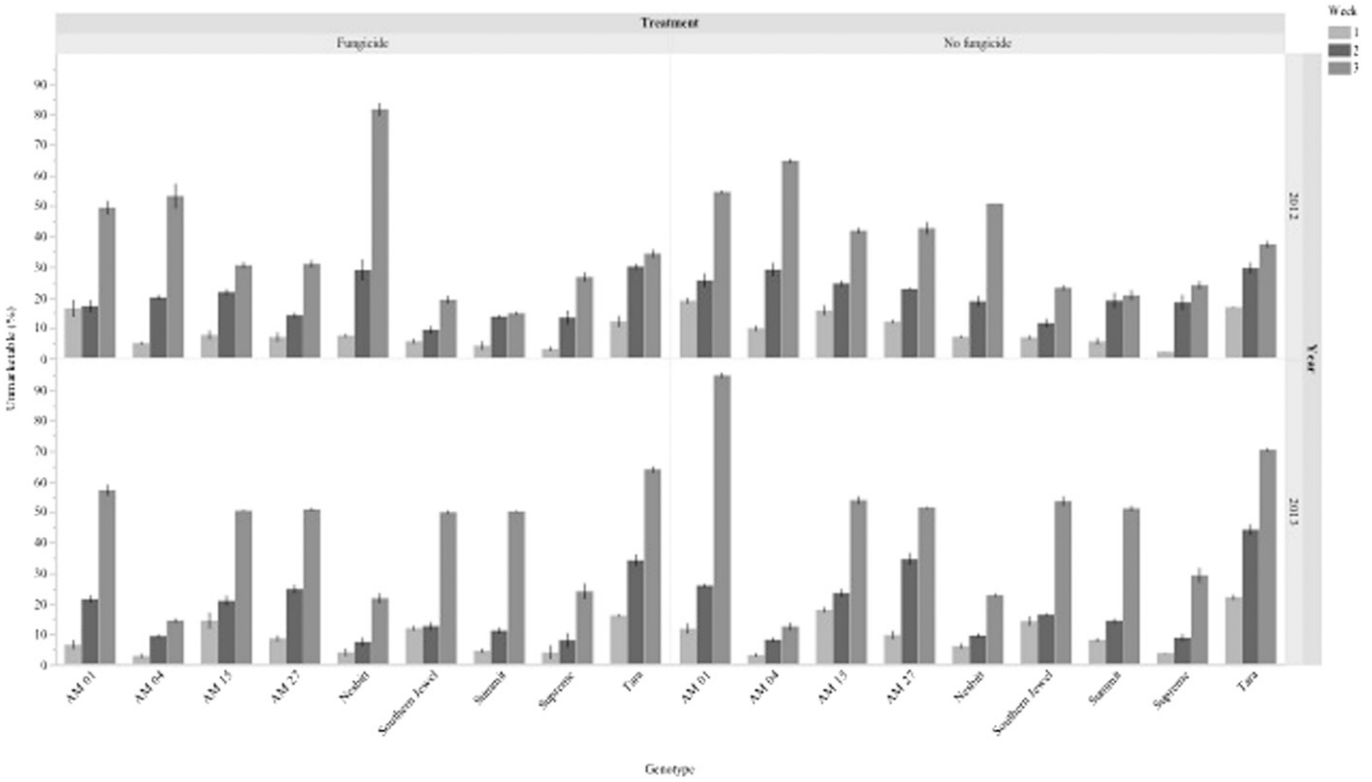


Fig. 1. Percent unmarketable of fungicide- and no fungicide-treated muscadine genotypes stored at 2 °C for 3 weeks in 2012 and 2013. Values at Week 0 (date of harvest) were excluded. Each SE bar was constructed using 1 SEM. The analysis of variance for each year indicated a three-way interaction of fungicide treatment, genotype, and week of storage for percent unmarketable berries ($P < 0.0001$). The bronze genotypes were AM 01, AM 15, 'Summit', and 'Tara', and the black genotypes were AM 04, AM 27, 'Nesbitt', 'Southern Jewel', and 'Supreme'.

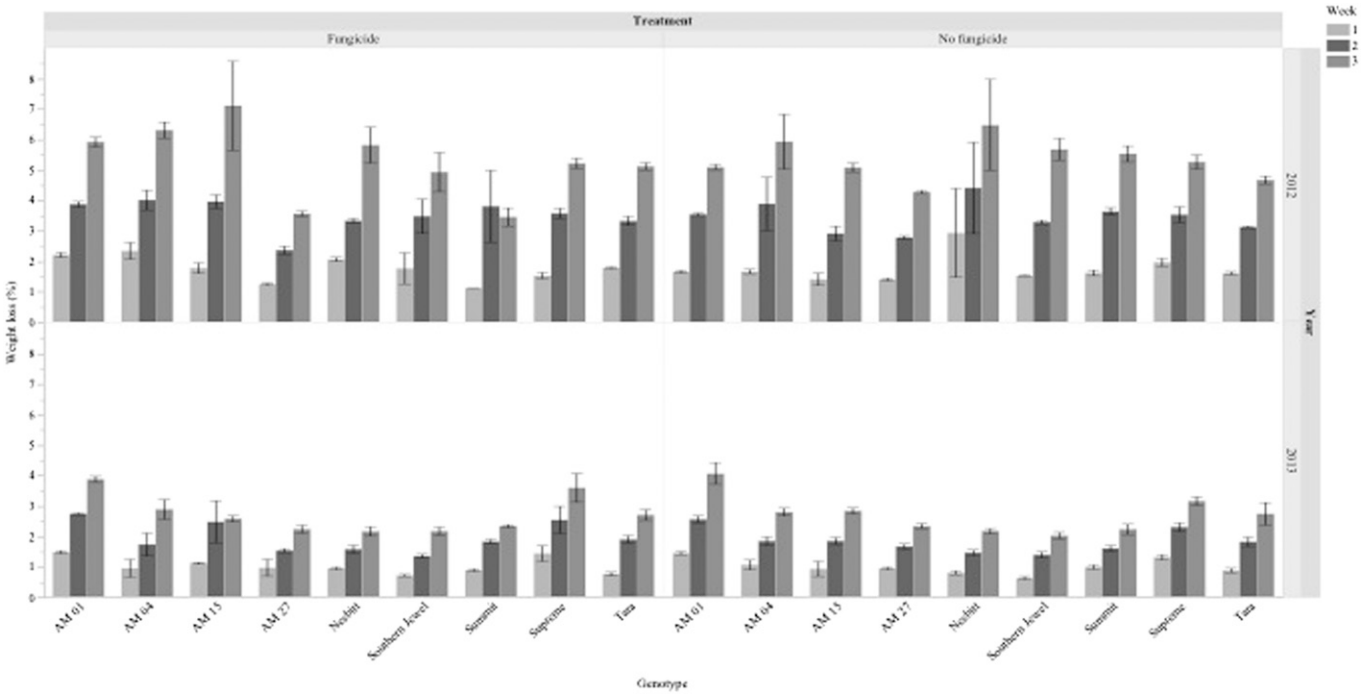


Fig. 2. Percent berry weight loss of fungicide- and no fungicide-treated muscadine genotypes stored at 2 °C for 3 weeks in 2012 and 2013. Values at Week 0 (date of harvest) were excluded. Each SE bar was constructed using 1 SEM. The analysis of variance indicated two-way interactions of genotype by fungicide treatment ($P < 0.0001$) and fungicide treatment by week of storage ($P = 0.0143$ in 2012 and $P < 0.0001$ in 2013) for percent berry weight loss. The bronze genotypes were AM 01, AM 15, 'Summit', and 'Tara', and the black genotypes were AM 04, AM 27, 'Nesbitt', 'Southern Jewel', and 'Supreme'.

decreased during storage but was occasionally lowest after 2 weeks of storage (Fig. 3). Similar results were reported by James et al. (1999) and may be attributed to water loss causing an increase of firmness at Week 3. The genotypes requiring the most force to penetrate the berry skin at harvest also required the most force to penetrate the berry skin after 3 weeks of storage (especially in

2013), showing force to be a strong indicator of storage performance (Fig. 3). Furthermore, force to penetrate the berry skin was negatively correlated with percent unmarketable berries ($r$ = –0.73), showing that as force decreased, percent unmarketable berries increased. Although fungicide-treated berries were often more firm (Fig. 3), genotype and year were much more influential on berry firmness.

The ANOVA for berry physicochemical attributes showed the main effect of genotype ($P < 0.0001$) each year of the study. Overall, berry physicochemical attributes were found not to significantly change during storage either year of the study (data not shown), and these findings were consistent with the results of other studies (James et al., 1997, 1999; Silva et al., 1994; Takeda et al., 1983; Walker et al., 2001). Interestingly, pH was largely the same among years of the study for most genotypes (Table 2). Conversely TA was higher in 2012 compared with 2013, which supports the findings of Jackson (1986), who found that high acidity levels in bunch grapes are often associated with warmer temperatures during the growing season. Similarly, SS was higher in 2012 compared with 2013 (Table 2); this was expected because the hotter and drier growing conditions in 2012 likely resulted in a concentrating of the sugars. The cultivar Supreme in 2013 had the highest TA (6.1%) and pH (3.93), whereas AM 15 and 'Southern Jewel' had the lowest TA (5.2) and pH (3.36) (Table 2). We found that pH was strongly correlated with TA ($r$ = 0.99) but was negatively correlated with total phenolics ($r$ = –0.70). Soluble solids ranged from

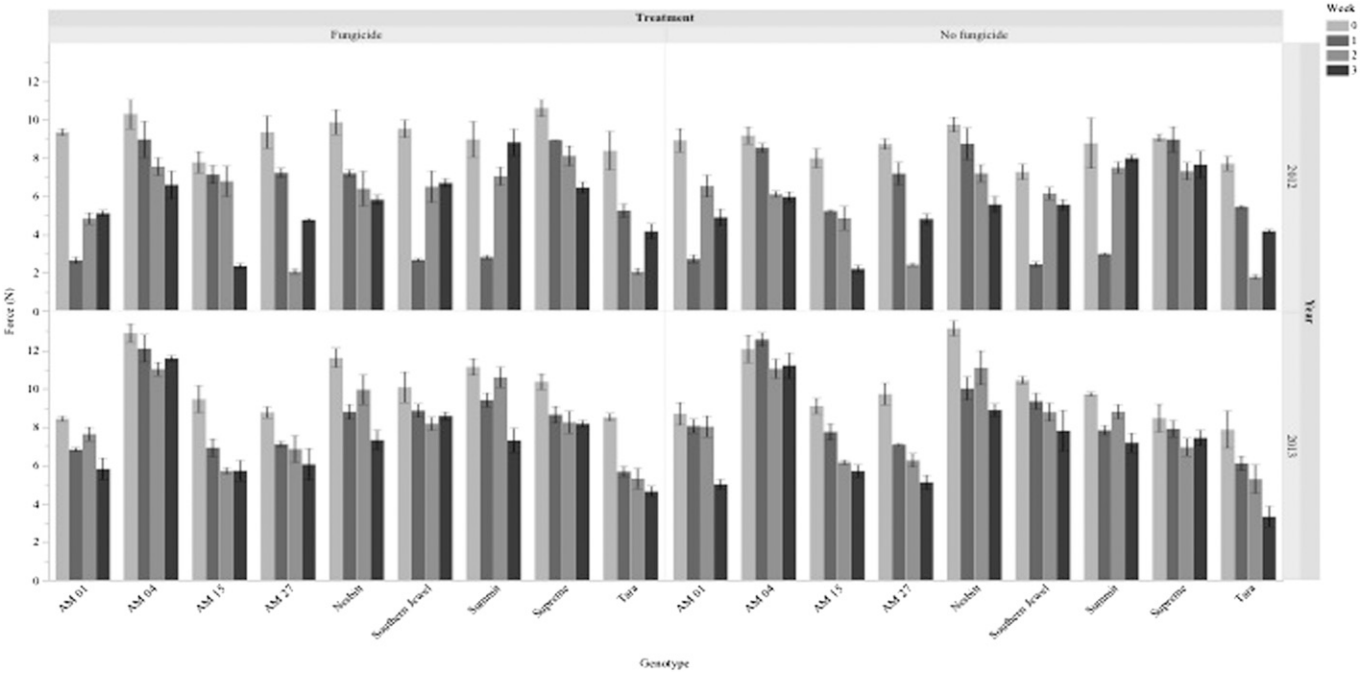


Fig. 3. Force to penetrate berry skin of fungicide- and no fungicide-treated muscadine genotypes stored at 2 °C for 3 weeks in 2012 and 2013. Each SE bar was constructed using 1 SEM. The analysis of variance indicated a three-way interaction for fungicide treatment, genotype, and week of storage ($P < 0.0001$). The bronze genotypes were AM 01, AM 15, 'Summit', and 'Tara', and the black genotypes were AM 04, AM 27, 'Nesbitt', 'Southern Jewel', and 'Supreme'.

Table 2. Physicochemical attributes of muscadine genotypes in 2012 and 2013.[z]

| Yr | Genotype | Berry color | Titratable acidity (%)[y] | pH | Soluble solids (%) | L* | Chroma | Hue |
|---|---|---|---|---|---|---|---|---|
| 2012 | AM 01 | Bronze | 0.57 ab[x] | 3.66 ab | 24.7 a | 41.6 b | 13.3 b | 73.8 d |
| | AM 15 | | 0.52 c | 3.36 c | 19.4 d | 41.6 b | 12.9 b | 54.9 d |
| | Summit | | 0.59 a | 3.76 a | 25.6 a | 39.3 c | 15.0 a | 53.0 d |
| | Tara | | 0.56 b | 3.59 b | 21.5 b | 43.7 a | 12.9 b | 80.4 d |
| | AM 04 | Black | 0.58 ab | 3.71 a | 19.7 d | 43.9 a | 3.3 d | 187.3 c |
| | AM 27 | | 0.53 c | 3.42 c | 19.4 d | 26.9 de | 2.5 d | 225.7 bc |
| | Nesbitt | | 0.58 ab | 3.68 ab | 20.8 bc | 26.8 e | 4.9 c | 277.7 b |
| | Southern Jewel | | 0.52 c | 3.36 c | 17.9 e | 28.0 d | 5.2 c | 219.3 bc |
| | Supreme | | 0.58 ab | 3.75 a | 20.1 cd | 27.7 de | 5.4 c | 359.1 a |
| | | | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 |
| 2013 | AM 01 | Bronze | 0.34 A | 3.55 DE | 17.7 ABC | 90.1 A | 4.9 D | 179.4 CD |
| | AM 15 | | 0.32 AB | 3.41 F | 17.1 BC | 51.6 B | 11.8 B | 111.2 DE |
| | Summit | | 0.23 CD | 3.69 BC | 17.0 BC | 40.9 D | 12.0 B | 88.6 E |
| | Tara | | 0.25 C | 3.73 BC | 17.1 BC | 43.6 C | 13.9 A | 92.8 E |
| | AM 04 | Black | 0.26 C | 3.75 BC | 16.6 C | 25.1 F | 3.3 EF | 258.6 AB |
| | AM 27 | | 0.30 B | 3.65 CD | 17.9 AB | 26.0 F | 2.0 F | 322.0 A |
| | Nesbitt | | 0.24 CD | 3.78 B | 16.5 C | 26.9 F | 3.8 DE | 240.7 BC |
| | Southern Jewel | | 0.30 B | 3.50 EF | 18.3 A | 34.5 E | 7.8 C | 292.4 AB |
| | Supreme | | 0.22 D | 3.93 A | 17.6 ABC | 26.5 F | 6.4 C | 266.4 AB |
| | | | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 |

[z]Date of harvest (Week 0) values averaged across fungicide treatments.
[y]Titratable acidity (%) expressed as tartaric acid.
[x]Means followed by the same letter (lowercase 2012 and uppercase 2013) are not significantly different at $\alpha = 0.05$, separated by Tukey's honestly significant difference.

17.9% ('Southern Jewel') to 25.6% ('Summit) in 2012 and from 16.5% ('Nesbitt') to 18.3% ('Southern Jewel') in 2013 (Table 2). The example of 'Southern Jewel' having the lowest SS in 2012 and the highest in 2013 further illustrates the significance of environment on SS (Tables 1 and 2). The effect of fungicide treatments on physicochemical attributes of muscadines is widely unstudied. Fungicide treatments were found to have no effect on TA, pH, or SS (data not shown), which is contrary to the findings of Smith (2013). The lack of differences in week, year, and fungicide treatment indicated that genotype was the greatest contributor as a source of variation for physicochemical attributes.

The ANOVA for berry color measurements indicated the main effect of genotype ($P < 0.0001$) each year of the study. The effect of storage time on L*, hue, and chroma values of fresh-market muscadine berries is widely unstudied, although it is well studied in juice and wine. We found no significant affect of storage time on berry color either year of the study. Additionally, the U.S. Department of Agriculture currently has no standards to grade muscadine berries on the color attributes of L*, chroma, and hue. Berry color measurements did not to change during storage (data not shown). Silva et al. (1994) found that L* values increased, or lightened, during storage, although the differences were not visibly discernable by panelists. Hue angle was generally greater for the black genotypes, whereas chroma values were generally highest for bronze genotypes with the exception of 'Southern Jewel' (Table 2), which is similar to the findings of Conner and MacLean (2013). AM 04 and 'Tara' had the highest L* values in 2012 (43.7 and 43.9, respectively), whereas 'Nesbitt' had the lowest (26.8), whereas in 2013, AM 01 had the highest L* value (90.1) and AM 04 had the lowest (25.1) (Table 2). The example of AM 04 illustrates the significance of environmental conditions on L* values with 2013 having overall lighter values (closer to 100) (Tables 1 and 2). Hue angle of the black genotypes ranged from 187.3° (AM 04) to 359.1° ('Supreme') in 2012 and from 240.7° ('Nesbitt') to 322.0° (AM 27) in 2013 (Table 2). Hue angle of bronze genotypes ranged from 53.0° ('Summit') to 80.4° ('Tara') in 2012 and from 88.6° ('Summit') to 179.4° (AM 01) (Table 2). Chroma was similar both years of the study with 'Summit' in 2012 having the highest (15.0) and AM 27 in 2013 having the lowest (2.0) (Table 2). We found chroma was negatively correlated with both hue angle ($r = –0.88$) and total anthocyanins ($r = –0.86$), showing that as chroma increased, hue and anthocyanin concentrations decreased, whereas hue angle was negatively correlated to total flavonols ($r = –0.70$). Interestingly, fungicide treatments had no effect on L*, hue, or chroma, a finding not previously reported.

In 2012 and 2013, the ANOVA for nutraceutical concentrations indicated a two-way interaction of genotype and fungicide treatment for total anthocyanins ($P < 0.0001$ and $P < 0.0001$, respectively), total ellagitannins ($P < 0.0001$ and $P = 0.0460$, respectively), ORAC ($P < 0.0001$ and $P < 0.0001$, respectively), total flavonols ($P = 0.0004$ and $P = 0.0086$, respectively), total phenolics ($P < 0.0001$ and $P = 0.0017$, respectively), and resveratrol ($P < 0.0001$ and $P = 0.0079$, respectively).

Total anthocyanin concentrations were similar to those previously reported (Ballinger et al., 1973; Conner and MacLean 2013; Lee et al., 2005; Marshall et al., 2012; Pastrana-Bonilla et al., 2003; Sandhu and Gu, 2010; Striegler et al., 2005; Stringer et al., 2009; Threlfall et al., 2007). As expected, anthocyanins were not detected in any of the bronze genotypes in either year of the study (Table 3). In 2012, fungicide-treated AM 04 and no fungicide-treated AM 27 had the highest anthocyanin concentrations (127.8 and 122.0 mg/100 g, respectively), whereas in 2013, fungicide-treated 'Nesbitt' had the highest concentration (49.4 mg/100 g) (Table 3). Anthocyanin concentrations were generally higher in 2012 than in 2013 with the exceptions of no fungicide-treated 'Nesbitt' and 'Supreme' and fungicide-treated 'Southern Jewel' (Table 3). The differences in total anthocyanins among years may be the result of higher temperature and greater sun exposure and therefore greater color development and anthocyanin concentration in the 2012 growing season (Tables 1 and 3). Fungicide treatments did not consistently affect total anthocyanin concentrations either year of the study (Table 3). Conversely, Nwankno et al. (2011) found that fungicide treatments enhanced the total anthocyanin concentrations of black currants (*Ribes nigrum* L.).

Total ellagitannin concentrations were lower than those reported for muscadines by Lee and Talcott (2004) and Marshall et al. (2012), but similar to those reported by Boyle and Hsu (1990), Lee et al. (2005), Pastrana-Bonilla et al. (2003), Stringer et al. (2009), and Talcott and Lee (2002). Total ellagitannins were higher in 2013 than in 2012 with fungicide-treated 'Summit' having the highest levels both years of the study (14.1 in 2012 and 13.1 mg/100 g in 2013), whereas fungicide-treated 'Supreme' had the lowest level in 2012 (0.6 mg/100 g) and no fungicide-treated AM 01 had the lowest level in 2013 (4.0 mg/100 g) (Table 3). Ellagitannin concentrations varied greatly among genotypes and treatments with no consistent effect of fungicide treatments (Table 3). These findings are contrary to those reported by Smith (2013), who found the total ellagitannins were greater in no fungicide-treated berries. Our findings may differ from those of Smith as a result of that study being conducted in southern Mississippi, an area with higher rainfall and humidity than our site.

Oxygen radical absorbance capacity is widely accepted as being a good estimation of antioxidant capacity of fruits, although its significance is often questioned, because it does not accurately represent the bioactivity of antioxidants in the human body. In 2012 and in 2013, fungicide-treated AM 27 had the highest ORAC levels [125.3 and 119.0 μmol Trolox equivalents (TE)/g, respectively], whereas fungicide-treated 'Supreme' in 2012 (56.6 μmol TE/g) and no fungicide-treated 'Tara' had the lowest ORAC levels in 2013 (47.7 μmol TE/g) (Table 3). The ORAC values found were similar to those previously reported by Sandhu and Gu (2010) and Talcott and Lee (2002) but were considerably higher than those reported by Lee et al. (2005), Striegler et al. (2005), and Threlfall et al. (2007). ORAC was higher overall in 2013 than in 2012, which could possibly be the result of the extremely hot and dry growing season in 2012 (Tables 1 and 3), which stressed the vines. Overall, the berries from fungicide-treated vines had higher ORAC values than those from no fungicide-treated vines, although variation did occur among genotypes (Table 3). This is contradictory to Nwankno et al. (2011), who found that fungicide treatments had no effect on antioxidant capacity of blackcurrants, and this has not been previously reported for muscadines. It is hypothesized that the reason for this difference in fungicide treatments is the result of the sterol-inhibiting effect of myclobutanil, the active ingredient in Rally®, potentially interfering with the sterol pathway of the muscadines (Fletcher, 1987).

Total flavonol concentrations were lower than those reported by Marshall et al. (2012) and Talcott and Lee (2002). In 2012, no fungicide-treated 'Summit' and no fungicide-treated AM 15 in 2013 had the highest total flavonols (63.1 and 47.9 mg/100 g, respectively) and fungicide-treated 'Supreme' has the lowest concentration in both 2012 and 2013 (5.0 and 8.4 mg/100 g, respectively) (Table 3). Overall, total flavonols were higher in 2012 than in 2013 (Table 3). The bronze genotypes contained higher concentrations of total flavonols than the darker genotypes, which may be attributed to the presence of myricetin in the bronze genotypes (Marshall et al., 2012). Total flavonol concentrations were higher for the fungicide-treated fruit overall, although this varied among genotypes and years (Table 3).

Total phenolic concentrations were similar to those previously reported for muscadines (Lee et al., 2005; Lee and Talcott, 2004; Marshall et al., 2012; Pastrana-Bonilla et al., 2003; Striegler et al., 2005; Stringer et al., 2009; Talcott and Lee, 2002; Threlfall et al., 2007). Total phenolics were higher in 2012 than in 2013, likely as a result of the less favorable growing conditions (Tables 1 and 3). In 2012, total phenolics were higher for the fungicide treatment, whereas in 2013, no differences were found among fungicide treatments (Table 3). In 2012 total phenolic concentrations ranged from 812.7 mg/100 g (fungicide-treated AM 27) to 366.1 mg/100 g (no fungicide-treated 'Supreme'), whereas in 2013, they ranged from 655.9 mg/100 g (fungicide-treated 'Southern Jewel') to 315.5 (fungicide-treated 'Supreme') (Table 3). Total phenolic concentration was positively correlated with ORAC ($r = 0.77$), showing that total phenolics likely make up a large component of antioxidant

Table 3. Nutraceutical contents of whole muscadine berries from no fungicide- and fungicide-treated-vines in 2012 and 2013.

| Yr | Genotype | Berry color | Treatment | Total anthocyanins (mg/100 g) | Total ellagitannins (mg/100 g) | ORAC (μmol TE/g)[z] | Total flavonols (mg/100 g) | Total phenolics (mg/100 g) | Resveratrol (mg/100 g) |
|---|---|---|---|---|---|---|---|---|---|
| 2012 | AM 01 | Bronze | F[y] | 0.0 d[x,w] | 2.2 bc | 70.2 e | 37.1 bcd | 606.5 abcd | 8.0 abc |
| | AM 01 | | N | 0.0 d | 2.1 bc | 71.2 e | 41.0 abc | 604.7 abcd | 13.2 abc |
| | AM 15 | | F | 0.0 d | 4.4 abc | 74.5 de | 61.7 a | 636.3 abcd | 3.7 c |
| | AM 15 | | N | 0.0 d | 4.4 abc | 86.7 c | 29.3 bcde | 639.8 abcd | 3.9 c |
| | Summit | | F | 0.0 d | 14.1 a | 71.9 e | 44.7 ab | 651.4 abcd | 9.3 abc |
| | Summit | | N | 0.0 d | 10.5 ab | 86.8 c | 63.1 a | 492.1 bcd | 4.8 c |
| | Tara | | F | 0.0 d | 1.6 bc | 54.5 f | 30.6 bcde | 500.9 bcd | 4.6 c |
| | Tara | | N | 0.0 d | 2.9 bc | 47.7 f | 19.5 cdef | 439.0 bcd | 5.1 bc |
| | AM 04 | Black | F | 127.8 a | 14.0 a | 74.3 de | 36.2 bcd | 512.4 bcd | 5.2 bc |
| | AM 04 | | N | 109.3 a | 7.1 abc | 71.3 e | 26.1 bcdef | 539.2 abcd | 7.0 abc |
| | AM 27 | | F | 107.9 a | 4.9 abc | 125.3 a | 29.1 bcde | 812.7 a | 15.3 ab |
| | AM 27 | | N | 122.0 a | 8.0 abc | 81.7 cd | 21.5 bcdef | 669.3 abc | 16.7 a |
| | Nesbitt | | F | 74.0 b | 7.5 abc | 103.3 b | 16.5 def | 498.4 bcd | 5.5 bc |
| | Nesbitt | | N | 17.9 cd | 2.0 bc | 72.2 e | 17.3 cdef | 518.6 abcd | 4.3 c |
| | Southern Jewel | | F | 31.5 c | 2.5 bc | 88.6 c | 20.8 bcdef | 580.6 abcd | 6.7 abc |
| | Southern Jewel | | N | 78.1 b | 4.3 bc | 67.6 e | 9.1 ef | 694.7 ab | 5.8 bc |
| | Supreme | | F | 10.5 cd | 0.6 c | 53.4 f | 5.0 f | 369.9 cd | 2.9 c |
| | Supreme | | N | 16.7 cd | 1.6 bc | 52.7 f | 7.3 ef | 366.1 d | 4.1 c |
| | | | | <0.0001 | <0.0001 | <0.0001 | 0.0004 | <0.0001 | <0.0001 |
| 2013 | AM 01 | Bronze | F | 0.0 E | 5.4 E | 73.0 F | 27.4 BCD | 482.4 ABC | 5.2 ABC |
| | AM 01 | | N | 0.0 E | 4.0 AB | 71.2 FG | 15.8 DEF | 528.3 ABC | 3.9 BC |
| | AM 15 | | F | 0.0 E | 11.0 ABC | 81.5 E | 38.9 AB | 530.9 ABC | 3.9 BC |
| | AM 15 | | N | 0.0 E | 11.9 AB | 87.2 D | 47.9 A | 604.3 A | 3.8 BC |
| | Summit | | F | 0.0 E | 13.1 A | 64.6 HI | 32.4 BC | 579.2 A | 8.1 ABC |
| | Summit | | N | 0.0 E | 11.2 ABC | 57.6 J | 23.4 CDE | 535.0 AB | 11.1 AB |
| | Tara | | F | 0.0 E | 5.9 DE | 60.6 IJ | 14.8 DEF | 452.7 ABC | 3.5 BC |
| | Tara | | N | 0.0 E | 4.2 E | 65.9 GHI | 12.7 EF | 476.6 ABC | 3.3 C |
| | AM 04 | Black | F | 42.8 AB | 13.0 A | 98.0 C | 19.5 CDEF | 492.3 ABC | 4.2 BC |
| | AM 04 | | N | 41.1 AB | 12.2 AB | 97.2 C | 18.4 DEF | 558.3 AB | 5.5 ABC |
| | AM 27 | | F | 46.7 AB | 6.6 DE | 119.0 A | 17.4 DEF | 543.4 AB | 4.9 ABC |
| | AM 27 | | N | 41.8 AB | 6.6 DE | 94.8 C | 14.7 DEF | 448.3 ABC | 4.6 ABC |
| | Nesbitt | | F | 49.4 A | 12.4 AB | 85.9 DE | 19.9 CDEF | 560.5 AB | 3.2 C |
| | Nesbitt | | N | 22.5 CD | 7.7 BCD | 67.8 FGH | 11.0 EF | 450.1 ABC | 8.1 ABC |
| | Southern Jewel | | F | 44.6 AB | 9.0 BCD | 109.8 B | 18.9 CDEF | 655.8 A | 3.9 BC |
| | Southern Jewel | | N | 31.2 BC | 7.5 BCD | 111.3 B | 15.7 DEF | 579.0 A | 3.2 C |
| | Supreme | | F | 9.1 DE | 5.9 DE | 56.5 J | 8.4 F | 315.5 C | 5.2 ABC |
| | Supreme | | N | 19.9 CD | 5.7 DE | 57.8 J | 11.5 EF | 354.2 BC | 12.1 A |
| | | | | <0.0001 | 0.0460 | <0.0001 | 0.0086 | 0.0017 | 0.0079 |

[z]ORAC = oxygen radical absorbance capacity (μmol Trolox equivalents/gram).
[y]F = fungicide treatment and N = no fungicide treatment.
[x]Means followed by the same letter (uppercase 2012 and lowercase 2013) are not significantly different at $\alpha = 0.05$, separated by Tukey's honestly significant difference.
[w]0.0 = concentrations lower than detectable level using high-performance liquid chromatography.

capacity. Overall, the cultivar Supreme had the overall lowest total phenolics (Table 3), whereas Striegler et al. (2005), found 'Supreme' had among the highest total phenolic levels.

We found resveratrol concentrations similar to those previously reported in muscadines (Ector et al., 1996; Magee et al., 2002; Marshall et al., 2012; Pastrana-Bonilla et al., 2003; Stringer et al., 2009). In 2012, no fungicide-treated AM 17 had the highest resveratrol concentration (16.7 mg/100 g) and fungicide-treated 'Supreme' had the lowest (2.9 mg/100 g), whereas in 2013, no fungicide-treated 'Supreme' had the highest resveratrol concentration (12.1 mg/100 g), whereas no fungicide-treated 'Southern Jewel' had the lowest (3.2 mg/100 g) (Table 3). We found no clear relationship between berry color and resveratrol concentrations; conversely, Ector et al. (1996) found resveratrol to be greater in black genotypes. Magee et al. (2002) found 'Summit' to have among the highest levels of resveratrol, which is similar to our findings (Table 3). Resveratrol concentrations were equivalent to those in *V. vinifera* (Vincenzi et al., 2013). In 2012, no differences were found among fungicide treatments, whereas in 2013, the no fungicide-treated fruit had higher levels of resveratrol than the fungicide-treated fruit (Table 3). These results are similar to those reported by Smith (2013), who found resveratrol concentrations to be 10 times greater in no fungicide-treated berries. The differences in fungicide treatment among years could be the result of the hot and dry conditions during the growing season of 2012 (Tables 1 and 3), because resveratrol can be produced in response to fungal infection, which occurs more readily in cooler, wetter conditions (Jeandet et al., 1995). Similar findings of increased resveratrol concentrations, of muscadines, resulting from no fungicide applications have been reported (Magee et al., 2002).

## Conclusions

Overall, both percent unmarketable and percent weight loss increased during storage, showing higher importance as storage parameters. Force to penetrate the berry skin and flesh generally decreased during storage, also showing potential as an important postharvest storage parameter, particularly because some genotypes experienced less loss in force during storage. Force to penetrate the berry skin was generally greater, whereas weight loss and percent unmarketable were less within fungicide treatments. Physicochemical attributes, TA, pH, SS, L*, chroma, and hue, remained relatively constant during storage and were unaffected by fungicide treatments. There were some effects of fungicide applications on nutraceuticals; however, results varied. It was determined that although significant differences did occur, the efficacy of field fungicide applications to increase muscadine storability did not justify their use.

## Literature Cited

Ballinger, W.E., E.P. Maness, and W.B. Nesbitt. 1973. Anthocyanins of black grapes of 10

clones of *Vitis rotundifolia*. Michx. J. Food Sci. 38:909–910.
Ballinger, W.E. and W.B. Nesbitt. 1982a. Postharvest decay of muscadine grapes (Carlos) in relation to storage temperature, time, and stem condition. Amer. J. Enol. Viticult. 33:173–175.
Ballinger, W.E. and W.B. Nesbitt. 1982b. Quality of muscadine grapes after storage with sulfur dioxide generators. J. Amer. Soc. Hort. Sci. 107:827–830.
Banini, A.E., L.C. Boyd, J.C. Allen, H.G. Allen, and D.L. Sauls. 2006. Muscadine grape products intake, diet and blood constituents of non-diabetic and type 2 diabetic subjects. Nutrition 22:1137–1145.
Ben-Yehoshua, S., B. Shapiro, Z.E. Chen, and S. Lurie. 1983. Mode of action of plastic film in extending life of lemon and bell pepper fruit by alleviation of water stress. Plant Physiol. 73:87–93.
Boyle, J.A. and L. Hsu. 1990. Identification and quantitation of ellagic acid in muscadine grape juice. Amer. J. Enol. Viticult. 41:43–47.
Bralley, E.E., D.K. Hartle, P. Greenspan, and J.L. Hargrove. 2007. Topical anti-inflammatory activities of *Vitis rotundifolia* (muscadine grape) extracts in the tetradecanoylphorbol acetate model of ear inflammation. J. Med. Food 10:636–642.
Burg, S.P. 2004. Postharvest physiology and hypobaric storage of fresh produce. 1st Ed. CABI Publishing, Wallingford, Oxfordshire, UK.
Cho, M.J., L.R. Howard, R.L. Prior, and J.R. Clark. 2004. Flavanoid glycosides and antioxidant capacity of various blackberry, blueberry, and red grape genotypes determined by high-performance liquid chromatography/mass spectrometry. J. Sci. Food Agr. 84:1771–1782.
Cho, M.J., L.R. Howard, R.L. Prior, and J.R. Clark. 2005. Flavonol glycosides and antioxidant capacity of various blackberry and blueberry genotypes determined by high-performance liquid chromatography/mass spectrometry. J. Sci. Food Agr. 85:2149–2158.
Conner, P.J. 2009. A century of muscadine grape (*Vitis rotundifolia* Michx.) breeding at the University of Georgia. Acta Hort. 827:481–484.
Conner, P.J. 2013. Instrumental texture analysis of muscadine grape germplasm. HortScience 48:1130–1134.
Conner, P.J. and D. Maclean. 2012. Evaluation of muscadine grape genotypes for storage ability. HortScience 47:S386 (abstr.).
Conner, P.J. and D. MacLean. 2013. Fruit anthocyanin profile and berry color of muscadine grape cultivars and *Muscadinia* germplasm. HortScience 48:1235–1240.
Ector, B.J. 2001. Compositional and nutritional characteristics, p. 341–367. In: Basiouny, F.M. and D.G. Himelrick (eds.). Muscadine grapes. ASHS Press, Alexandria, VA.
Ector, B.J., J.B. Magee, C.P. Hegwood, and M.J. Coign. 1996. Resveratrol concentration in muscadine berries, juice, pomace, purees, seeds, and wines. Amer. J. Enol. Viticult. 1:57–62.
Fletcher, R.A. 1987. Plant growth regulating properties of sterol-inhibiting fungicides, p. 103–113. In: Purohit, S.S. (ed.). Hormonal regulation if plant growth and development. Springer Sci. and Business Media, Berlin, Germany.
God, J.M., P. Tate, and L.L. Larcom. 2007. Anticancer effects of four varieties of muscadine grape. J. Med. Food 10:54–59.
Greenspan, P., A. Ghaffar, J.L. Hargrove, D.K. Hartle, E.P. Mayer, J.D. Bauer, S.H. Pollock, and J.D. Gangemi. 2005. Antiinflammatory properties of the muscadine grape (*Vitis rotundifolia*). J. Agr. Food Chem. 53:8481–8484.
Hager, T.J., L.R. Howard, R. Liyanage, J.O. Lay, and R.L. Prior. 2008. Ellagitannin composition of blackberry as determined by HPLC-ESI-MS and MALD-TOF-MS. J. Agr. Food Chem. 56:661–669.
Himelrick, D.G. 2003. Handling, storage, and postharvest physiology of muscadine grapes. Small Fruits Rev. 2:45–62.
Huang, Z., R.D. Pace, P. Williams, and B. Wang. 2009. Identification of anthocyanins in muscadine grapes with HPLC-ESI-MS. Food Sci. Tech. 42:819–824.
Jackson, D.I. 1986. Factors affecting soluble solids, acid, pH, and color in grapes. Amer. J. Enol. Viticult. 37:179–183.
James, J., O. Lamikanra, G. Dixon, S. Leong, J.R. Morris, G. Main, and J. Silva. 1997. Shelf-life study of muscadine grapes for the fresh fruit market. Proc. Fla. State Hort. Soc. 110:234–237.
James, J., O. Lamikanra, J.R. Morris, G. Main, T. Walker, and J. Silva. 1999. Interstate shipment and storage of fresh muscadine grapes. J. Food Qual. 22:605–617.
Jeandet, P., R. Bessis, M. Sbaghi, P. Meunier, and P. Trollat. 1995. Resveratrol content of wines of different ages: Relationship with fungal disease pressure in the vineyard. Amer. J. Enol. Viticult. 46:1–4.
Lane, R.P. 1978. Effect of vineyard fungicide treatments on the shelf life of muscadine grapes. Ga. Agr. Res. 19:12–14.
Lane, R.P. and L.F. Flora. 1980. Some factors influencing storage of muscadine grapes. HortScience 15:273 (abstr.).
Lee, J.-H., J.V. Johnson, and S.T. Talcott. 2005. Identification of ellagic acid conjugates and other polyphenolics in muscadine grapes by HPLC-ESI-MS. J. Agr. Food Chem. 53:6003–6010.
Lee, J.-H. and S.T. Talcott. 2004. Fruit maturity and juice extraction influences ellagic acid derivatives and other antioxidant polyphenolics in muscadine grapes. J. Agr. Food Chem. 52:361–366.
Lutz, J.M. 1938. Factors influencing the quality of American grapes in storage. U.S. Dept. Agr. Tech. Bul. 606:1–27.
MacLean, D., P.J. Conner, J. Paulk, and L. Grant. 2009. Postharvest control of decay organisms. The Southern Region Small Fruit Consortium. Prog. Rpt. 2009–12.
Magee, J.B., B.J. Smith, and A. Rimando. 2002. Resveratrol content of muscadine berries is affected by disease control spray program. HortScience 37:358–361.
Marshall, D.A., S.J. Stringer, and J.D. Spiers. 2012. Stilbene, ellagic acid, flavanol, and phenolic content of muscadine grape (*Vitis rotundifolia* Michx.) cultivars. Pharmaceutical Crops 3:69–77.
Morris, J.R. 1980. Handling and marketing of muscadine grapes. FruitSouth 4:12–14.
Morris, J.R., O.L. Oswald, G.L. Main, J.N. Moore, and J.R. Clark. 1992. Storage of new seedless grape cultivar with sulfur dioxide generators. Amer. J. Enol. Viticult. 43:230–232.
Musingo, M.N., S.F. O'Keefe, O. Lamikanra, C.A. Sims, and R.P. Bates. 2001. Changes in ellagic acid and other phenols in muscadine grape (*Vitis rotundifolia*) juices and wines during storage. Amer. J. Enol. Viticult. 52:109–114.
Nwankno, A.J., S.L. Gordon, S.R. Verrall, R.M. Brennan, and R.D. Hancock. 2011. Treatment of fungicides influences phytochemical quality of blackcurrant juice. Ann. Appl. Biol. 160:86–96.
Pastrana-Bonilla, E., C.C. Akoh, S. Sellappan, and G. Krewer. 2003. Phenolic content and antioxidant capacity of muscadine grapes. J. Agr. Food Chem. 51:5497–5503.
Perkins-Veazie, P., S. Spayd, B. Cline, and C. Fisk. 2012. Handling and marketing guide for fresh market muscadine grapes. SFRC E03:1–12.
Prior, R.L., H. Hoang, L. Gu, X. Wu, M. Bacchiocca, L. Howard, M. Hampschwoodill, D. Haung, B. Ou, and R. Jacob. 2003. Assays for hydrophilic and lipophilic antioxidant capacity [oxygen radical absorbance capacity ($ORAC_{F1}$)] of plasma and other biological and food samples. J. Agr. Food Chem. 51:3272–3279.
Sandhu, A.K. and L.W. Gu. 2010. Antioxidant capacity, phenolic content, and profiling of phenolic compounds in the seeds, skin, and pulp of *Vitis rotundifolia* (muscadine grapes) as determined by HPLC-DAD-ESI-MSn. J. Agr. Food Chem. 58:4681–4692.
Silva, J.L., E. Marroquin, C.P. Hegwood, G.R. Silva, and J.O. Garner, Jr. 1994. Quality changes in muscadines for table grapes during refrigerated storage in various packaging systems. Proc. Viticult. Sci. Symp. Fla. A and M. Univ. 17:65–72.
Smit, C.J.B., H.L. Cancel, and T.O.M. Nakayama. 1971. Refrigerated storage of muscadine grapes. Amer. J. Enol. Viticult. 22:227–230.
Smith, B.J. 2013. Fruit quality, phytochemical content, and disease severity of muscadine grapes affected by fungicide applications. Pharmaceutical Crops 4:21–37.
Smith, B.J. and J.B. Magee. 2002. Limited fungicide applications affect berry rot severity and resveratrol content of muscadine grapes. Phytopathology 92:577 (abstr.).
Smittle, D.A. 1990. Requirements for commercial CA storage of muscadine grapes. Proc. Viticult. Sci. Symp. Fla. A and M. Univ. 13:140–146.
Striegler, R.K., P.M. Carter, J.R. Morris, J.R. Clark, R.T. Threlfall, and L.R. Howard. 2005. Yield, quality, and nutraceutical potential of selected muscadine cultivars grown in southwestern Arkansas. HortTechnology 15:276–284.
Stringer, S.J., D.A. Marshall, and P. Perkins-Veazie. 2009. Nutraceutical compound concentrations of muscadine (*Vitis rotundifolia* Michx.) grape cultivars and breeding lines. Acta Hort. 841:553–556.
Takeda, F., M. Starnes Saunders, C.F. Savoy, and T.T. Hatton. 1983. Storageability of muscadines for use as fresh fruit. Proc. Viticult. Sci. Symp. Fla. A and M. Univ. 3:31–33.
Takeda, F., M. Starnes Saunders, J.A. Saunders, and T.T. Hatton. 1982. Effects of prestorage treatment and storage temperature on incidence of decay and chemical composition in muscadine grape. Proc. Fla. State. Hort. Soc. 95:109–112.
Talcott, S.T. and J.-H. Lee. 2002. Ellagic acid and flavonoid antioxidant content of muscadine wine and juice. J. Agr. Food Chem. 50:3186–3192.
Threlfall, R.T., J.R. Morris, J.F. Meullenet, and R.K. Striegler. 2007. Sensory characteristics,

composition, and nutraceutical content of juice from *Vitis rotundifolia* (muscadine) cultivars. Amer. J. Enol. Viticult. 58:268–273.

Vincenzi, S., D. Tomasi, F. Gaiotti, L. Lovat, S. Giacosa, F. Torchio, S. Rio Segade, and L. Rolle. 2013. Comparative study of the resveratrol content of twenty-one Italian red grape varieties. South African J. Enol. Viticult. 34:30–35.

Walker, T.L., J.R. Morris, R.T. Threlfall, G.L. Main, O. Lamikanra, and S. Leong. 2001. Density separation, storage, shelf life, and sensory evaluation of 'Fry' muscadine grapes. HortScience 36:941–945.

Wang, C.Y. 1990. Chilling injury of horticultural crops. 1st Ed. CRC Press, Boca Raton, FL.

Yi, W., C.C. Akoh, and J. Fischer. 2005. Study of anticancer activities of muscadine grape phenolics in vitro. J. Agr. Food Chem. 53:8804–8812.