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Muscadine Grapes: Identifying Unique Attributes and Postharvest Practices

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Muscadine Grapes: Identifying Unique Attributes and Postharvest Practices

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by

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OVERALL ABSTRACT

Arkansas has a long history of grape and wine production, and muscadine grapes (*Vitis rotundifolia* Michx.), a native disease-resistant grape, are an important part of that industry. Muscadine grapes can be sold as a fresh-market grape or made into juice, wine, and other products. Additionally, the University of Arkansas System Division of Agriculture (UA System) breeding program has a focus on creating new muscadine cultivars with commercial potential. The objectives of this research were to evaluate muscadine grape genotypes (cultivars and breeding selections) for fresh market consumption and wine production in 2020 and 2021. 33 seeded and seedless genotypes of muscadines grown in Kings Mountain, North Carolina and at the UA System Fruit Research Station in Clarksville, Arkansas were evaluated for fresh market potential. At harvest, most physical and all composition attributes of the muscadines from both locations were significantly impacted by genotype. These grapes that were packaged in clamshells were also evaluated for postharvest storage potential for 14 and 28 d at 2 °C. Most genotypes had good storability with low weight loss (<9%) after 28 d even though berry firmness tended to decrease and weight loss and unmarketable berries increased. Of the genotypes evaluated in each year and location, only seven of 33 had unmarketable berries greater than 10%. The color of the berry skins showed that the L* decreased during storage, with dark/black muscadines having much less decreases in L* compared to bronze muscadines. This data provided information on physical, composition, and postharvest attributes of muscadine grapes that can be used for developing recommendations for standards for grades, marketing, and supporting breeding efforts. For wine production, AM-77 and 'Noble' muscadine grapes were harvested from a commercial vineyard as well as at the UA System Fruit Research Station and processed into wine using two skin contact times (0 and 3 d) during fermentation. The 2020

wines were evaluated at bottling and during storage at 15 °C, and the 2021 wines were evaluated at bottling. AM-77 wine had lower pH and higher titratable acidity than ‘Noble’, but ‘Noble’ wines had higher red color, brown color, and color density during 12-months of storage. ‘Noble’ wines with increased skin contact had higher red color and astringent flavors. For the 2020 wines, the wines with 0-days skin contact had fruitier, candy like aromas characteristic of muscadine juice, and AM-77 0-day skin contact was preferred over all ‘Noble’ wines and 3-day skin contact wines in consumer sensory (n=54) evaluation. AM-77 showed potential as compared to ‘Noble’, the commercial standard for muscadine wine production. Overall this research showed that muscadine grapes including new genotypes, have potential for both fresh market consumption and wine production.

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Dedication

I would like to dedicate this research to my father, Keith Earl Rawls (1938-Present). I was the first of his children to graduate in undergraduate. Without the support and type of upbringing he provided, I certainly would not be where I am today. He was a tax revenue agent for the state of Mississippi for most of his career, but in my upbringing, he was retired. This allowed him to start a small beef cattle farm that we all worked on in spare time. I remember him teaching me how to prune our muscadine vine from a very young age, and at that time I hated doing it. Now, I look back and know that without those experiences, I wouldn't be involved in such a topic today and am grateful for them.

TABLE OF CONTENTS

OVERAL INTRODUCTION

Grapes (*Vitis* spp.) are a widely grown horticultural crop, cultivated for fresh market fruit consumption (table grapes) and production of juice, wine, and other products. Because *V. vinifera,* the most wildly planted grapevines for commercial production, are vulnerable to pests, diseases, and extreme temperatures and are difficult to grow in much of the southern United States, other native and hybrid cultivars are typically grown. Muscadine grapevines (*Vitis rotundifolia* Michx.) are plants that are native to the southeast, disease and pest resistant and have a long history in the United States with over 200 years of cultivation.

Muscadines are cultivated from Texas to Delaware with more than 1,214 ha of muscadines grown in Florida, Georgia, North Carolina, and South Carolina (Hoffman et al., 2020). Commercial vineyards grow muscadines to produce juice, wine, and jelly/jam, and the majority of the commercial muscadine crop is used to produce wine. Muscadines are also grown for fresh markets but mainly sold during peak muscadine season at commercial markets near the growing locations.

While *V. vinifera* wine and table grapes and *V. labrusca,* a native 'Concord' grape, have 38 chromosomes, muscadine grapes have 40 chromosomes, so this makes breeding between species more difficult. There are both private and public U.S. muscadine breeding programs in the United States, and the University of Arkansas System Division of Agriculture (UA System) Fruit Breeding Program initiated muscadine breeding in 2007 to develop new cultivars that grow well in Arkansas while retaining the unique characteristics of muscadines and improving attributes important for fresh market consumption and winemaking.

In terms of fresh-market muscadine grapes, postharvest storability of fruit is important for extended shelf life. The only visual aid for fresh market muscadines provided by the United

States Department of Agriculture is an unofficial guide for stem scar, surface discoloration, and spotted damage/rot of bronze muscadines (Perkins et al., 2012; USDA, 2006). There is a lot of variation in color among muscadine cultivars, which makes grading muscadines for commercial markets challenging. Texture and the presence of seeds is one of the largest limiting factors in the likability of muscadines as a fresh-market fruit.

Muscadines also play a key role in juice and wine production with 'Noble' and 'Carlos' as the most commonly used muscadine grapes. Striegler and Morris (1984) determined that 'Noble' (black-skinned) muscadine grapes from Arkansas produced quality wines. Wines produced from muscadine grapes have unique fruity, candy, floral aromas and flavors but can have high bitterness and astringency, poor color and color stability (Lamikanra et al. 1996; Sims et al., 1995; Threlfall et al. 2007).

The grape and wine industry has a large economic impact in Arkansas, and muscadine grapes are a majority of the grapes grown in the state. The evaluation of potential for both fresh and processing muscadines is critical for the future of the industry in Arkansas and other southeastern states.

OBJECTIVES

1) Evaluating Postharvest Quality Attributes of Fresh-market Muscadine Grapes

2) Determining Impact of Skin Contact Time during Wine Production of 'Noble' and AM-77 Muscadine Grapes

Literature Review

History of muscadines

Muscadine grapevines (*Vitis rotundifolia* Michx.) are plants that are disease and pest resistant and have a long history in the United States. The genus *Vitis* is commonly divided into *Euvitis* (bunch grapes) and *Muscadinia* (muscadine grapes). Of the three species of *Muscadinia*, only *V. rotundifolia* is cultivated commercially. Of the over 50 wild *Vitis* grape species, muscadines are one of a few species indigenous to the southeast United States (Olien, 1990). Early explorers in North Carolina noted that muscadine grapes were used as food and cordage by Native Americans. Muscadines, particularly bronze-colored muscadines, were sometimes called "scuppernong" derived from "askupanong," meaning "place of the sweet bay tree" in the Algonquin language (Helsey, 2010; Olien, 1990). However, 'Scuppernong' is a specific bronze muscadine cultivar, so while all scuppernongs are muscadines, not all muscadines are scuppernongs.

The muscadine grape has been cultivated for about 200 years in the southern United States. The muscadine "mother vine", one of the oldest living grapevines in the world, was found in 1584 by the English explorer, Sir Walter Raleigh, off the coast of North Carolina (Hoffman et al., 2020). This vine is 'Scuppernong', the original wild bronze cultivar. At its largest, this vine covered over half an acre and is currently owned by a commercial vineyard in Roanoke Island, NC. Early explorers described the vines as vigorous and bountiful, making muscadines a dietary staple for colonists by the 1700s, though winemaking with the grape was not yet established (Helsey, 2010; Olien, 1990). Muscadine cultivation is easier and yields a more abundant crop than *V. vinifera* because diseases resulting from humidity and pest pressures that devastate *V.*

vinifera do not have the same deleterious effect on muscadine cultivars (Bouquet, 1981; Hopkins et al., 1974; Morris and Brady, 2004; Ren and Lu, 2002).

U.S. production of muscadines

Muscadines are cultivated throughout the southeastern states from as far west as Texas to the eastern coast and as far north as Delaware. In 2019, more than 1,214 ha of muscadines were grown in Florida, Georgia, North Carolina, and South Carolina (Hoffman et al. 2020). North Carolina, Georgia, and Florida are the top three muscadine-producing states by acreage at 1,052, 688, and 486 hectares, respectively in 2012 (Vilsack and Clark, 2014). In 2016 the Arkansas grape industry assessment survey conducted by University of Arkansas Department of Horticulture reported that muscadine grapes were the most common grape grown in the state (Alman 2016), and economic analysis has indicated that muscadine grape production can be profitable for vineyards in Arkansas (Noguera et al. 2005).

Commercial vineyards grow muscadines for the production of juice, wine, and jelly/jam, and the majority of the commercial muscadine crop is used to produce wine in Arkansas (Sims and Morris 1985). Muscadines are also grown for fresh-markets but mainly sold during peak muscadine season at commercial markets near the growing locations. Some of the larger, commercial muscadine growers sell muscadines across the U.S. east coast in grocery chains. In addition, muscadines can be used to make other products like energy drinks, vinegars, grape seed oil, supplements, and lotions.

Muscadine grapevines

Muscadine grapevines thrive in fertile, sandy loam and alluvial soils but struggle to grow well in extremely dry or wet areas especially soil with high amounts of calcium or calcareous soil. Muscadine grapevines have unbranched tendrils and smooth and thin bark (Hickey et al.,

2019; Hoffman et al. 2020). The plant is resistant to phylloxera, an insect that kills grapevine roots, grape fan leaf virus (*Nepovirus spp*.) Pierce's disease (*Xylella fastidiosa*) and anthracnose (*Elsinoë ampelina* Shear) that devastate *V. vinifera* (Bouquet, 1981; Hopkins et al., 1974; Morris and Brady, 2004; Olien and Hegwood 1990; Ren and Lu, 2002). With proper cultivation, the plant will typically produce 8-27 metric tons/hectare (Stanley, 1997).

In Arkansas muscadine grapevines typically flower in May to June, with muscadine harvest September to October. Muscadine grapevines can have three different flower types: perfect hermaphroditic, staminate (male), or imperfect hermaphrodite (female) flowers. Staminate flowers are comprised of only filaments and anthers, while imperfect hermaphroditic flowers have sterile pollen and stunted filaments and anthers. The perfect hermaphroditic have fully autonomous flowers that have functioning filaments, anthers, and flower (Hickey et al., 2019; Hoffman et al., 2020). Commercial muscadine growers typically grow cultivars that are perfect hermaphroditic.

Muscadine grapevine cultivation

Muscadine grapevines are grown commercially on trellis systems, physical structures that support the growth of the vine. Young vines need to be trained to the trellis so that vines do not grow outwardly into the rows and grow properly on the trellis (Anderson et al., 2020). Many designs are used for trellising including single wire, double wire, and Geneva Double Curtain (GDC) systems. Single, high wire trellis systems are less expensive and laborious to establish than GDC. However, the GDC system allows for the growth of two vines from the same root growing parallel to each other increasing yield potential, thus more profit. Carpio et al. (2018) found that muscadine grapes grown on GDC trellis systems were more profitable, than muscadines grown on a single wire.

Muscadine vines can grow vigorously and may need canopy management, such as hedging, skirting, and fruit/shoot thinning to achieve the vines full potential for muscadine grape production (Anderson et al., 2020; Hoffman et al., 2020; Olien., 1990). Hedging is needed to trim back vines for row access two to three times a year, typically in early summer and late summer before harvest. Skirting is trimming the underside of a canopy and must be performed often. The amount of skirting depends on the cultivar as some are more vigorous. Shoots that spur from the root must be trimmed to keep them from intertwining with vines in the canopy. Fruit thinning is needed in some cultivars since fruit can overweigh vines, causing broken branches or toppling of vines. Thinning is especially needed in fresh-market cultivars like 'Supreme' that have very large berries

Fruit characteristics

Muscadines are part of the genus *Vitis* which branches into two subgenera, *Euvitis* and *Muscadinia*. Some authors even state that muscadines are an entirely different genus than the more common bunch grapes species including *V. vinifera* and 'Concord' (*V. labrusca*) (Bailey, 1934; Reisch and Pratt, 1996). While *Euvitis* grapes, such as the European wine and table grapes (*V. vinifera*) and the American 'Concord' grape (*V. labrusca*) have 38 chromosomes, *Muscadinia* grapes have 40 chromosomes. Genetic mapping shows strong genome collinearity between *V. rotundifolia* and *V. vinifera* (Lewter et al. 2019).

Morphologically, muscadines are drastically different than *V. vinifera* grapes. Characteristically, muscadine grapes have thick skins, large seeds, small clusters, abscissions in between fruit and rachis, prominent lenticels, continuous piths, and a distinguishing aroma and flavor (Hickey et al., 2019; Hoffman et al., 2020). Because muscadines abscise from the berry and rachis, the berries can have issues with stem scar tears or wet stem scars that can impact the

marketability of the fruit. Barchenger et al. (2015a) evaluated 17 muscadines genotypes and found berry weight and volume were positively correlated with percent wet stem scar.

Cultivars of muscadines

There are approximately 24,000 named cultivars of *Vitis* grapevines (Viala and Vermorel 1909), and over 100 of those are different muscadine cultivars that have been released with various sizes, shapes, colors, and flavors (Anderson et al., 2020; Hickey et al., 2019; Hoffman et al. 2020; Olien and Hegwood 1990). Cultivars ripen at different times and have varying amounts of cold hardiness, so it is important to choose a cultivar suited to grow in a specific environment. The way a muscadine may be used depends on the cultivar, as different cultivars have different characteristics better suited for fresh eating or juice and wine production. Characteristics common among processing cultivars include small to medium sized berries, high yield, even ripening, and higher sugar and acid levels. 'Carlos' (bronze) and 'Noble' (black) are the most common muscadine grapes for processing due to their high production amounts and are both popular for juice and wine production (Anderson et al., 2020). Other processing cultivars include 'Alucha', 'Doreen', 'Magnolia', and 'Welder'. For fresh market consumption, it is preferable that the berry is large, sweet, visually appealing, and has thin skins with recommended fresh-market cultivars including 'Black Beauty', 'Darlene' 'Fry', 'Hall', 'Paulk', 'Summit', and 'Supreme' (Anderson et al., 2020; Hickey et al., 2019; Hoffman et al. 2020).

Muscadine breeding programs

Public breeding programs across the southern United States include those at Florida A&M University, North Carolina State University, University of Arkansas, University of Florida, University of Georgia, and the United States Department of Agriculture (USDA) in Poplarville, MS (Olien, 2001). The major private breeding program is based in North Carolina, which has

made substantial progress on seedless muscadine development. Jeff Bloodworth (2017), a private fruit breeder in North Carolina collaborates with Gardens Alive! (Lawrenceburg, IN), developing seedless muscadines, including the first seedless muscadine cultivars, 'Oh My!®' and 'RazzMatazz®'. Previous advances in muscadine breeding include the development of perfect-flowered and self-fruitful cultivars, increased berry size and sugar content, presence of dry picking scars, and the introduction of a seedless muscadine grape (Conner, 2010). Other traits undergoing development include more cultivars with perfect flowers and large fruit, improved textures, thinner skins, and a broader range of ripening dates. These efforts will also help the expansion of the germplasm base used in muscadine breeding. Retaining the unique flavors and aromas of muscadines is a focus in creating new cultivars for the commercial fresh markets. The University of Arkansas System Division of Agriculture (UA System) Fruit Breeding Program began breeding muscadines in 2007 with a focus on large fruit size, crisp texture, edible skin, self-fruitful flowers, seedlessness, and improved postharvest storability (Barchenger et al., 2015b; Felts et al. 2018; Worthington, 2019). This fruit breeding program works to develop and release new cultivars of grapes (table, wine, and muscadine), peaches/nectarines, and blackberries. The muscadine breeding program is working to develop muscadine grape and muscadine hybrids (crosses with *V. vinifera*) that have thinner more edible skins and no seeds (Worthington, 2019).

Muscadine skin color

Breeding cultivars of muscadines that result in new skin color components is important to breeding programs. Muscadine skin color is also important because color is extracted from the skin during juice and wine processing. Muscadine processers want deep, rich color and color stability in juice or wine that have an extended shelf life (Conner, 2010). The exterior of the

muscadine grape skins are less homogeneous in color than table grapes. The lack of homogeneity on the muscadine grapes is caused by the presence of lenticels. In most *Vitis* species of grapes, lenticels are absent on shoots but present on berries and pedicels. The density of lenticels on berries is low, and they are often filled with cuticular wax as the berries develop. The lenticels look like spots on the grape skins and can also be referred to as russeting (Hoffman et al., 2020, Perkins-Veazie et al., 2012). In addition, even on the same grape, the color shades of the muscadine skin can vary.

The USDA (2006) has color standards regarding muscadines describing skin color in two categories, white or black/red. White muscadines have either a bronze or blush tone with shades of green, straw, amber, bronze, and some small amounts of red or blush. Black/red muscadines can include red, pink, purple, and black colors with an outer skin with at least 75% red, purple, or black tones. Black muscadines can be classified further to red and black categories. Black muscadines are typically very dark, and red muscadines can show lighter tones of red, pink, and purple. Muscadine color characteristics are important as they can change during ripening and during postharvest storage. It has been found that 90% of the total anthocyanins in muscadines were 3,5-diglucoside of delphinidin, cyanidin and petunidin; the remaining 10% were 3,5-diglucoside of peonidin and malvidin. Significant variation between the amounts of total anthocyanin content among different cultivars of muscadine grapes with dark/purple skinned muscadine grapes having significantly higher levels of anthocyanins than bronze-skinned muscadine grapes (Huang, et. al. 2009). Connor and Mclean (2013) examined anthocyanin profiles and color of muscadines grown in Georgia and found that malvidin, an important anthocyanin for color stability, was only found in a few genotypes (cultivars and advanced breeding selections) but found positive correlations among other color parameters measured with

anthocyanin content. In 2020, Varanasi et al. (2022) identified a single intragenic marker corresponding to a proline to leucine mutation within the muscadine *GST4* (*VrGST4*), but the protein is non-functional in bronze berries. These results imply that berry pigmentation in muscadines is regulated by different mechanism than the *MybA* gene cluster that is responsible for berry skin color variation among *V. vinifera* genotypes. These color changes in muscadine grapes and muscadine products can impact commercial marketability.

Measuring muscadine color

There are many types of equipment used to measure the color of horticultural crops including colorimeters. Commission Internationale de l'Eclairage (CIE) Lab transmission values of L*=100, a*=0, and b*=0 (CIE, 1986) describes color variations as perceived by the human eye. CIELAB is a uniform three-dimensional space defined by colorimetric coordinates, L*, a*, and b*. The vertical axis L* measures lightness from completely opaque (0) to completely transparent (100), while on the hue-circle, +a* red, -a* green, +b* yellow, and -b* blue are measured. Hue angle, calculated as $\tan^{-1}\frac{b*}{a*}$, describes color in angles from 0 to 360°: 0° is red, 90° is yellow, 180° is green, 270° is blue, and 360° is red. Chroma, calculated as $\sqrt{a*^2 + b*^2}$, will identify color by which a wine appeared to differ from gray of the same lightness and corresponded to saturation (intensity/purity) of the perceived color. The CIE values can be used to convert colors to visual images using software designed for color conversion.

Importance of color for harvest and storage

Color in fresh muscadines, like many other fruits, can be used to determine the ripeness of each berry. The color change is more observable in white categories of muscadines, because as white muscadines mature on the vine the berries brown or darken (North Carolina Muscadine Grape Association, 2021; Walker et al. 2001). Although less observable in dark muscadines,

black/red cultivars also darken during ripening. In addition, the color of the muscadines can darken during postharvest storage (Barchenger et al., 2015b; Felts, 2018).

Research has been done at the UA System on skin color of muscadines of different genotypes. Walker et al. (2001) determined that it is possible to effectively separate 'Fry' (bronze) berries by color for maturity level. Barchenger et al. (2015b) found after three weeks of storage at 2 °C, the black genotypes had a 25% reduction in L* and 36% reduction in chroma, whereas the bronze genotypes had a 20% reduction in L* and 36% reduction in chroma. The reduction in L* means that the berries were getting darker regardless of grape skin color. Additionally, the bronze muscadines were visually darker during storage (Barchenger et. al., 2015b). In general, bronze muscadines had an L* value of about 40 and black muscadines had L* value of 25, so black muscadines were darker based on the L* value (Barchenger et al., 2015b; Felts, 2018). Felts et al. (2018) found significant correlations between the analytical berry skin color attributes with the descriptive sensory attributes of external appearance, basic tastes, aromatics, and feeling factors. L* was negatively correlated to color-purple, bitter, grape/other aromatics, and astringent feeling factor, and positively correlated to color-bronze, fruity flavor, and glossiness (Felts, 2018; Felts et al., 2018). Campbell et al. (2021) found that L*, hue, and chroma were better indicators of color than the total anthocyanin content for 90 muscadine genotypes evaluated.

Damage in muscadines

Damage in a clamshell, plastic vented container, of muscadines detracts from the appearance and impacts marketability. The USDA also has guides for the damage of muscadines for fresh markets. Damage on a muscadine is defined as 10% of the outer skin being excessively dark and affecting the surrounding area, or lighter discoloration on more than 15% of the berry.

Discoloration is a form of damage, and it can be contributed to sunburn, disease, or age. Discoloration is defined as a browning or blackening of color. Severe damage is defined as 25% of the outer area of the muscadine berry is excessively dark and affecting surrounding areas, or 50% of the outer area has lighter superficial discoloration (USDA, 2006).

Additional resources for standards and grades for muscadines

Currently, the only muscadine visual aid provided by the USDA is an unofficial guide for stem scar, surface discoloration, and spotted damage/rot of bronze muscadines (Perkins et al., 2012, USDA, 2006). There is a lot of variation in color among muscadine cultivars which makes grading muscadines challenging. If a cultivar is darker bronze or pink, is does not necessarily mean the berry color has changed during storage. Guidelines need to be written carefully to not disqualify cultivars that are darker/pinker as compared to bronze cultivars. New analytical and visual resources for muscadine grapes are needed to provide inspectors, buyers, and retailers materials to more accurately define color and quality attributes representative of fresh-market muscadines that are commercially available. These resources can help people unfamiliar with muscadines as a commercial fruit know what to look for when buying or grading, thus creating more consistency in the product for the consumer.

Firmness of muscadines

Firmness of muscadine grapes is not a factor in processing muscadines but is important to fresh markets. Traditionally, *V. vinifera* table grapes have a firm/crisp texture that appeals to consumers. Conner and Mclean (2013) analyzed the texture of 26 different genotypes of muscadines and compared them to *V. vinifera* grapes. Overall, the muscadines were less firm and tender than *V. vinifera* grapes, but there were some genotypes of muscadines that had exceedingly high skin break forces. Berry penetration work (distance skin ruptures measured in

millimeters, also known as skin elasticity) and flesh maximum force (maximum force to puncture berry skin measured as Newtons or grams) were the most useful characteristics for routine screening of breeding program material for muscadine grapes (Chizk et al., 2021; Conner, 2013).

Texture is one of the largest limiting factors in the likability of muscadines. Berry puncture force was significantly correlated to the liking of skin texture and pulp texture in sensory testing of fresh market muscadine grapes, and puncture force (maximum force to puncture berry skin measured as Newtons or grams) is a better predictor of overall liking than skin elasticity (distance skin ruptures measured in millimeters) (Brown et al., 2016). Therefore, texture or firmness analysis is important tool for muscadine breeding programs.

Postharvest of muscadines

Due to varying handling practices, storage practices, and genotypes, the postharvest evaluation of fruit is important to understand how to package and store fruit for extended shelf life. After harvest, berries must be precooled, sorted, and washed before packaging. The primary losses of muscadine grapes in storage is from decay and berry softening (Basiouny and Himelrick, 2001; Takeda et al., 1983). Low temperature storage and chlorine washes are used to delay softening and pathogen growth during storage (Smit et al., 1971), but maximum storage periods are 2-4 weeks. Barchenger et al. (2015b) evaluated postharvest attributes of 17 Arkansas-grown muscadine genotypes and found that AM-26 (a UA System muscadine breeding selection) and 'Southern Jewel' had the best postharvest storage for three weeks at 2 °C. Studies on muscadines grown in Arkansas have shown that bronze genotypes did not have as much storage potential as black genotypes, since bronze muscadines show more prevalent browning (Barchenger et al., 2015b; Felts et al., 2018). Barchenger et al. (2015b) found after three weeks

of storage at 2 °C, the black genotypes had 30% reduction in penetration force and 39% increase in unmarketability, whereas the bronze genotypes had 36% reduction in penetration force and 48% increase in unmarketability.

Takeda et al. (1983) evaluated postharvest attributes of 'Fry' muscadine grapes in storage for 24 days at different storage temperatures and found that the organic acids, tartaric and malic, did not change significantly during storage. However, there was a small reduction in the amount of tartaric acid in the skin of the muscadines, but the concentrations in the pulp remained the same. This is interesting since *V. vinifera* typically show a decrease in malic acid concentrations (Kliewer, 1965). Takeda et al. (1983) also evaluated the firmness of muscadines and found after storage at 4.5 °C and 0 °C, showing that the amount of force to penetrate a berry reduced by 37% (softening) of the initial force.

Temperature plays an important role in the preservation of muscadines during storage. Although 'Concord' grapes can lose a considerable amount of soluble solids if exposed to warmer conditions after harvest (Kliewer, 1967), Takeda et al. (1983) found insignificant soluble solid loss and very little weight loss due to respiration at 0 °C, 4.5 °C, or 20 °C over any storage dates. Ballinger and Nesbitt (1982) found that for 'Carlos' muscadines held at 0 °C, 10 °C , and 20 °C up to six weeks, berries that were stored at 0 °C lasted two and six times longer than those at 10 °C and 20 °C, respectively, and those stored at 0 °C had least decay in total by the end of 3 weeks of storage. Also, the muscadines provided were sourced from three different commercial vineyards in North Carolina, and the amount of stem scar tears in the muscadines received varied from 56%-80% with dry stem scars (Ballinger and Nesbitt, 1982).

Use of controlled atmosphere is modification of the atmosphere in packaging where the oxygen (O_2) or carbon dioxide (CO_2) levels are modified. Controlled atmosphere can reduce

decay, mold growth, and weight loss in muscadine grapes. Shahkoomahally et al. (2021) evaluated 'Triumph' and 'Supreme' stored at 4 °C with 95 % relative humidity in regular atmosphere, regular controlled atmosphere (6 % O_2 + 10 % CO_2), or controlled atmosphere with extreme CO_2 level (4 % O_2 + 30 % CO_2) for up to 42 d. Both controlled atmosphere treatments had muscadines with less weight loss and reduced decay incidence, but after 42 d for both cultivars there was no decay in extreme controlled atmosphere berries and no evidence of CO_2 injury. Berry softening was significantly delayed by controlled atmosphere, which had a lower ethylene production rate than berries in packaging with regular atmosphere (Shahkoomahally et al., 2021).

Muscadine composition

Muscadine grapes typically have three sections: the flesh (pulp), skins, and seeds. The flesh contains primary metabolites of the grape, such as water, sugar, acids, and pectin, whereas skins and seeds contain more secondary metabolites, such as phenolic and aroma compounds (Waterhouse et al., 2016). Mature grapes contain water, sugar, organic acids, and pectin. Sugars (glucose and fructose) make up a majority of grape carbohydrate content with muscadine grapes having 15-23% soluble solids. In grapes, the acidity attributes measured are pH and titratable acidity (% tartaric acid). Mature muscadine grapes grown in Arkansas typically have 0.50-0.70% titratable acidity and 3.0-3.3 pH (Barchenger, et al., 2015 b, Felts et al., 2018).

Muscadine Phenolics

Phenolic compounds have at least one 6-carbon aromatic ring and one or more hydroxyl groups and can be divided into two groups: non-flavonoids and flavonoids. Within the flavonoid category, compounds are further classified as anthocyanins, flavonols, or tannins. Anthocyanins are responsible for the red color of grapes and wine and are found primarily in the skin of red

grape cultivars. Vinifera grapes typically have monoglucosides, whereas muscadine grapes have diglucosides. Connor and MacLean (2013) evaluated the anthocyanin content and composition of 22 muscadine grape genotypes and found delphinidin, cyanidin, petunidin, pelargonidin, peonidin, and malvidin in their 3,5-diglucosidic forms with delphinidin in the highest concentration, but found malvidin, the most important anthocyanin for muscadine wine and juice color stability, abundant in only a few clones. Pastrana-Bonilla et al. (2003) evaluated 10 cultivars of muscadine grapes grown in southern Georgia and found that in general across cultivars, the total phenolics in the seed, skin, pulp, and leaves was of 2,179, 375, 24, and 352 mg/g gallic acid equivalent, respectively.

Flavonols found in grapes include quercetin, kaempferol, myricetin, and isorhamnetin. Tannins, or flavan-3-ols, include catechin, epicatechin, epicatechin gallate, and epigallocatechin and are responsible for grape astringency and bitterness in both the skins and seeds of grapes. Threlfall et al. (2005) evaluated the pressing effects on the nutraceutical contents of seeds, skins, and juice of 'Black Beauty' and found that the juice generally had less total phenolics, total anthocyanins than the whole grapes. The juice from heated 'Black Beauty' musts had the total phenolics of 1,354 mg/L and anthocyanins of 414 mg/L, while dried seeds had more phenolics and less anthocyanins than the skins (Threlfall et al., 2005).

Previous research has shown that flavonols increase in grapes exposed to the sun prior to harvest (Price et al. 1995, Spayd et al., 2002). Spayd et al. (2002) found that the flavonol concentration was increased by 10-fold in Merlot grapes that were exposed to the sun, relative to grapes that were shaded. Because flavonols are found mostly in the outer layer of cells in the grape skin and they absorb ultraviolet light strongly at 360 nm, it is believed that plants produce them as a form of protection. Flavonols are known to have a bitter taste, but it is unclear if, at the

concentrations found in wine, they make a contribution to flavor. Sáenz-Navajas et al. (2010) found that there was no correlation between bitterness and flavonol concentration in red wines. However, it was proposed that other compounds could have overpowered their effect. Preys et al. (2006) showed that when phenolic fractions were added back to wine, there was an association between bitterness and the fractions higher in flavonols. Hufnagel and Hofmann (2008) concluded that flavonols possess a 'velvety astringency.'

Muscadine health benefits

Muscadine grapes have many nutraceutical impacts (foods containing health-giving additives and having medicinal benefit). According to the USDA-Agricultural Research Service (2011), a 10-berry serving of muscadines has 16% of the daily Adequate Intake and 13-14% of the Recommended Daily Allowance of vitamin C. Muscadines also have high amounts of healthy bioactive compounds including resveratrol, ellagic acid, anthocyanins, and proanthocyanidin phenolics (Ector et al., 1996; Lee and Talcott, 2004; Pastrana-Bonilla et al., 2003; Threlfall et al., 2005). Anthocyanin content is highest in the skin of dark berries (Striegler et al., 2005), and although found throughout berries, phenolic content is highest in the seeds (Ector et al. 1996; Pastrana-Bonilla et al., 2003; Sandhu and Gu, 2010; Threlfall et al., 2005). Kim et al., (2009) found that red muscadine juice had natural antibacterial properties by showing the inhibition of *Escherichia coli* growth when exposed to fresh of processed muscadine juice. Muscadine juice has lower amounts of anthocyanin and phenolic than whole berries (Threlfall et al., 2005), but muscadine juice has still been shown to inhibit in vitro growth of leukemia cells (Merotens-Talcott, 2008).

In addition, some cell culture studies (Mertens-Talcott et al. 2008, Yi et al. 2005) have indicated that muscadine polyphenols can inhibit proliferation of colon cancer cells and induce

apoptosis. As consumers have become aware of these muscadine health benefits, the demand for fresh and processed muscadine products has increased. In fact, the muscadine grape industry is experiencing its greatest growth in decades (Striegler et al. 2005).

Arkansas wine production

In 2017, Arkansas was number 21 among U.S. states for total grapevine area, with 322 hectares. From 2008-2015, the number of grapes harvested and the price per tonne in Arkansas fluctuated. Grape production peaked in 2010 at over 2,300 tonnes, and the price peaked at about $1,290/tonne in 2012 (USDA NASS 2019). American Viticultural Areas (AVA) are areas designated by the Alcohol and Tobacco Tax and Trade Bureau (TTB), used to determine the appellation of origin of a bottle of wine. (U.S. Department of Treasury, TTB , 2022). There are three AVAs in Arkansas including the Altus AVA, the Arkansas Mountain AVA, and the Ozark Mountain AVA. The Altus AVA is in northwestern Arkansas in Franklin County. This region is a plateau above the Arkansas River to the south and below the Boston Mountains to the north. A majority of wine grapes in Arkansas come from the Altus AVA. The Arkansas Mountain AVA is in the Ozark Mountains of Northwest Arkansas and encompasses the Altus AVA, and the Ozark Mountain AVA also includes areas of southern Missouri and northeast Oklahoma. The Ozark Mountain AVA is the sixth-largest AVA in the United States by area, covering almost 1.5 million hectares (U.S. Department of Treasury, TTB, 2022).

Muscadine juice and wine production

A majority of the commercial muscadine crop is used to produce wine. The two most popular cultivars for processing are ‘Noble’, a black muscadine, and ‘Carlos’, a bronze muscadine. Sistrunk and Morris (1984) determined that ‘Noble’ muscadine grapes grown in Arkansas were excellent for juice and wine production. The production of grapes to wine

involves a fermentation where grape sugars are converted to ethanol and carbon dioxide by yeast added to juice or must (skins, seeds, juice, and pulp). There are many other physical and biochemical changes occurring due to extraction and microbial metabolism of other grape compounds.

Muscadine wines can have poor color, color stability, and cloudiness/sediment. Muscadine grapes and wines contain only diglycosidic anthocyanins, which are unable to form stable polymeric pigment complexes (Sims and Morris, 1985). There have been several studies examining the attributes and quality of 'Noble' muscadine wines (Gürbüz et al., 2013; Lamikanra, 1987, 1997; Lamikanra et al., 1996; Nesbitt et al., 1974; Sims and Bates, 1994; Sims and Morris 1985, 1986; Sistrunk and Morris, 1984; Talcott and Lee, 2002). Research has shown that most of the phenolic compounds in muscadines are predominantly located in the skins (11.3%) and seeds (87.1%), and the extraction and solubility of these compounds during wine and juice making are greatly influenced by the time spent on the must during fermentation. (Baderschneider and Winterhalter, 2001; Huang et al., 2009; Pastrana-Bonilla et al., 2003; Sandhu and Gu, 2010). Sims and Bates (1994) observed an increase in anthocyanin content with increasing skin contact time for 'Noble' muscadine wines, but also saw that longer skin fermentation times resulted in higher astringency and lower fruity and floral aromas. Mayfield (2020) evaluated 'Noble' muscadine wine with different enzyme treatments and skin contact times (zero, three, and seven days) and found the longer skin contact times characterized wines with deeper, richer, spicier flavors, while wine from zero-day skin contact had light, fruity, floral characteristics.

Muscadine juice/wine color stability

The color instability of muscadine wines can be attributed to limited anthocyanin-tannin polymerization. Muscadines contain only diglucoside anthocyanins, which are unable to form stable polymeric pigment complexes like the monoglucoside anthocyanins in *V. vinifera* grapes and wine (Sims and Morris, 1985). Sims and Bates (1994) observed an increase in anthocyanin content with increasing skin contact time for 'Noble' muscadine wines, but also saw that longer skin fermentation times resulted in higher astringency and lower fruity and floral aromas.

Mayfield (2020) found only the diglucoside anthocyanins delphinidin-, malvidin-, petunidin-, peonidin-, and cyanidin-3,5-diglucoside in 'Noble' muscadine wines grown in Arkansas, and multiple studies have shown muscadine grapes with large amounts of malvidin-3,5-diglucoside produce wines and juices with the best color quality (Ballinger et al. 1974, Flora 1978, Nesbitt et al. 1974). In addition, Mayfield (2020) found that increasing skin contact time also increased the red color, brown color, and color density of the 'Noble' muscadine wines. Regardless of skin contact, the red color of wines increased slightly from 0- to 3-months storage, but then decreased from 3- months to 6-months storage. This decrease in red color can be attributed to degradation of the less stable diglucoside anthocyanins found in 'Noble' muscadine wine. While there were slight decreases in color density during storage, there was no increase in brown color observed (Mayfield, 2020). This was significant, since muscadine wines typically experience browning during storage that negatively impacts their shelf-life and consumer acceptability (Sims and Morris, 1986).

Muscadine grape and wine sensory

Consumer acceptance research on fresh-market muscadines has been limited, but it is hypothesized that consumers prefer larger berries with less, smaller, or no seeds. In addition, consumers prefer the skin and pulp texture of established *V. vinifera* grapes to muscadine

textures, which is why breeding programs focus on skin texture (Brown et al., 2016). Brown et al. (2016) evaluated the consumer acceptability of fresh-market muscadines and found appearance, skin texture, pulp texture, and flavor were positively correlated. Flavor had the closest correlation to overall liking, which is promising since some of the muscadines were comparable to *V. vinifera* grapes in their flavor liking. Skin and pulp texture were limiting factors for the overall liking of muscadine grapes when compared to the control, *V. vinifera* grapes. Results of research conducted by Brown et al. (2016) indicated that people enjoy muscadine flavors, and there is market incentives and opportunities for breeders to improve the texture of muscadine grapes.

Juices and wines produced from muscadine grapes have unique fruity and floral aromas and flavors. Baek et al. (1997) investigated the dominant aromas compounds in muscadine juice and found that furaneol (strawberry or pineapple) and o-aminoacetophenone (fruity-grape like) are major characteristic contributing candy and foxy-like aromas. Furaneol exhibits a burnt sugar-like aroma at higher concentrations (Baek et al., 1997). Muscadine juices from Arkansas had cooked muscadine, apple, pear, cooked grape, green/unripe, and slightly musty aromas and flavors (Threlfall et al., 2007). Meullenet et al. (2008) found correlations between general muscadine flavor and musty flavor, general grape flavor and metallic flavor, green/unripe flavor and sourness/astringency, and sweetness and floral, apple, and pear flavors for Arkansas muscadine juice. Muscadine juice has shown promising results in consumer acceptance when blended with other fruit juice and juice cocktails (Flora et al., 1979; Trappey et al., 2007). Flora et al. (1979) found the optimal titratable acidity to soluble solids ratio to be 30, including an acceptable range of 25-35, regardless if the juice is from a bronze or black cultivar. Lamikanra (1987) determined that higher alcohols and fatty acid ethyl esters were the largest classes of

volatile aroma compounds in ‘Noble’ muscadine wine with 2-Phenylethanol (rose and honey aroma) responsible for the characteristic rose aroma of muscadine wines. Sims and Bates (1994) evaluated the effect of skin contact time (time that the wine is fermented with the juice, pulp, skins and seeds before pressing) on ‘Noble’ muscadine wines and found that wines with longer skin contact times had lower general muscadine aroma intensities. Regardless of the appealing aromas and flavors, muscadine wines, especially longer skin contact times during wine production, can have high bitterness and astringency due to their phenolic composition, poor color and color stability, and cloudiness/sediment caused by ellagic acid precipitation during storage (Sims et al., 1994; Sims and Morris 1985).

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Chapter 1

Evaluating Postharvest Quality Attributes of Fresh-market Muscadine Grapes

Abstract

Muscadine grapes (*Vitis rotundifolia* Michx.) are a disease-resistant specialty crop native to the southeastern United States. There have been major advances in U.S. muscadine breeding efforts resulting in unique traits emerging, particularly new seedless cultivars, to expand commercial, fresh-market potential. In 2020 and 2021, muscadine genotypes (cultivars and advanced breeding selections) were evaluated at the University of Arkansas (UA) System Division Food Science Department. The genotypes were harvested from the UA System Fruit Research Station in Clarksville, AR (seeded) and a private grower in Kings Mountain, NC (seeded and seedless). In 2020 and 2021, seven and nine genotypes were harvested in Arkansas, respectively, and 10 and seven genotypes were harvested in North Carolina, respectively. Approximately 1.8 kg of berries were harvested for each genotype, and fruit was shipped in clamshells from North Carolina to Arkansas for evaluation. The physical and composition attributes of the muscadines were evaluated at harvest, and postharvest attributes were evaluated at 0, 14 and 28 d storage at 2 °C. At harvest, most physical and all composition attributes of the muscadine from both locations and years were significantly impacted by genotype. Regardless of year and location, the physical attributes varied, including berry weight (1-21 g), berry length (10-31 mm), berry width (10-33 mm), seed number (0-5), seed weight (0-0.4 g), stem scar tear (0-29%), berry firmness (4-11 N), skin firmness (0.5-1.8 N/mm), skin elasticity (5-9 mm), L* (24-52), hue (7-103), and chroma (2-18). For the composition attributes, there was a range of soluble solids (14-19%), pH (3-4), titratability acidity (0.3%-1.2%), and soluble solids/titratable acidity ratio (16-70). The total sugars and total organic acids ranged (10%-20%) and (0.3-0.9%), respectively. In terms of postharvest storage of the muscadine grapes in clamshells stored at 2 °C

regardless of location and year, the L* ranged from 24-52, berry firmness ranged from 3-11 N, weight loss ranged from 0-11%, and unmarketable berries ranged from 0-83%. However, at 14 d postharvest storage there was <8% weight loss for the muscadines in the clamshells with only 4 of 33 genotypes with unmarketable berries over 10%, whereas at 28 d weight loss was <12% with 15 of 33 genotypes with unmarketable berries over 10%. Introduction of new cultivars like 'RazzMatazz®' and the breeding selection, AM-148, which had very low stem scar tear and unmarketable berries, have the potential to broaden the market for growers and consumers of fresh-market muscadines. Data generated from this project provided information on physical, composition, and postharvest attributes of muscadine grapes that can be used for developing recommendations for standards for grades, marketing, and supporting breeding efforts.

Introduction

Muscadine grapevines (*Vitis rotundifolia* Michx.) are disease and pest resistant and have a long history in the southeastern United States. Muscadines are part of the genus *Vitis* which branches into two subgenera, *Euvitis* and *Muscadinia*. While *Euvitis* grapes, such as the European wine and table grapes (*V. vinifera*) and the American 'Concord' grape (*V. labrusca*) have 38 chromosomes, *Muscadinia* grapes have 40 chromosomes. Muscadine cultivation is easier and yields a more abundant crop than *V. vinifera* when grown in the U.S. southeast because diseases resulting from humidity and pest pressures that devastate *V. vinifera* do not detrimentally impact muscadine cultivars (Bouquet, 1981; Hopkins et al., 1974; Morris and Brady, 2004; Ren and Lu, 2002).

Commercial vineyards grow muscadines for the production of juice, wine, jelly/jam, and other products (energy drinks, vinegars, grape seed oil, and supplements). Muscadines are also grown for fresh-markets but mainly sold during peak muscadine season at commercial markets near the growing locations. Some of the larger, commercial muscadine growers sell muscadines across the U.S. east coast in grocery chains. Muscadines are grown throughout the southeastern states from as far west as Texas to the eastern coast and as far north as Delaware. In 2019, more than 1,214 ha of muscadines were grown in Florida, Georgia, North Carolina, and South Carolina (Hoffman et al., 2020). North Carolina, Georgia, and Florida were the top three muscadine-producing states by acreage at 1,052, 688, and 486 hectares, respectfully in 2012 (Vilsack and Clark, 2014). In 2016, the Arkansas grape industry assessment survey reported that muscadine grapes were the most common grape grown in Arkansas (Alman, 2016) and can be profitable for vineyards in Arkansas (Noguera et al., 2005).

Muscadine grapevines are grown commercially on trellis systems, physical structures that support the growth of the vine. The muscadine grapevines typically flower in May to June, with muscadine harvest September to October. Muscadine grapes are drastically different than *V. vinifera* grapes. Characteristically, muscadine grapes have thick skins, large seeds, small clusters, abscissions in between fruit and rachis, prominent lenticels, continuous piths, and a distinguishing aroma and flavor (Hickey et al., 2019; Hoffman et al., 2020). Because muscadines abscise from the berry and rachis, the berries can have issues with stem scar tears or wet stem scars that can impact the marketability of the fruit. Barchenger et al. (2015a) evaluated 17 muscadines genotypes (cultivars and advanced breeding selections) grown in Arkansas and found berry weight and volume were positively correlated with percent wet stem scar. Muscadine berries typically have three sections, flesh (pulp), skins, and seeds. The flesh contains primary metabolites of the grape, such as water, sugar, acids, and pectin, whereas skins and seeds contain more secondary metabolites, such as phenolic and aroma compounds (Waterhouse et al., 2016). Mature grapes contain water, sugar, organic acids, and pectin. Sugars (primarily glucose and fructose) make up a majority of grape carbohydrate content with muscadine grapes having 15-23% soluble solids. In grapes, the acidity attributes measured are pH and titratable acidity primarily tartaric acid followed by malic and citric. Mature muscadine grapes grown in Arkansas typically have 0.5-0.7% titratable acidity and 3.0-3.3 pH (Barchenger et al., 2015b, Felts et al., 2018).

There are over 100 muscadine cultivars with various sizes, shapes, colors, and flavors (Anderson et al., 2020; Hickey et al., 2019; Hoffman et al., 2020; Olien and Hegwood, 1990). Cultivars ripen at different times and have varying amounts of cold hardiness, so it is important to choose a cultivar suited to grow in a specific environment. The way a muscadine may be used

depends on the cultivar, as different cultivars have different characteristics better suited for fresh eating or juice and wine production. Characteristics common among processing cultivars include small to medium sized berries, high yield, even ripening, and higher sugar and acid levels. 'Carlos' (bronze) and 'Noble' (black) are the most common muscadine grapes for processing due to their high production amounts and are both popular for juice and wine production (Anderson et al., 2020). Other processing cultivars include 'Alucha', 'Doreen', 'Magnolia', and 'Welder'. For fresh markets, it is preferable that the berry is large, sweet, visually appealing, and has thin skins with recommended fresh-market cultivars including 'Black Beauty', 'Darlene', 'Fry', 'Hall', 'Paulk', 'Summit', and 'Supreme' (Anderson et al., 2020; Hickey et al., 2019; Hoffman et al., 2020).

Muscadine breeding programs use existing cultivars and advanced breeding selections to create and release new cultivars. Public breeding programs across the southern United States include programs in Arkansas, Florida, North Carolina, Georgia, and Mississippi (Olien, 2001). The major private breeding program is based in North Carolina, which has made substantial progress on seedless muscadine development. Jeff Bloodworth (2017), a private fruit breeder in North Carolina collaborates with Gardens Alive! (Lawrenceburg, IN), developed seedless muscadines, including the spermostenocarpic first seedless muscadine cultivars, 'Oh My!®' and 'RazzMatazz®'. Advances in muscadine breeding also include the development of perfect-flowered and self-fruitful cultivars, increased berry size and sugar content, and presence of dry picking scars (Conner, 2010). Other traits undergoing development include more cultivars with perfect flowers and large fruit, improved textures, thinner skins, and a broader range of ripening dates. These breeding efforts will also help the expansion of the germplasm base used in muscadine breeding. Retaining the unique flavors and aromas of muscadines is a focus in

creating new cultivars for the commercial fresh markets. The University of Arkansas System Division of Agriculture (UA System) Fruit Breeding Program began breeding muscadines in 2007 with a focus on large fruit size, crisp texture, edible skin, self-fruitful flowers, seedlessness, and improved postharvest storability (Barchenger et al., 2015b; Felts et al., 2018; Worthington, 2019) as well as developing muscadine grape and muscadine hybrids (crosses with *V. vinifera*) that have thinner, more edible skins and no seeds (Worthington, 2019).

The color of the skin of muscadines is important for both fresh markets and processing. The exterior of the muscadine grape skins are less homogeneous in color than table grapes. The lack of homogeneity on the muscadine grapes is caused by the presence of lenticels that look like spots on the grape skins, also referred to as russeting (Hoffman et al., 2020; Perkins-Veazie et al., 2012). In addition, even on the same grape, the color shades of the muscadine skin can vary. Varanasi et al. (2022) found that berry pigmentation in muscadines is regulated by different mechanism than the gene responsible for berry skin color variation among *V. vinifera*. Lewter et al. (2019) determined that a genetic mutation in the anthocyanin biosynthesis pathway on a separate gene is responsible for the color difference in muscadines. Thus, the United States Department of Agriculture (USDA) (2006) has color standards regarding fresh-market muscadines describing skin color in two categories, white or black/red. White muscadines have either a bronze or blush tone with shades of green, straw, amber, bronze, and some small amounts of red or blush. Black/red muscadines can include red, pink, purple, and black colors with an outer skin with at least 75% red, purple, or black tones. Black muscadines can be classified further to red and black categories. Black muscadines are typically very dark, and red muscadines can show lighter tones of red, pink, and purple.

Muscadine color characteristics are important as they can change during ripening and during postharvest storage. It has been found that 90% of the total anthocyanins in muscadines were 3,5-diglucoside of delphinidin, cyanidin, and petunidin; the remaining 10% were 3,5-diglucoside of peonidin and malvidin, and the total anthocyanin content of dark/purple skinned muscadines had higher levels of anthocyanins than bronze-skinned muscadines (Huang et. al., 2009). Connor and Mclean (2013) examined anthocyanin profiles and color of muscadines grown in Georgia and found that malvidin, an important anthocyanin for color stability, was only present in a few genotypes but found positive correlations among other color parameters measured with anthocyanin content. These color changes in muscadine grapes and muscadine products can impact commercial marketability. Color in fresh muscadines, like many other fruits, can be used to determine the ripeness of each berry. The color change is more observable in white categories of muscadines, because as white muscadines mature on the vine the berries brown or darken (North Carolina Muscadine Grape Association, 2021; Walker et al., 2001). Although less observable in dark muscadines, black/red cultivars also darken during ripening. In addition, the color of the muscadines can darken during postharvest storage (Barchenger et al., 2015b; Felts, 2018).

Muscadines for fresh markets are typically packed in vented, plastic clamshell containers. Damage to muscadine grapes in a clamshell detracts from the appearance and impacts marketability. The USDA also has guides for damage of muscadines for fresh markets. Damage on a muscadine is defined as 10% of the outer skin being excessively dark and affecting the surrounding area, or lighter discoloration on more than 15% of the berry. Discoloration is a form of damage, and it can be contributed to sunburn, disease, or age. Discoloration is defined as a browning or blackening of color. Severe damage is defined as 25% of the outer area of the

muscadine berry is excessively dark and affecting surrounding areas, or 50% of the outer area has lighter superficial discoloration (USDA, 2006). Currently, the only muscadine visual aid provided by the USDA is an unofficial guide for stem scar, surface discoloration, and spotted damage/rot of bronze muscadines (Figure 1) (Perkins et al., 2012, USDA, 2006). There is a lot of variation among muscadine cultivars which makes grading muscadines challenging.

Firmness of muscadine grapes is not a factor in processing muscadines but is important to fresh markets. Traditionally, *V. vinifera* table grapes have a firm/crisp texture that appeal to consumers more than muscadine grapes (Chizk et al., 2021; Conner, 2013; Conner and Mclean, 2013) Texture is one of the largest limiting factors in the likability of muscadines. Berry puncture force was significantly correlated to the liking of skin texture and pulp texture in sensory testing of fresh-market muscadine grapes, and puncture force (maximum force to puncture berry skin measured as Newtons or grams) is a better predictor of overall liking than skin elasticity (distance skin ruptures measured in millimeters) (Brown et al., 2016). Therefore, texture or firmness analysis is an important tool for muscadine breeding programs.

Due to varying handling practices, storage practices, and genotypes, the postharvest evaluation of fruit is important to understand how to package and store fruit for extended shelf life. Muscadines can be harvested directly into clamshells and sold at commercial markets or some growers harvest, sort and wash the berries before packaging. The primary losses of muscadine grapes in storage is from decay and berry softening with a maximum storage periods of 2-4 weeks (Barchenger et al., 2015b; Basiouny and Himelrick, 2001; Felts et al., 2018; Takeda et al, 1983). Studies on muscadines grown in Arkansas have shown that bronze genotypes did not have as much storage potential as black genotypes, since bronze muscadines show more

prevalent browning (Barchenger et al., 2015b; Felts et al., 2018). However, temperature plays an important role in the preservation of muscadines during storage.

Muscadine grapes have many nutraceutical impacts (foods containing health-giving additives and having medicinal benefit). According to the USDA-Agricultural Research Service (2011), a 10-berry serving of muscadines has 16% of the daily Adequate Intake and 13-14% of the Recommended Daily Allowance of vitamin C. Muscadines also have high amounts of healthy bioactive compounds including resveratrol, ellagic acid, anthocyanins, and proanthocyanidin phenolics (Ector et al., 1996; Lee and Talcott, 2004; Pastrana-Bonilla et al., 2003; Threlfall et al., 2005). Anthocyanin content is highest in the skin of dark berries (Striegler et al., 2005), and although found throughout berries, phenolic content is highest in the seeds (Ector et al., 1996; Pastrana-Bonilla et al., 2003; Sandhu and Gu, 2010; Threlfall et al., 2005). Kim et al. (2009) found that red muscadine juice had natural antibacterial properties by showing the inhibition of *Escherichia coli* growth when exposed to fresh of processed muscadine juice. Muscadine juice has lower amounts of anthocyanin and phenolic than whole berries (Threlfall et al., 2005), but muscadine juice has been shown to inhibit in vitro growth of leukemia cells (Merotens-Talcott, 2008). In addition, some cell culture studies (Mertens-Talcott et al., 2008, Yi et al., 2005) have indicated that muscadine polyphenols can inhibit proliferation of colon cancer cells and induce apoptosis. As consumers have become aware of these muscadine health benefits, the demand for fresh and processed muscadine products has increased.

New analytical and visual resources for muscadine grapes are needed to provide inspectors, buyers, and retailers materials to more accurately define color and quality attributes representative of fresh-market muscadines that are commercially available. These resources can help people unfamiliar with muscadines as a commercial fruit know what to look for when

buying or grading, thus creating more consistency in the product for the consumer. In addition, it is important to determine the postharvest marketability of muscadines for commercial fresh markets. Therefore, the objectives of this research were to evaluate the harvest and postharvest attributes of fresh-market muscadine grapes grown in Arkansas and North Carolina.

Materials and Methods

Plants and culture

The muscadine genotypes for this study included grapes grown in Arkansas and North Carolina in 2020 and 2021 (Table 1).

Arkansas. Muscadine were harvested from vines grown at the UA System Fruit Research Station, Clarksville AR [west-central Arkansas, 35.533798404565445, -93.40583345945807; U.S. Dept of Agriculture (USDA) hardiness zone 7a; soil type Linker fine sandy loam (Typic Hapludult)]. Vines are spaced 6.1 m apart and rows are spaced 3.0 m apart. The vines are trained to a bi-lateral, high-cordon/curtain training system and pruned to three- to four-bud spurs annually. Weeds were controlled by applications of preemergence and postemergence herbicides applied annually. Vines were fertilized annually in March or April with nitrogen or complete fertilizers. Fungicides were applied similar to a commercial requirement to control macrophoma rot (*Botryosphaeria dothidea*), bitter rot (*Greeneria uvicola*), and ripe rot (*Colletotrichum spp*.). The last application of any fungicide is usually done near the end of June to early July. On average, five fungicide sprays and two insecticide sprays are applied to the grapes.

North Carolina. Muscadines were harvested from a commercial vineyard in King Mountain North Carolina. The commercial vineyard was formerly Lineberger's Killdeer Farms, now owned by Gardens Alive! [west-central North Carolina, 35.288541278322555, -81.37195264596885; U.S. Dept of Agriculture (USDA) hardiness zone 7a; Madison-Bethlehem

complex soil type sandy clay loam)]. Pest and weed management of muscadines were followed using the Muscadine Grape Production Guide for the Southeast (Hofmann et al., 2020).

Harvest

Fruit was harvested from both the UA System Fruit Research Station, Clarksville, AR and a private commercial grower in Kings Mountain, NC. The muscadines were hand harvested in the early morning (prior to 11:00 AM) September-October. The fruit was harvested at optimal ripeness and free of major visible blemishes, flaws, or damage. Approximately 1.8 kg of berries were harvested into 846 g (1-quart) vented clamshells for each genotype at each site. In Arkansas, the clamshells of grapes were placed in an ice chest chilled with ice packs and transported to the UA System Department of Food Science in Fayetteville, AR. The clamshells of grapes from North Carolina were placed in a walk-in cooler (4 °C) after harvest for 24 hrs prior to shipping to Arkansas. After harvest (and upon arrival of the North Carolina fruit), the grapes were sorted into 470 g (1-pint) vented clamshells in triplicate for each genotype and storage date. For muscadines that shipped from North Carolina, fruit without any shipping damage was used for this study. After analysis of harvest (day 0) attributes, grapes were stored at 2 °C (85% to 89% relative humidity) for 14 and 28 days

Arkansas. All the muscadine genotypes harvested from Arkansas were seeded. Nine muscadine genotypes (AM-26, AM-70, AM-77, AM-102, AM-131, AM-135, AM-195, 'Summit', and 'Supreme') were harvested in 2020, and seven genotypes (AM-26, AM-70, AM-77, AM-135, AM-148, AM-154, and AM-240) were harvested in 2021. Severe cold weather in the spring of 2021 damaged many of the muscadine vines thus different cultivars that survived the freeze were used in 2021.

North Carolina. Seeded and seedless muscadine genotypes were harvested from North Carolina. Seven genotypes (JB-06-30-2-20, JB-08-38-1-10, JB-09-15-3-09, 'Oh My!®', 'RazzMatazz®', 'Summit', and 'Supreme') were harvested in 2020, and ten genotypes ('Hall', JB-06-30-2-20, JB-08-38-1-10, JB-09-15-3-09, 'Lane', 'Oh My!®', 'Paulk', 'RazzMatazz®', 'Summit', and 'Supreme') were harvested in 2021. JB-06-30-2-20, JB-08-38-1-10, JB-09-15-3-09, 'Oh My!®', 'RazzMatazz®' were reported as seedless genotypes. The clamshells of muscadine from North Carolina were shipped overnight to UA System Food Science Department, Fayetteville, AR. A shipping container with appropriate packaging was used to minimize muscadine fruit bruising and keep temperatures below 10 °C. There were 2-4 clamshells for small-sized genotypes and 4-6 clamshells for large-sized genotypes. The clamshells of muscadines were packed in carboard/Styrofoam shipping containers with ice packs. Each clamshell was secured with a rubber band and placed in carboard trays. A moisture resistant foam or bubble wrap was used inside the container to protect the fruit during shipping. The temperature of the container was monitored with DeltaTrak FlashLink® In-Transit BLE Temperature and Humidity Logger (Model 40910, Pleasanton, CA). The maximum temperature during shipping did not exceed 13.3 °C in 2020 and 12.8°C in 2021.

Physical attributes

Five berries per genotype, storage date, and replication were evaluated for physical attributes. The physical (berry size, color, firmness, seed number, seed size, and stem scar tear) attributes of each of the fresh-market muscadines grown in Arkansas and North Carolina were evaluated at the UA System Food Science Department. All physical attributes were measured at harvest (day 0 or upon arrival after shipping) and berry size, color, and firmness were measured

during storage (14 and 28 days at 2 °C). After physical attributes were analyzed, the samples for composition were placed in zip-type bags and stored at -10 °C until analysis.

Berry size. Size attributes of the muscadines evaluated included individual berry weight, length, and width. Each berry was weighed (g) on a digital scale, and the width (mm) and length (mm) of each berry was measured with digital calipers.

Color. The color of the grape skins was analyzed using a Konica Minolta CR-400 Chroma Meter (Konica Minolta, Inc., Ramsey, NJ). The L*, chroma, and hue angle was evaluated using Commission Internationale de l'Eclairage (CIE) Laboratory transmission values of L* = 100, a* = 0, and b* = 0 (CIE, 1986). The CIELAB system describes color variations as perceived by the human eye. CIELAB is a uniform three-dimensional space defined by colorimetric coordinates, L*, a*, and b*. The vertical axis L* measures lightness from completely opaque (0) to completely transparent (100), while on the hue-circle, +a* red, -a* green, +b* yellow, and -b* blue are measured. Hue angle, calculated as $\tan^{-1}\frac{b*}{a*}$, described color in angles from 0 to 360°: 0° is red, 90° is yellow, 180° is green, 270° is blue, and 360° is red. For samples with hue angles <90°, a 360° compensation (hue + 360°) was used to account for discrepancies between red samples with hue angles near 0° and those near 360° (McLellan et al. 2007). Chroma, calculated as $\sqrt{a*^2 + b*^2}$, identified color by which a wine appeared to differ from gray of the same lightness and corresponded to saturation (intensity/purity) of the perceived color.

Firmness. Firmness of each berry was measured using a Stable Micro Systems TA.XT.plus texture analyzer (Texture Technologies Corporation, Hamilton, MA). The berries were placed on the texture unit vertically, stem scar down, using a 2-mm diameter probe at a rate of 2 mm/s with a trigger force of 0.02 N. Berry firmness was measured as force (N) to penetrate the berry. Skin firmness was the force required to puncture the skin of the berry divided by the distance traveled

before the berry skin ruptured (N/mm). Skin elasticity was measured as the distance (mm) traveled before the berry skin ruptured.

Seed number and size. For genotypes with seeds or trace seeds, the seeds of each berry were removed, weighed, and counted. Total seed weight (g) was measured on a digital scale (PA224 Analytic Balance; Ohaus Corporation, Parsippany, NJ). Average seed weight was calculated (total seed weight/number of seeds).

Stem scar tear. The stem scar tear (tear > 2x diameter of stem scar) of the berries was calculated as (number of torn berries/total berries) × 100 and expressed as percent.

Composition attributes

Five to twenty-five berries (depending on the size of the berries) per genotype, storage date, and replication were evaluated for composition attributes. Berries were thawed placed in cheesecloth, and the berries were squeezed to extract the juice from the berries. The juice from the berry samples was used to determine composition attributes. The composition (soluble solids, pH, titratable acidity, organic acids, and sugars) attributes of each of the fresh-market muscadines grown in Arkansas and North Carolina were evaluated at the UA System. The composition attributes were measured at harvest (day 0 or upon arrival after shipping) and during storage (14 and 28 days at 2 °C). Samples for composition were placed in zip-type bags and stored at -10 °C until analysis.

Soluble solids. Soluble solids (expressed as percent) of the juice were measured using an Abbe Mark II refractometer (Bausch and Lomb, Scientific Instrument, Keene, NH).

pH. The pH of juice was measured using a PH700 pH meter (Apera Instruments, Columbus, Ohio). The pH was measured after the probe had been in the sample for 2 min.

Titratable acidity. The titratable acidity of the juice was measured using a Metrohm 862 Compact Titrosampler (Metrohm AG, Herisau, Switzerland) fitted with a pH meter. Titratable acidity was determined using 6 mL of juice diluted with 50 mL of deionized, degassed water by titration with 0.1 N sodium hydroxide (NaOH) to an endpoint of pH 8.2; results was expressed as g/L tartaric acid.

Sugars and organic acids. Sugars and organic acids of the juice were determined using high performance liquid chromatography (HPLC). The juice for compositional analysis was filtered through a 0.45 μm nylon filter (VWR International, Radnor, PA) and was analyzed using HPLC. Glucose, fructose, tartaric acid, malic acid, and citric acid of blackberries were measured using previously established HPLC procedures (Walker et al., 2003). The HPLC was equipped with a Bio-Rad HPLC Organic Acid Analysis Aminex HPX-87H ion exclusion column (300 × 7.8 mm), Bio-Rad HPLC Fast Acid Analysis column (100 x 7.8 mm), and a Bio-Rad HPLC column for fermentation monitoring (150 × 7.8 mm) in series. A Bio-Rad Micro-Guard Cation-H refill cartridge (30 × 4.5 mm) was used for a guard column (Bio-Rad, Hercules, CA). Columns were maintained at 65 °C by a temperature control unit. Mobile phase consisted of a pH 2.28 solution of sulfuric acid and water with a resistivity of 18 M obtained from a Millipore Milli-Q reagent water system. The sulfuric acid solution was used as the solvent with 0.35 mL/min flow rate. The solvent delivery system was a Waters 515 HPLC pump equipped with a Waters 717 plus autosampler (Waters Corporation, Milford, MA). Injection volumes were 10 µL for all samples, and run time for completion was 45 min. A Waters 410 differential refractometer to measure refractive index connected in series with a Waters 996 photodiode array detector monitored the eluting compounds. Tartaric, malic, and citric acids were detected by photodiode array at 210 nm and glucose and fructose were detected by the differential refractometer. The peaks were

quantified using external standard calibration based on peak height estimation with baseline integration. Individual sugars, individual organic acids, total sugars (glucose + fructose), and total organic acids (tartaric + malic + citric) were expressed as g/100 mL (or %) of the muscadine juice.

Marketability attributes

The marketability attributes of the grapes grown in Arkansas and North Carolina were evaluated at the UA System and included decay and weight loss. Decay and weight loss were evaluated at 0, 14, and 28 d at 2 °C for each genotype and replication.

Decay. The decay (visible mold or rot) of the berries were calculated as (number of decayed or torn berries/total berries) × 100 and expressed as percent.

Weight loss. The weight loss of the muscadines in the clamshell were calculated as the total weight decrease of the grapes in the clamshell expressed as percent.

Statistical design and analysis

For physical, composition, and marketability attributes, all genotypes were evaluated in triplicate by year. The data was analyzed by analysis of variance (ANOVA) using JMP® (version 16.0.0; SAS Institute Inc., Cary, NC). Tukey's Honestly Significant Difference was used for mean separations ($p \leq 0.05$).

Results and Discussion

Physical attributes at harvest

Most of the physical attributes of the muscadines from both locations and years were significantly impacted by genotype. Seed number (3.00) and seed weight (0.28 g) in 2020 and 2021, respectively, in Arkansas-grown muscadines, and skin elasticity (6.79 mm) of muscadines harvested from North Carolina in 2021 were not significantly impacted. (Tables 2-3). Figs 2-3

show the range of colors, sizes, and shapes of muscadines evaluated from Arkansas and North Carolina. Regardless of year and location, the physical attributes varied including berry weight (1-21 g), berry length (10-31 mm), berry width (10-33 mm), seed number (0-5), seed weight (0.0-0.4 g), stem scar tear (0-29%), berry firmness (4-11 N), skin firmness (0.5-1.8 N/mm), skin elasticity (5-9 mm), L* (24-52), a* (-4-15), b* (0.4-23), hue (7-103), and chroma (2-18) (Tables 2-5).

The berry weights (9-14 g), seed number (1-4) and seed weights (0.1 g) varied for Arkansas-grown muscadines, as well as stem scar tear (1-11%) (Felts et al., 2018). Ballinger et al. (1982) investigated 'Carlos' muscadine grapes and found that the grapes decayed faster at 20°C and 10°C as compared to 0°C, in addition decay potential and percent of grapes with dry (untorn) stem scars varied. Grapes with torn stem scars, stored for one week at 10°C or three weeks at 0°C, had six to ten times more decay than grapes with dry stem scars (Ballinger et al., 1982). In terms of firmness, Worthington et al. (2021) evaluated the firmness of Arkansas and North Carolina grown muscadines and found that berry firmness ranged from 5-11 N. Felts et al. (2018) also observed a range of skin firmness (0.9-1.5 N/mm) and skin elasticity (4-9 mm) in Arkansas-grown muscadines. Barchenger et al. (2015b) observed L*, chroma, and hue values of 25-91, 2-18, and -11-91, respectively in Arkansas-grown muscadines. Arkansas grown muscadines harvested in 2013 were firmer than berries harvested in 2012, and berry firmness at harvest was up to 14 N. (Barchenger et al., 2015b). Conner (2013) found that muscadine grown in Georgia had skin elasticity 4-8 mm and berry firmness 6-14 N, and these muscadines were not as firm but were crisper than *V. vinifera* seedless table grape berries, 'Midnight Beauty' (black) and 'Sugraone' (green) that had skin elasticity of 3 mm and berry firmness of 4-5 N. Worthington et al. (2019) also evaluated the firmness of muscadines and *V. vinifera* grapes. The

evaluation included ‘Red Globe’ (*V. vinifera*), a commercial seeded table grape cultivar originating in China and found that the berry firmness was 3 N and skin elasticity was 6 mm. In contrast, the berry firmness of seven muscadine genotypes from Arkansas and North Carolina and ranged from 7-11 N. According to a trained descriptive sensory panel, detachability and visual separation of muscadine berry skins were positively correlated with skin elasticity and negatively correlated with berry firmness indicating that genotypes with softer, gummier flesh tended to slip from skins more easily (Worthington et al., 2019).

Arkansas 2020. AM-70 had the highest berry weight (12.50 g) and berry width (27.49 mm). AM-77 had the lowest berry weight (4.76 g), berry length (19.63 mm), berry width (19.43 mm), and skin firmness (0.96 N/mm) and the highest seed weight (0.42 g) and skin elasticity (7.90 g). AM-131 had the highest berry length (28.00 mm) and skin firmness (1.82 N/mm), but AM-26 had the same skin firmness as AM-131. AM-135 had the lowest berry firmness (6.53 N) and skin elasticity (4.87 mm), and ‘Summit’ had the highest berry firmness (10.75 N). Overall, ‘Supreme’ had the highest stem scar tear percent (6 %). All genotypes had 2-4 seeds per berry. In terms of color, AM-26 had the highest b* (16.70) and ‘Summit’ had the highest chroma (16.81). AM-135 had the lowest a* (-2.33) and the highest hue (97.48). AM-131 had the highest L* (46.33), and AM-77 had the lowest L* (24.69), b* (0.79), and chroma (3.05). AM-102 had the lowest hue (10.26), and AM-70 had the highest a* (10.04). In general, bronze genotypes had an L*, hue, and chroma of 44, 93, and 16, respectively, while black genotypes had 26, 12, and 7, respectively. Black genotypes were about 41% darker than bronze genotypes in terms of the L* value.

Arkansas 2021. AM-135 had the highest berry weight (13.88 g), berry length (29.88), and seed number (4.67) and lowest berry firmness (7.90 N). Again, AM-77 had the lowest berry weight (5.67 g), berry length (20.83 mm), berry width (20.76 mm), skin firmness (1.21 N/mm), but the

highest berry firmness (10.78 N) and skin elasticity (8.92 mm). AM-148 had no stem scar tear, while AM-154 had the highest stem scar tear (22.60 %). AM-154 also had the highest skin firmness (1.65 N/mm) and the lowest skin elasticity (5.35 mm). The genotypes had 2-5 seeds with seed weights 0.2-0.4 g. AM-77 had the lowest L* (24.38) and chroma (2.47), AM-135 had the highest L* (52.15), b* (17.15), and chroma (17.59). AM-26 had the highest hue (88.91) and lowest a* (-0.06). AM-70 had the lowest b* (0.60) and hue (8.28). AM-154 had the highest a* (12.75). In general, bronze genotypes had an L*, hue, and chroma of 47, 85, and 16, respectively, black genotypes had 25, 15, and 4, respectively, and pink/red genotypes had 28, 14, and 13, respectively. Black genotypes were about 47% darker than bronze genotypes in terms of the L* value.

North Carolina 2020. 'Supreme' had the highest berry weight (21.14 g), berry length (31.28 mm), berry width (32.66 mm), berry firmness (10.50 N), and skin firmness (1.56 N/mm). 'Summit' had one the highest seed numbers along with other genotypes (JB-08-83-1-10 and JB-09-15-3-9). 'Summit' had the highest seed weight (0.28 g). 'RazzMatazz®' had the lowest berry weight (0.77 g), berry length (10.32 mm), berry width (9.67 mm), and stem scar tear (0.11%) due to cluster harvesting. JB-06-30-2-20 had the lowest berry firmness (4.38 N), and skin firmness (0.51 N/mm). 'RazzMatazz®' and 'Oh My®' had no seeds. 'Summit had the highest L* (45.45), b* (16.68), hue (95.73), chroma (16.88), and the lowest a* (-2.10). JB-8-38-1-10 had the lowest L* (23.51), b* (0.39), hue (11.03), and chroma (2.18). 'RazzMatazz®' had the highest a* (13.17). In general, bronze genotypes had an L*, hue, and chroma of 42, 89, and 13, respectively, black genotypes had 24, 11, and 3, respectively, and pink/red genotypes had 32, 43, and 12, respectively. Black genotypes were about 43% darker than bronze genotypes in terms of the L* value.

North Carolina 2021. ‘Supreme’ had the highest berry weight (14.41 g), length (27.59 mm), width (28.10 mm), stem scar tear (29.42%), berry firmness (11.03 N), and skin firmness (1.67 N/mm). ‘RazzMatazz®’ had the lowest berry weight (1.12 g), length (11.17 mm), width (10.56 mm), stem scar tear (1.88%), berry firmness (4.98 N), skin firmness (0.77 N/mm), and skin elasticity (6.53 mm). The genotypes JB-06-30-2-20, JB-09-15-3-9. ‘Oh My!® ’ and ‘RazzMatazz®’ had no seeds found in 2021, but JB-08-38-1-10, although seedless, had trace seeds. In 2020, there were aborted/trace seeds found in JB-06-30-2-20, JB-08-38-1-10, and JB-09-15-3-09 that were counted and weighed as seeds. ‘Lane’ had the highest seed weight (0.22 g), and ‘Paulk’ had the highest number of seeds (3.67). JB-06-30-2-20 had the highest skin elasticity (8.77 mm). ‘Hall’ had the highest L* (47.13), b* (16.85), and chroma (17.22). JB-06-30-2-20 had the highest hue (102.86) and the lowest a* (-3.82). JB-08-38-1-10 had the lowest L* (23.59), b* (0.53), and chroma (2.69). ‘Paulk’ had the lowest hue (6.67). ‘RazzMatazz®’ had the highest a* (14.70). In general, bronze genotypes had an L*, hue, and chroma of 45, 92, and 16, respectively, black genotypes had 24, 10, and 4, respectively, and pink/red genotypes had 32, 46, and 13, respectively. Black genotypes were about 47% darker than bronze genotypes in terms of the L* value.

Composition attributes at harvest

All composition attributes of the muscadines from both locations and years were significantly impacted by genotype (Tables 6-9). Regardless of year and location, the composition attributes varied including soluble solids (11-19%), pH (2.8-4.0), titratable acidity (0.25-1.21%), soluble solids/titratable acidity ratio (11-70), total organic acids (0.25-0.93%), and total sugars (10-21%). Felts et al. (2018) evaluated composition attributes of six muscadine genotypes grown in Arkansas with a soluble solid range from 13-15%, pH from 2.9-3.3,

titratable acidity from 0.5-1.0%, and titratable acidity/soluble solid ratio 13-28. Campbell et al. (2021) evaluated composition attributes of 90 genotypes including 21 cultivars, 60 breeding lines, and nine *V. vinifera* x *V. rotundifolia* hybrids and found a range for pH (3.1-3.9), titratable acidity (0.2-0.5%), soluble solids (8-18%), and titratable acidity/soluble solids ratio (2-7).

It has been shown that the optimal titratable acidity/soluble solids ratio is 25-35 (Flora, 1979), and another research on consumer sensory of muscadines showed optimal soluble solids/ titratable acidity ratio from 26-31 (Threlfall et al., 2007). In addition, total organic acids ranged from 0.5-0.8 g/100 mL with tartaric acid (0.4%), malic acid (0.2%), isocitric (0.1%) as the major acids (Felts et al., 2018). The 'RazzMatazz®' from North Carolina in both years generally had high sugar and high acid components. Whereas AM-77 from Arkansas both years tended to have high acids and low sugars. Kliewer (1967) evaluated the glucose/fructose ratio of *V. vinifera* table grapes and observed a range from 0.7-1.0 with an average of 0.9. In general for our study, all muscadines evaluated at harvest had a glucose/fructose ratio from 0.76-1.10 with an average of 0.97.

Arkansas 2020. AM-77 had the highest titratable acidity (1.06%) but the lowest soluble solids (11.37%), pH (2.81), and soluble solids/titratable acidity (10.75). AM-70 had had the highest soluble solids/titratable acidity ratio (35.17) and the lowest titratable acidity (0.43%). AM-195 had the highest pH at 3.8, and 'Supreme' had the highest soluble solids (17.43%). For the individual and total sugars and organic acids, 'Supreme' had the highest glucose (8.72%), fructose (8.46%), and total sugars (17.18%) and also had the lowest malic acid (0.07%). AM-195 had the lowest tartaric acid (0.16%) and total organic acids (0.27%). AM-131 had the highest malic acid (0.16%), and AM-102 had the lowest citric acid (0.02%). AM-77 had the lowest

glucose (4.09%), fructose (5.64%), and total sugars (9.73%) but had the highest tartaric acid (0.47%), and total organic acids (0.61%).

Arkansas 2021. For the muscadines from Arkansas, AM-135 had the highest soluble solids (19.47%) and soluble solids/titratable acidity ratio (70.31). AM-240 had the highest pH (3.98). AM-77 had the highest titratable acidity (0.88%), lowest pH (3.04), lowest soluble solids (14.00%), and soluble solids/titratable acidity ratio (16.06). AM-77 had the highest tartaric acid (0.41%), malic acid (0.11%), citric acid (0.09%), and total organic acids (0.61%). AM-135 had the highest glucose (9.95%), fructose (10.23%), total sugars (20.18%), and lowest tartaric acid (0.16%). AM-154 had the lowest malic acid (0.03%), citric acid (0.02%), and total organic acids (0.26%).

North Carolina 2020. In 2020, 'RazzMatazz®' had the highest soluble solids (19.43%) and titratable acidity (1.21%) but the lowest pH (2.83) and lowest soluble solid/titratable acidity ratio (16.20). Summit had the lowest soluble solids (16.17%). 'Supreme' had the highest pH (3.45), lowest titratable acidity (0.41 %) and soluble solids/titratable acidity (40.30). JB-06-30-2-20 had the lowest amount of malic acid (0.04%). 'Oh My! ®' had the highest citric acid (0.04%). 'RazzMatazz®' had the highest amount of glucose (9.65%), fructose (8.96%), total sugars (18.61%), tartaric acid (0.57%), malic acid (0.18%), total organic acids (0.76%), and lowest citric acid (0.02%). 'Supreme' had the lowest glucose (6.88%), fructose (7.00%), total sugars (13.88%), tartaric acid (0.15%), and total organic acids (0.25%).

North Carolina 2021. For the muscadines from North Carolina, 'Summit' had the highest soluble solids (18.60%) and soluble solids/titratable acidity ratio (37.66). JB-08-38-1-10 had the lowest soluble solids (14.40%). 'Lane' had the highest pH (3.55) and lowest titratable acidity (0.47%). RazzMatazz® had the highest titratable acidity (1.14%) and lowest soluble

solids/titratable acidity ratio (16.16). JB-06-30-2-20 had the lowest malic acid (0.05%), and JB-08-38-1-10 had the lowest glucose (6.56%), fructose (6.75%), and citric acid (0.01%). 'Paulk' had the highest citric acid (0.05%), and 'RazzMatazz®' had the highest glucose (8.30%), fructose (8.53%), total sugars (16.83%), tartaric acid (0.78%), malic acid (0.14%), and total organic acids (0.93%). 'Summit' had the lowest total organic acids (0.30%), and 'Supreme' had the lowest amount of tartaric acid (0.17%).

Marketability attributes during storage

The color attributes (L*, Hue, and Chroma), firmness attributes (berry firmness, skin firmness, and skin elasticity), weight loss, and unmarketable berries were evaluated during storage for 0, 14, and 28 days at 2 °C. The L*, berry firmness, weight loss, and unmarketable berries for muscadines from both locations and years were significantly impacted by genotype (Tables 10-13). Regardless of location and year, the L* ranged from 24-49, berry firmness ranged from 4-11 N, weight loss ranged from 0-6%, and unmarketable berries ranged from 0-42%. Correlation test for berry firmness, skin firmness, skin elasticity, stem scar tear, L*, and percent unmarketable berries were ran on all berries and years. Berry firmness was positively correlated to skin firmness (r^2=0.93). Skin firmness was negatively correlated to unmarketables berries (r^2= -0.21) and stem scar tear (r^2= -0.23). Stem scar tear was positively correlated (r^2=0.43) to unmarketable berries. Barchenger et al (2015a) investigated Arkansas-grown muscadines and found that the muscadines had up to 7% weight loss during storage at 2 °C, and unmarketability of the berries in clamshells was high (42%) in Arkansas-grown muscadine grapes at three weeks of storage. In the same study, berry firmness and L* of the berry skin were analyzed and ranged from 2-11 N and 23-105, respectively. L*, hue and chroma of muscadines grapes and *V. vinifera* x *V. rotundifolia* hybrids and were relatively stable through storage up to

42 days, with the exception of decreasing L* value in some instances (Campbell et al., 2021). James et al. (1999) observed weight loss and unmarketability in three muscadine cultivars from Arkansas, Mississippi, and Florida with up to 13% weight loss observed over 28 days storage, and the unmarketability ranged from 8-72% for the four-week period.

Arkansas 2020. L*, hue, chroma, berry firmness, weight loss, and unmarketable berries for muscadines were significantly impacted by genotype (Table 10 and Figs. 4-6). For the color attributes, harvest date only impacted the L* of AM-135 and 'Summit' and hue of 'Summit'. AM-135, a bronze, at day 0 (45.63) was lower than days 14 (50.71) and 28 (51.22), which means that AM-135 got lighter in color during storage. Whereas, 'Summit', a bronze, at day 0 (42.99) had a higher L* value than day 28 (37.22). Hue was higher for 'Summit' at day 0 (89.40) and day 14 (91.74) than at day 28 (78.38) which means the berry was less yellow after storage. Storage did not impact the berry firmness of the muscadines except for 'Summit.' that had a higher firmness at day 0 (10.75 N) than at day 28 (7.77 N), which was a 28% decrease in berry firmness. 'Summit' day 0 (10.75 N) had the highest berry firmness, and AM-77 at 28 days (6.29 N) was the least firm. Genotype and storage impacted skin firmness and skin elasticity. AM-131 (1.85 N/mm) had the highest skin firmness and AM-77 (0.86 N/mm) the lowest. AM-77 (8.55 mm) had the highest skin elasticity and AM-135 mm) the lowest. In term of storage, skin firmness decreased during storage and skin elasticity increased. The skin firmness at day 0 was higher than day 14 and 28, where for skin elasticity, the day 0 was lower than day 14 and 28. For Arkansas muscadines, weight loss was < 8% and unmarketability < 25% after storage for 28 days. Weight loss increased from day 0 as compared to day 14 and 28 for all genotypes. At day 28, AM-102 had the highest weight loss (7.83%), and AM-195 (4.88%) had the lowest. At day 28, 'Supreme' had the highest unmarketability (24.56%), and AM-26 had the lowest (4.42 %).

AM-70, AM-131, AM-135, AM-195, 'Summit', and 'Supreme' all had increases in unmarketability from day 0 to day 28.

Arkansas 2021. The L*, berry firmness, skin firmness, weight loss, and unmarketable berries for muscadines were significantly impacted by genotype (Table 11 and Figs. 7-9). L* was not affected by storage except for AM-135 which was darker at day 28 (47.2) than at day 0 (52.2) or day 14 (50.7). Genotype impacted hue of these muscadines. AM-26 (85.95) and AM 70 (78.76) had higher hue than the other genotypes. Storage did not impact hue or chroma. Storage did not impact berry firmness except for AM-70 and AM-240. AM-70 day 0 (10.00 N) was firmer than day 28 (6.91 N), and AM-240 day 0 (10.20 N) was firmer than day 28 (6.22 N). This was a decrease of berry firmness by 31% and 39% for AM-70 and AM-240, respectively. For the skin firmness, each genotype was affected by storage, with skin firmness decreasing during storage. At day 0, AM-26 day 0 (1.53 N/mm) had the highest skin firmness, and AM-77 8 (1.21 N/mm) had the lowest. Skin elasticity of the berries increased during storage. AM-77 (9.45 mm) had the highest skin elasticity. Weight loss was < 9% and unmarketability < 23% after 28 days of storage. All of the genotypes had significantly higher weight loss at 28 days as compared to day) and day 14. At day 28, AM-26 (5.06%) had the lowest weight loss, and AM-70 (8.66%) had the highest. The percent of berries that were unmarketable were not impacted by storage except AM-70 day 28 (22.54%) which had more unmarketable berries than the other storage days. AM-148 had no unmarketable berries at any storage day, and AM-154 at day 28 had no unmarketable berries. In fact, AM-148 had no stem scar tear stem scar tear at harvest.

North Carolina 2020. L*, hue, berry firmness, skin firmness, weight loss, and unmarketable berries for muscadines were significantly impacted by genotype (Table 12 and Figs. 10-12). Storage did not impact except L* and hue except for 'Summit', L* for 'Oh My! ®' and hue for

JB-09-15-3-9. The L* value for 'Summit' at day 0 (45.45) decreased at day 28 (37.28), and the L* value for 'Oh My! ®' at day 0 (38.73) decreased at day 28 (34.22). The hue for 'Summit' at day 0 (95.73) decreased at day 28 (77.73), and JB-09-15-3-9 at day 0 (70.66) decreased at day 28 (56.88). Genotype impacted chroma of the berry skins but not storage. 'Oh My! ®' and 'Summit' had a significant decrease in berry firmness and skin firmness during storage. The berry firmness of 'Oh My! ®' decreased from day 0 (7.21 N) to day 28 (2.76 N), and 'Summit' decreased from day 0 (9.84 N) to day 28 (5.45 N). The skin firmness of 'Oh My! ®' from day 0 (0.94 N/mm) lowered significantly by day 28 (0.40 N/mm), and 'Summit' also lowered from day 0 (1.35 N/mm) to day 28 (0.62 N/mm). The skin firmness of 'Supreme' muscadines lowered significantly only at day 14 (1.09 N/mm) of storage, down from day 0 (1.56 N/mm). Skin elasticity was not impacted by genotype or storage. Storage significantly impacted weight loss for each genotype at each storage date, with a weight loss from 5%-11% after 28 days of storage. At day 28, JB-06-30-2-20 (59.72%), JB-08-38-1-10 (34.84%), and 'Oh My! ®' (83.33%) had higher unmarketable berries than at day 0 or 14.

North Carolina 2021. L*, berry firmness, weight loss, and unmarketable berries for muscadines were significantly impacted by genotype (Table 13 and Figs. 13-15). Storage did not impact L* except 'Hall', bronze cultivar, at day 0 (47.13) got darker by day 28 (43.29). Genotype impacted both hue and chroma, and storage only impacted hue which decreased during storage. Storage did not impact berry firmness except for 'Hall' and JB-08-38-1-10. The berry firmness of 'Hall' at day 0 (9.17 N) lowered significantly by day 28 (5.61 N), and JB-08-38-1-10 also lowered from day 0 (8.59) to day 28 (5.67). This is a decrease in berry firmness of 38.82% and 33.99% for 'Hall' and JB-08-38-1-10, respectively. Genotype and storage impacted skin firmness and skin elasticity. The skin firmness at day 0 was higher than day 14 and 28, where for skin elasticity,

the day 0 was lower than day 14 and 28. For North Carolina muscadines at day 28, weight loss was < 9% and unmarketability was < 37%. The weight loss of all genotypes increased during storage. At day 28, JB-09-15-3-9 (8.55%) had the highest weight loss and 'Hall' (3.97%) had the lowest. Storage did not impact the unmarketable berries except at day 28 'Hall' (37.09%) and JB-08-38-1-10 (34.80%) had higher unmarketable berries than at day 0 and 14. It was interesting that JB-06-30-2-20 (59.72%) and 'Oh My! ®' (83.33%) had high unmarketable berries after storage in 2020, but these genotypes had much lower unmarketable berries (9.91% and 2.6%, respectfully) in 2021.

Conclusions

Understanding the attributes that impact the quality of muscadines at harvest and during storage, as well as the differences between muscadines and *V. vinifera* grapes is important to improve the current USDA standards and grades for fresh-market muscadine grapes. In 2020 and 2021, a total of 33 muscadine genotypes grown in Arkansas (16 genotypes) and North Carolina (17 genotypes) were evaluated at harvest (0 d) and during postharvest storage (14 and 28 d at 2 °C). At harvest, most physical and all composition attributes of the muscadine from both locations and years were significantly impacted by genotype. Overall, genotype had the most impact on the postharvest quality of fresh-market muscadine grapes grown in Arkansas and North Carolina in 2020 and 2021. Additionally, evaluation of the fruit at 28 d postharvest storage at 2 °C indicated that while no one genotype performed well in all categories, most genotypes had good storability with most muscadines having low weight loss (<9) and unmarketable berries (<29%). This implies that there is significant diversity for consumers and producers in the overall eating experience of muscadines based on composition, firmness, and berry size. Weight loss, unmarketable berries, berry firmness, and skin firmness were greatly impacted by storage.

The changes in these muscadines during storage included decreased berry firmness, increased weight loss, increased unmarketable berries, and decreased L* values (darkening). However, the black muscadines had much less decreases in L* values in comparison to bronze muscadines which in some cases visibly darkened. Of the 33 muscadines evaluated in the two years on seven genotypes had unmarketable berries above 10% after storage for 28 d. This research is important information for breeding programs to understand how these new genotypes compare to cultivars (both muscadines and *V. vinifera*) that are currently commercially available. Introduction of new cultivars like 'RazzMatazz® ' and the breeding selection, AM-148, that had very low stem scar tear and unmarketable berries have the potential to broaden the market for growers and consumers of fresh-market muscadines. Data generated from this project provided information attributes of muscadine grapes that can be used for developing recommendations for standards for grades, marketing, and support muscadine breeding efforts.

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Table 1. Muscadine grapes grown in Arkansas (Clarksville, AR) and North Carolina (Kings Mountain, NC) and evaluated at the University of Arkansas System Division of Agriculture (2020 and 2021).

Year	Location	Genotype	Skin color	Seeds
2020	**Arkansas**	AM-26	Bronze	Seeded
		AM-70	Dark/black	Seeded
		AM-77	Dark/black	Seeded
		AM-102	Dark/black	Seeded
		AM-131	Bronze	Seeded
		AM-135	Bronze	Seeded
		AM-195	Dark/black	Seeded
		Summit	Bronze	Seeded
		Supreme	Dark/black	Seeded
	North Carolina	JB-06-30-2-20	Bronze	Seedless
		JB-08-38-1-10	Dark/black	Seedless
		JB-09-15-3-9	Bronze	Seedless
		Oh My!®	Bronze	Seedless
		RazzMatazz®	Red	Seedless
		Summit	Bronze	Seeded
		Supreme	Dark/black	Seeded
2021	**Arkansas**	AM-26	Bronze	Seeded
		AM-70	Dark/black	Seeded
		AM-77	Dark/black	Seeded
		AM-135	Bronze	Seeded
		AM-148	Dark/black	Seeded
		AM-154	Red	Seeded
		AM-240	Dark/black	Seeded
	North Carolina	Hall	Bronze	Seeded
		JB-06-30-2-20	Bronze	Seedless
		JB 08-38-1-10	Dark/black	Seedless
		JB-09-15-3-9	Red	Seedless
		Lane	Dark/Black	Seeded
		Oh My!®	Bronze	Seedless
		Paulk	Dark/black	Seeded
		RazzMatazz®	Red	Seedless
		Summit	Bronze	Seeded
		Supreme	Dark/black	Seeded

Table 2. Physical attributes at harvest of muscadine grapes grown in Arkansas (Clarksville, AR) and North Carolina (Kings Mountain, NC) and evaluated at the University of Arkansas System Division of Agriculture (2020).

Location and genotype[z]	Berry weight (g)	Berry length (mm)	Berry width (mm)	Seed number	Seed weight (g)	Stem scar tear (%)	Berry firmness (N)	Skin firmness (N/mm)	Skin elasticity (mm)
Arkansas									
AM-26	9.47 b	25.96 ab	24.77 bc	3.00 a	0.32 abc	0.00 c	9.66 ab	1.82 a	5.49 cd
AM-70	12.50 a	27.19 ab	27.49 a	3.33 a	0.35 ab	2.67 bc	8.90 abc	1.39 b	6.47 bc
AM-77	4.76 c	19.63 d	19.43 e	4.00 a	0.42 a	0.33 c	7.54 cd	0.96 c	7.90 a
AM-102	6.15 c	22.98 c	20.22 de	2.33 a	0.18 c	0.33 c	8.43 bcd	1.36 bc	6.21 bcd
AM-131	8.79 b	28.00 a	22.79 cd	3.67 a	0.24 bc	4.67 ab	9.52 ab	1.82 a	5.34 cd
AM-135	8.76 b	26.59 ab	23.16 c	3.33 a	0.23 bc	0.67 c	6.53 d	1.35 bc	4.87 d
AM-195	10.17 b	26.42 ab	24.82 abc	3.00 a	0.22 bc	2.67 bc	8.74 bc	1.40 b	6.27 bc
Summit	8.48 b	23.66 c	24.36 bc	2.67 a	0.26 abc	1.00 c	10.75 a	1.55 ab	7.00 ab
Supreme	10.17 b	25.10 bc	26.06 ab	2.67 a	0.27 abc	6.00 a	9.53 ab	1.72 ab	5.89 bcd
P-value	*<0.0001*	*<0.0001*	*<0.0001*	*<0.1277*	*<0.0024*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*
North Carolina									
JB-06-30-2-20	4.49 cd	19.10 c	18.66 c	1.33 ab	0.01 b	8.73 b	4.38 c	0.51 d	5.83 a
JB 08-38-1-10	2.76 de	16.44 d	15.89 d	3.00 a	0.02 b	2.24 b	8.03 ab	1.25 ab	6.87 a
JB-09-15-3-09	3.99 cd	19.16 c	18.26 cd	3.00 a	0.01 b	4.06 b	8.30 a	1.26 ab	6.67 a
Oh My!®	5.44 c	19.74 c	20.30 c	0.00 b	0.00 b	26.33 a	7.21 abc	0.95 bc	7.81 a
RazzMatazz®	0.77 e	10.32 e	9.67 e	0.00 b	0.00 b	0.11 b	4.69 bc	0.70 cd	6.81 a
Summit	10.35 b	25.21 b	25.02 b	3.00 a	0.28 a	11.11 b	9.84 a	1.35 a	6.76 a
Supreme	21.14 a	31.28 a	32.66 a	2.00 a	0.26 a	2.78 b	10.50 a	1.56 a	6.76 a
P-value	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*0.7091*

[z] Genotypes were evaluated in triplicate. Means highlighted are highest value and means underlined are lowest in each location. Means with different letters for each attribute by location are significantly different ($p<0.05$) within each location using Tukey's Honestly Significant Difference test.

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Table 3. Physical attributes at harvest of .muscadine grapes grown in Arkansas (Clarksville, AR) and North Carolina (Kings Mountain, NC) and evaluated at the University of Arkansas System Division of Agriculture (2021).

Location and genotype[z]	Berry weight (g)	Berry length (mm)	Berry width (mm)	Seed number	Seed weight (g)	Stem scar tear (%)	Berry firmness (N)	Skin firmness (N/mm)	Skin elasticity (mm)
Arkansas									
AM-26	11.08 bc	27.49 b	25.57 ab	2.33 a	0.24 a	3.03 bc	9.68 ab	1.53 ab	6.36 bc
AM-70	13.50 ab	27.62 b	27.86 a	2.00 a	0.22 a	11.55 abc	10.04 ab	1.51 ab	6.72 b
AM-77	5.67 d	20.83 c	20.76 c	4.00 a	0.41 a	10.83 abc	10.78 a	1.21 c	8.92 a
AM-135	13.88 a	29.88 a	27.49 a	4.67 a	0.32 a	8.77 abc	7.90 c	1.31 bc	6.07 bc
AM-148	11.86 abc	28.16 ab	26.30 a	2.33 a	0.33 a	0.00 c	8.65 bc	1.41 abc	6.38 bc
AM-154	9.61 c	27.38 b	23.74 b	2.00 a	0.18 a	22.60 a	8.74 bc	1.65 a	5.35 c
AM-240	13.49 ab	29.14 ab	27.69 a	3.00 a	0.26 a	16.84 ab	10.21 a	1.55 ab	6.61 b
P-value	*<0.0001*	*<0.0001*	*<0.0001*	*0.0307*	*0.1048*	*0.0038*	*<0.0001*	*0.0003*	*<0.0001*
North Carolina									
Hall	10.07 b	24.02 b	24.52 b	1.33 bcd	0.09 bc	28.05 ab	9.17 b	1.12 bc	8.32 ab
JB-06-30-2-20	3.55 cd	17.54 cd	16.51 cd	0.00 d	0.00 c	24.33 abc	6.62 c	0.78 d	8.77 a
JB 08-38-1-10	2.72 d	15.25 d	15.24 d	2.33 abc	0.03 bc	6.38 cd	8.58 b	1.12 bc	7.90 ab
JB-09-15-3-09	4.29 cd	18.24 cd	17.47 cd	0.00 d	0.00 c	9.26 bcd	8.89 b	1.31 bc	6.93 ab
Lane	9.35 b	23.90 b	23.79 b	3.00 ab	0.22 a	19.87 abcd	8.94 b	1.27 bc	7.04 ab
Oh My!®	5.87 c	19.46 c	19.75 c	0.00 d	0.00 c	13.72 abcd	9.59ab	1.36 b	7.16 ab
Paulk	8.96 b	23.02 b	23.35 b	3.67 a	0.06 bc	15.84 abcd	8.90 b	1.03 cd	8.67 a
RazzMatazz®	1.12 e	11.17 e	10.56 e	0.00 d	0.00 c	1.88 d	4.98 c	0.77 d	6.53 b
Summit	9.85 b	23.54 b	24.41 b	1.33 bcd	0.13 ab	13.14 abcd	9.89 ab	1.34 b	7.49 ab
Supreme	14.41 a	27.59 a	28.10 a	1.00 cd	0.09 bc	29.42 a	11.03a	1.67 a	6.66 b
P-value	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*0.0029*

[z] Genotypes were evaluated in triplicate. Means highlighted are highest value and means underlined are lowest in each location. Means with different letters for each attribute by location are significantly different ($p<0.05$) within each location using Tukey's Honestly Significant Difference test.

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Table 4. Skin color attributes at harvest of .muscadine grapes grown in Arkansas (Clarksville, AR) and North Carolina (Kings Mountain, NC) and evaluated at the University of Arkansas System Division of Agriculture (2020).

Location and genotype	L*	a*	b*	Hue	Chroma
Arkansas					
AM-26	42.92 a	-1.50 d	23.23 a	94.91 ab	16.05 a
AM-70	28.73 b	10.04 a	2.57 b	14.04 c	10.44 b
AM-77	24.69 c	2.90 c	0.79 b	12.84 c	3.05 d
AM-102	25.72 bc	6.73 b	1.39 b	10.26 c	6.91 c
AM-131	46.33 a	-0.53 d	15.44 a	91.74 ab	15.54 a
AM-135	45.63 a	-2.33 d	16.15 a	97.48 a	16.42 a
AM-195	25.95 bc	6.47 b	1.25 b	10.34 c	6.61 c
Summit	42.99 a	-0.05 d	16.70 a	89.40 b	16.81 a
Supreme	27.10 bc	7.93 ab	1.63 b	11.28 c	8.14 bc
P-value	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*
North Carolina					
JB-06-30-2-20	41.26 b	-0.44 cd	12.39 b	90.69 ab	12.24 b
JB 08-38-1-10	23.51 c	2.12 bc	0.39 d	11.03 d	2.18 c
JB-09-15-3-09	38.30 b	3.42 b	9.48 b	70.66 cd	10.28 b
Oh My!®	38.73 b	1.48 bc	9.69 b	81.09 bc	9.83 b
RazzMatazz®	25.04 c	13.17 a	4.45 c	15.77 d	13.93 ab
Summit	45.45 a	-2.10 d	16.68 a	95.73 a	16.88 a
Supreme	25.36 c	3.55 b	1.54 cd	11.86 d	4.38 c
P-value	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*

[z] Genotypes were evaluated in triplicate. Means highlighted are highest value and means underlined are lowest in each location. Means with different letters for each attribute by location are significantly different ($p<0.05$) within each location using Tukey's Honestly Significant Difference test.

Table 5. Skin color attributes at harvest of .muscadine grapes grown in Arkansas (Clarksville, AR) and North Carolina (Kings Mountain, NC) and evaluated at the University of Arkansas System Division of Agriculture (2021).

Location and genotype	L*	a*	b*	Hue	Chroma
Arkansas					
AM-26	42.17 b	-0.06 d	14.15 b	88.91 a	13.97 b
AM-70	25.62 cd	3.83 bc	0.60 c	8.28 c	3.89 cd
AM-77	24.38 d	2.28 c	0.83 c	19.65 b	2.47 d
AM-135	52.15 a	2.59 c	17.15 a	81.17 a	17.59 a
AM-148	25.59 cd	3.70 bc	0.81 c	15.06 bc	3.81 cd
AM-154	27.53 c	12.75 a	3.30 c	14.07 bc	13.19 b
AM-240	24.60 d	4.95 b	1.34 c	15.06 bc	5.13 c
P-value	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*
North Carolina					
Hall	47.13 a	- 0.99 cd	16.85 a	93.51 b	17.22 a
JB-06-30-2-20	45.98 a	- 3.82 d	16.57 a	102.86 a	17.04 a
JB 08-38-1-10	23.59 c	2.73 bc	0.53 d	10.61 e	2.69 d
JB-09-15-3-09	38.05 b	3.08 bc	9.34 bc	70.58 c	10.28 bc
Lane	24.62 c	3.50 bc	0.58 d	10.03 e	3.55 d
Oh My!®	44.21 a	- 1.70 cd	13.43 ab	97.34 ab	13.61 ab
Paulk	25.01 c	5.40 b	0.70 d	6.67 e	5.47 cd
RazzMatazz®	25.58 c	14.70 a	6.37 cd	20.95 d	16.12 ab
Summit	40.76 b	4.78 b	15.37 a	72.51c	16.23 ab
Supreme	24.60 c	3.13 bc	0.76 d	12.83 e	3.26 d
P-value	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*

[z] Genotypes were evaluated in triplicate. Means highlighted are highest value and means underlined are lowest in each location. Means with different letters for each attribute by location are significantly different ($p<0.05$) within each location using Tukey's Honestly Significant Difference test.

Table 6. Composition attributes at harvest of .muscadine grapes grown in Arkansas (Clarksville, AR) and North Carolina (Kings Mountain, NC) and evaluated at the University of Arkansas System Division of Agriculture (2020).

Location and genotype [z]	Soluble solids (%)	pH	Titratable acidity (%)[y]	Soluble solids/titratable acidity ratio
Arkansas				
AM-26	11.77 ef	3.45 bc	0.57 de	20.79 bcd
AM-70	14.50 bcd	3.49 b	0.43 e	35.17 a
AM-77	11.37 f	2.81 f	1.06 a	10.75 d
AM-102	16.80 ab	3.18 e	0.67d	24.90 abc
AM-131	16.13 abc	3.27 cde	0.96 ab	16.83 cd
AM-135	13.33 def	3.37 b-e	0.70 cd	18.91 bcd
AM-195	14.67 bcd	3.80 a	0.72 cd	20.44 bcd
Summit	14.07 cde	3.21 de	0.85 bc	16.53 cd
Supreme	17.43 a	3.41 bcd	0.60 d	29.60 ab
P-value	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*
North Carolina				
JB-06-30-2-20	17.63 ab	3.14 b	0.48 c	36.86 bc
JB 08-38-1-10	18.83 ab	3.30 ab	0.64 b	29.47 b
JB-09-15-3-09	17.27 bc	3.10 b	0.55 bc	31.22 bc
Oh My!®	16.90 c	3.41 a	0.44 c	38.27 bc
RazzMatazz®	19.43 a	2.83 c	1.21 a	16.20 c
Summit	16.17 c	3.31 ab	0.52 bc	31.77 bc
Supreme	16.30 c	3.45 a	0.41 c	40.30 a
P-value	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*

[z] Genotypes were evaluated in triplicate. Means highlighted are highest value and means underlined are lowest in each location. Means with different letters for each attribute by location are significantly different ($p<0.05$) within each location using Tukey's Honestly Significant Difference test.
[y] Titratable acidity expressed as % tartaric acid.

Table 7. Composition attributes at harvest of muscadine grapes grown in Arkansas (Clarksville, AR) and North Carolina (Kings Mountain, NC) and evaluated at the University of Arkansas System Division of Agriculture (2021).

Location and genotype [z]	Soluble solids (%)	pH	Titratable acidity (%)[y]	Soluble solids/titratable acidity ratio
Arkansas				
AM-26	16.23 b	3.62 b	0.50 b	32.65 b
AM-70	18.90 a	3.89 a	0.29 c	66.06 a
AM-77	14.00 c	3.04 c	0.88 a	16.06 b
AM-135	19.47 a	3.89 a	0.28 c	70.31 a
AM-148	16.30 b	3.67 b	0.54 b	30.53 b
AM-154	16.93 b	3.58 b	0.25 c	68.92 a
AM-240	16.87 b	3.98 a	0.26 c	64.93 a
P-value	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*
North Carolina				
Hall	15.23 c	3.40 ab	0.48 bc	31.67 ab
JB-06-30-2-20	17.63 a	2.95 d	0.56 bc	31.50 ab
JB 08-38-1-10	14.40 c	3.01 d	0.56 bc	25.76 bc
JB-09-15-3-09	17.30 ab	3.24 bc	0.61 bc	28.53 b
Lane	14.87 c	3.55 a	0.47 c	32.12 ab
Oh My!®	15.00 bc	3.09 cd	0.78 b	20.18 cd
Paulk	15.47 c	3.32 b	0.58 bc	25.94 bc
RazzMatazz®	17.40 ab	2.98 d	1.14 a	16.16 d
Summit	18.60 a	3.29 b	0.50 bc	37.66 a
Supreme	15.77 c	3.27 b	0.56 bc	27.77 bc
P-value	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*

[z] Genotypes were evaluated in triplicate. Means highlighted are highest value and means underlined are lowest in each location. Means with different letters for each attribute by location are significantly different ($p<0.05$) within each location using Tukey's Honestly Significant Difference test.
[y] Titratable acidity expressed as % tartaric acid.

Table 8. Individual and total sugars and organic acid attributes at harvest of .muscadine grapes grown in Arkansas (Clarksville, AR) and North Carolina (Kings Mountain, NC) and evaluated at the University of Arkansas System Division of Agriculture (2020).

Location and genotype[z]	Glucose (%)	Fructose (%)	Total sugars (%)	Tartaric acid (%)	Malic acid (%)	Citric acid (%)	Total organic acids (%)
Arkansas							
AM-26	4.40 d	5.68 d	10.07 e	0.23 e	0.15 a	0.04 ab	0.41 bc
AM-70	7.13 bc	7.04 bc	14.18 bc	0.22 e	0.07 b	0.02 cd	0.32 de
AM-77	4.09 d	5.64 d	9.73 e	0.47 a	0.10 b	0.04 ab	0.61 a
AM-102	8.31ab	7.94 ab	16.26 ab	0.37 b	0.10 b	0.02 d	0.49 b
AM-131	7.62 abc	7.48 abc	15.10 abc	0.24 de	0.16 a	0.03 ab	0.43 bc
AM-135	4.89 d	6.43 cd	11.32 de	0.28 cde	0.08 b	0.03 bc	0.39 cd
AM-195	6.63 c	7.46 abc	14.09 bc	0.16 f	0.07 b	0.04 a	0.27 e
Summit	6.61 c	6.82 bcd	13.43 cd	0.30 c	0.07 b	0.03 bc	0.40 c
Supreme	8.72 a	8.46 a	17.18 a	0.29 cd	0.07 b	0.02 d	0.38 cd
P-value	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*
North Carolina							
JB-06-30-2-20	8.73 ab	8.85 a	17.57 ab	0.31 b	0.04 c	0.02 c	0.37 cd
JB 08-38-1-10	9.15 a	8.65 a	17.79 ab	0.34 b	0.08 b	0.02 c	0.44 b
JB-09-15-3-09	8.83 ab	8.86 a	17.69 ab	0.32 b	0.07 b	0.03 ab	0.41 bc
Oh My! ®	8.52 ab	7.80 ab	16.32 abc	0.18 c	0.07 b	0.04 a	0.29 ef
RazzMatazz®	9.65 a	8.96 a	18.61 a	0.57 a	0.18 a	0.02 c	0.76 a
Summit	7.88 bc	7.66 ab	15.53 bc	0.20 c	0.09 b	0.03 ab	0.32 de
Supreme	6.88 c	*7.00 b*	13.88 c	0.15 c	0.07 b	0.02 bc	0.25 f
P-value	*<0.0001*	*<0.0011*	*<0.0002*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*

[z] Genotypes were evaluated in triplicate. Means highlighted are highest value and means underlined are lowest in each location. Means with different letters for each attribute by location are significantly different ($p<0.05$) within each location using Tukey's Honestly Significant Difference test.

[y] Titratable acidity expressed as % tartaric acid.

Table 9. Individual and total sugars and organic acid attributes at harvest of .muscadine grapes grown in Arkansas (Clarksville, AR) and North Carolina (Kings Mountain, NC) and evaluated at the University of Arkansas System Division of Agriculture (2021).

Location and genotype[z]	Glucose (%)	Fructose (%)	Total sugars (%)	Tartaric acid (%)	Malic acid (%)	Citric acid (%)	Total organic acids (%)
Arkansas							
AM-26	7.91 cd	8.13 cd	16.05 cd	0.23 c	0.09 a	0.05 b	0.37 b
AM-70	9.17 ab	9.43 b	18.60 ab	0.19 cd	0.06 b	0.02 d	0.27 c
AM-77	6.71 e	6.90 e	13.61 e	0.41 a	0.11 a	0.09 a	0.61 a
AM-135	9.95 a	10.23 a	20.18 a	0.16 d	0.06 b	0.04 bcd	0.26 c
AM-148	7.42 de	7.63 de	15.05 de	0.24 bc	0.10 a	0.04 bc	0.39 b
AM-154	8.59 bc	8.82 bc	17.41 bc	0.21 cd	0.03 c	0.02 d	0.26 c
AM-240	8.13 cd	8.36 cd	16.50 cd	0.30 b	0.04 bc	0.02 cd	0.37 b
P-value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
North Carolina							
Hall	6.92 abc	7.11 abc	14.03 abc	0.39 bc	0.08 cd	0.03 bc	0.50 bc
JB-06-30-2-20	8.29 a	8.52 a	16.82 a	0.40 bc	0.05 d	0.02 de	0.47 bc
JB 08-38-1-10	6.56 c	6.75 c	13.31 c	0.37 bc	0.06 d	0.01 e	0.44 bc
JB-09-15-3-09	8.11 ab	8.33 ab	16.44 ab	0.33 bc	0.07 cd	0.03 cd	0.42 bc
Lane	6.97 abc	7.16 abc	14.13 abc	0.30 bc	0.07 cd	0.03 bc	0.41 bc
Oh My!®	6.65 bc	6.84 bc	13.49 bc	0.46 b	0.11 b	0.04 abc	0.60 b
Paulk	7.67 abc	7.89 abc	15.56 abc	0.30 bc	0.07 cd	0.05 a	0.43 bc
RazzMatazz®	8.30 a	8.53 a	16.83 a	0.78 a	0.14 a	0.02 de	0.93 a
Summit	8.33 a	8.57 a	16.90 a	0.21 bc	0.06 d	0.03 bc	0.30 c
Supreme	7.37 abc	7.57 abc	14.94 abc	0.17 c	0.09 bc	0.04 ab	0.31 c
P-value	*0.0004*	*0.0004*	*0.0004*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*

[z] Genotypes were evaluated in triplicate. Means highlighted are highest value and means underlined are lowest in each location. Means with different letters for each attribute by location are significantly different ($p<0.05$) within each location using Tukey's Honestly Significant Difference test.

[y] Titratable acidity expressed as % tartaric acid.

Table 10. Main and interaction effects on color, firmness, and marketability attributes for muscadines grown in Arkansas (Clarksville, AR) and stored at 2 °C for 0, 14, and 28 days at the University of Arkansas System Division of Agriculture (2020).

Effects[z]	L*	Hue	Chroma	Berry firmness (N)	Skin firmness (N/mm)	Skin elasticity (mm)	Weight loss (%)	Unmarketable (%)
Genotype								
AM-26	42.89 b	95.45 a	15.24 b	9.43 ab	1.51 ab	6.51 cde	3.16 bc	2.36 b
AM-70	27.82 d	18.26 c	8.19 c	7.79 cd	1.06 de	7.11 bc	3.00 bc	6.39 ab
AM-77	24.51 e	13.36 de	2.87 d	7.27 de	0.86 e	8.55 a	3.51 ab	3.15 b
AM-102	25.87 de	10.16 e	7.18 c	8.53 bc	1.29 bcd	6.77 cde	4.12 a	3.81 b
AM-131	47.87 a	93.47 a	16.62 ab	9.39 ab	1.58 a	6.18 de	3.34 b	7.29 ab
AM-135	49.19 a	97.75 a	17.61 a	6.53 e	1.12 d	6.04 e	3.42 ab	5.69 ab
AM-195	26.52 de	15.02 cd	7.37 c	8.62 abc	1.26 cd	6.92 bcd	2.42 c	6.45 ab
Summit	40.55 c	86.51 b	15.49 b	9.44 ab	1.25 cd	7.60 b	2.97 bc	6.03 ab
Supreme	26.76 d	12.62 de	7.09 c	9.75 a	1.47 abc	6.96 bc	2.82 bc	10.53 a
P value	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*
Storage								
0	34.45 a	48.03 a	11.11 a	8.84 a	1.48 a	6.16 c	0.0 e	0.0 e
14	34.79 a	49.90 a	10.50 a	8.72 a	1.25 b	7.18 b	3.29b	2.49b
28	34.75 a	49.60 a	10.94 a	8.03 b	1.06 c	7.54 a	6.29 a	14.74 a
P value	0.6272	0.0655	0.1864	<0.0007	*<0.0001*	*<0.0001*	*<0.0001*	*<.0001*
Genotype x Storage *(P value)*	*<0.0001*	*<0.0001*	*0.0017*	*<0.0267*	0.2443	0.3112	*0.0011*	*0.0219*

[z] Genotypes were evaluated in triplicate. Means highlighted are highest value and means underlined are lowest in each location. Means with different letters for each attribute by location are significantly different ($p<0.05$) within each location using Tukey's Honestly Significant Difference test.

Table 11. Main and interaction effects on color, firmness, and marketability attributes for muscadines grown in Arkansas (Clarksville, AR) and stored at 2 °C for 0, 14, and 28 days at the University of Arkansas System Division of Agriculture (2021).

Effects[z]	L*	Hue	Chroma	Berry firmness (N)	Skin firmness (N/mm)	Skin elasticity (mm)	Weight loss (%)	Unmarketable berries (%)
Genotype								
AM-26	41.67 b	85.95 a	13.38 b	9.66 a	1.38 a	7.10 bcd	3.69 b	0.58 b
AM-70	25.20 d	78.76 a	4.56 c	8.06 bc	1.08 c	7.73 b	6.25 a	12.75 a
AM-77	24.61 d	19.18 b	2.38 d	9.48 a	1.01 c	9.45 a	5.60 a	2.99 b
AM-135	50.04 a	18.19 b	16.90 a	7.15 c	1.07 c	6.79 cd	4.44 b	1.15 b
AM-148	25.54 d	16.64 b	4.00 cd	8.60 ab	1.25 ab	7.11 bcd	3.84 b	0.00 b
AM-154	27.07 c	14.84 b	11.95 b	7.96 bc	1.24 a	6.69 d	5.63 a	1.37 b
AM-240	24.87 d	13.75 b	5.12 c	8.11 bc	1.13 bc	7.38 bc	4.24 b	4.23 b
P value	*0.0004*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*
Storage								
0	31.72 a	38.03 a	8.58 a	9.43 a	1.45 a	6.63 c	0.00	0.00 a
14	31.61 a	33.45 a	8.29 a	8.16 b	1.11 b	7.45 b	3.02	4.51 a
28	30.53 b	34.50 a	8.11 a	7.71 b	0.93 c	8.30 a	6.61	5.38 a
P value	*<0.0001*	*0.5681*	0.5000	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*
Genotype x Storage								
(P value)	*0.0096*	*0.7373*	*0.4785*	*0.0014*	*<0.0001*	*0.1358*	*<0.0001*	*0.0003*

[z] Genotypes were evaluated in triplicate. Means highlighted are highest value and means underlined are lowest in each location. Means with different letters for each attribute by location are significantly different ($p<0.05$) within each location using Tukey's Honestly Significant Difference test.

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Table 12. Main and interaction effects on color, firmness, and marketability attributes for muscadines grown in North Carolina (Kings Mountain, NC) and stored at 2 °C for 0, 14, and 28 days at the University of Arkansas System Division of Agriculture (2020).

Effects [z]	L*	Hue	Chroma	Berry firmness (N)	Skin firmness (N/mm)	Skin elasticity (mm)	Weight loss (%)	Unmarketable berries (%)
Genotype								
JB-06-30-2-20	41.24 a	88.22 a	13.18 a	4.29 c	0.53 d	6.03 a	4.47 cd	26.36 b
JB 08-38-1-10	23.65 d	12.42 e	2.23 c	7.28 b	1.06 b	7.14 a	6.09 a	17.14 b
JB-09-15-3-09	36.69 b	63.28 c	9.73 b	8.11 ab	1.08 ab	7.70 a	5.28 b	3.27 c
Oh My!®	37.19 b	81.35 b	10.41 b	5.07 c	0.67 cd	6.45 a	6.03 a	42.28 a
RazzMatazz®	26.48 c	20.04 d	13.54 a	4.82 c	0.72 c	6.60 a	4.51 c	5.40 c
Summit	40.62 a	84.62 ab	14.85 a	8.02 ab	0.99 b	6.54 a	3.71 d	2.82 c
Supreme	24.89 cd	12.72 e	3.67 c	9.35 a	1.27 a	6.64 a	2.60 e	3.70 c
P value	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*0.1040*	*<0.0001*	*<0.0001*
Storage								
0	34.40 a	53.83 a	9.95 a	7.56 a	1.08 a	6.93 a	0.00 c	5.91 b
14	33.27 a	51.96 ab	9.88 a	6.61 b	0.89 b	6.79 a	5.50 b	8.60 b
28	31.67 b	49.63 b	9.14 a	5.80 b	0.74 c	6.48 a	8.79 a	28.77 a
P value	*<0.0001*	*0.0130*	*0.1726*	*0.0004*	*<0.0001*	*0.4625*	*<0.0001*	*<0.0001*
Genotype x Storage *(P value)*	*<0.0001*	*0.0008*	*0.2353*	*0.0020*	*0.0004*	*0.1067*	*<0.0001*	*<0.0001*

[z] Genotypes were evaluated in triplicate. Means highlighted are highest value and means underlined are lowest in each location. Means with different letters for each attribute by location are significantly different ($p<0.05$) within each location using Tukey's Honestly Significant Difference test.

Table 13. Main and interaction effects on color, firmness, and marketability attributes for muscadines grown in North Carolina (Kings Mountain, NC) and stored at 2 °C for 0, 14, and 28 days at the University of Arkansas System Division of Agriculture (2021).

Effects [z]	L*	Hue	Chroma	Berry firmness (N)	Skin firmness (N/mm)	Skin elasticity (mm)	Weight loss (%)	Unmarketable berries (%)
Genotype								
Hall	45.10 a	88.96 b	16.91 a	7.46 cd	0.86 cd	8.83 ab	2.71 bc	15.69 a
JB-06-30-2-20	44.86 a	99.07 a	16.70 ab	6.51 d	0.76 de	8.75 abc	3.36 abc	8.13 ab
JB-08-38-1-10	23.87 e	11.70 e	3.07 f	7.13 d	0.90 cd	7.96 cd	3.69 abc	14.36 a
JB-09-15-3-9	37.22 c	65.33 c	10.40 d	8.56 bc	1.17 b	7.48 d	4.05 ab	8.64 ab
Lane	24.46 de	10.69 e	3.88 ef	8.71 bc	1.16 b	7.56 d	2.64 c	2.76 b
Oh My!®	43.49 a	93.84 ab	14.13bc	9.19 b	1.19 b	7.86 d	3.43 abc	5.91 b
Paulk	25.61 d	9.35 e	6.41 e	8.52 bc	0.96 c	9.00 a	4.50 a	5.90 b
RazzMatazz®	25.54 de	19.54 d	13.57 c	4.64 e	0.64 e	7.41 d	3.11 bc	1.79 b
Summit	39.26 b	69.17 c	15.91 abc	9.32 b	1.17 b	8.12 bcd	3.39 abc	8.40 ab
Supreme	24.98 de	13.28 e	3.81 ef	11.05 a	1.45 a	7.58 d	2.63 c	2.62 b
P-value	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*0.0002*	*<0.0001*
Storage								
0	33.95 a	49.79 a	10.55 a	8.66 a	1.18 a	7.55 c	0.00 c	0.00 c
14	33.31 ab	47.26 b	10.47 a	8.15 b	1.02 b	8.11 b	3.77 b	7.43 b
28	33.05 b	47.23 b	10.43 a	7.51 c	0.89 c	8.51 a	6.28 a	14.83 a
P value	*0.0063*	*0.0092*	*0.9626*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*
Genotype x Storage								
(P value)	*0.0091*	*0.0685*	*0.4587*	*0.0402*	*0.1831*	*0.2264*	*0.0005*	*<0.0001*

[z] Genotypes were evaluated in triplicate. Means highlighted are highest value and means underlined are lowest in each location. Means with different letters for each attribute by location are significantly different ($p<0.05$) within each location using Tukey's Honestly Significant Difference test.

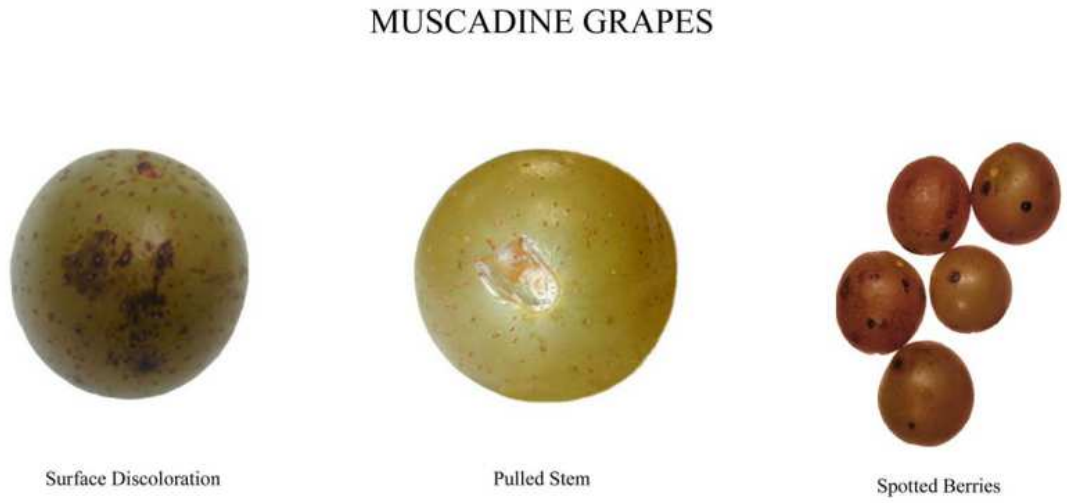
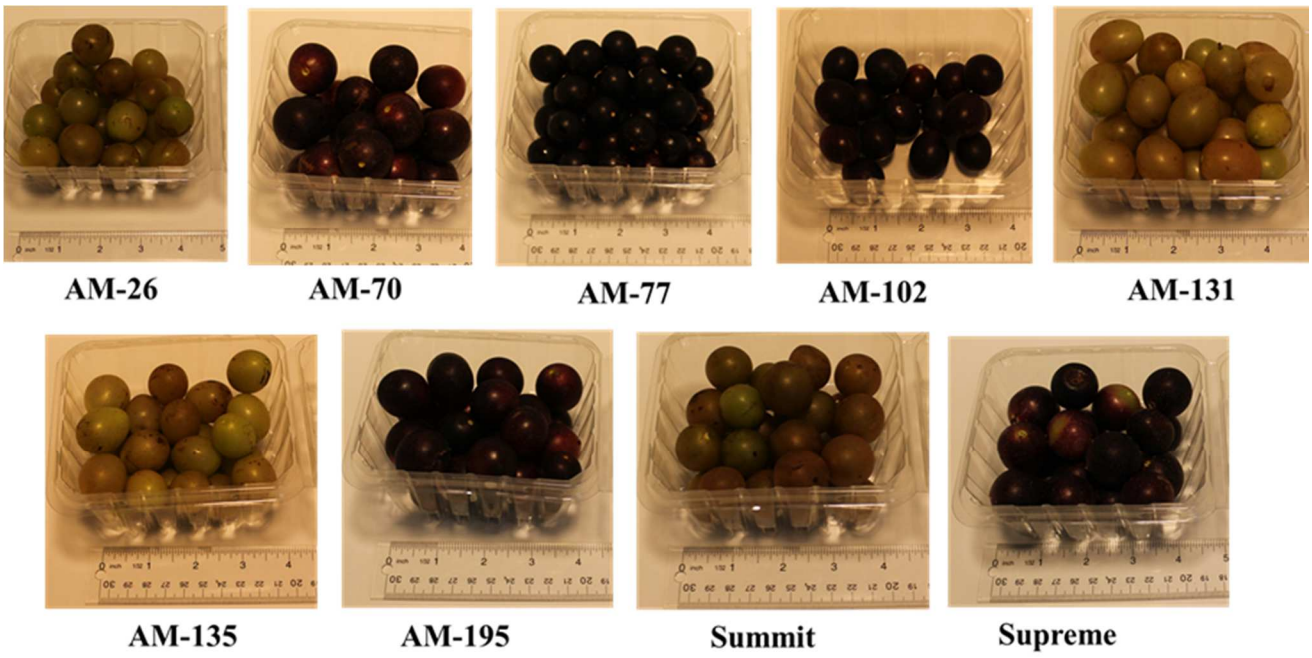


Fig. 1. United States Department of Agriculture unofficial guide for stem scar, surface discoloration, and spotted berries on bronze muscadines (USDA, 2006) https://www.ams.usda.gov/sites/default/files/media/Muscadine_Grape_Visual_Aid%5B1%5D.pdf

A. Arkansas



B. North Carolina

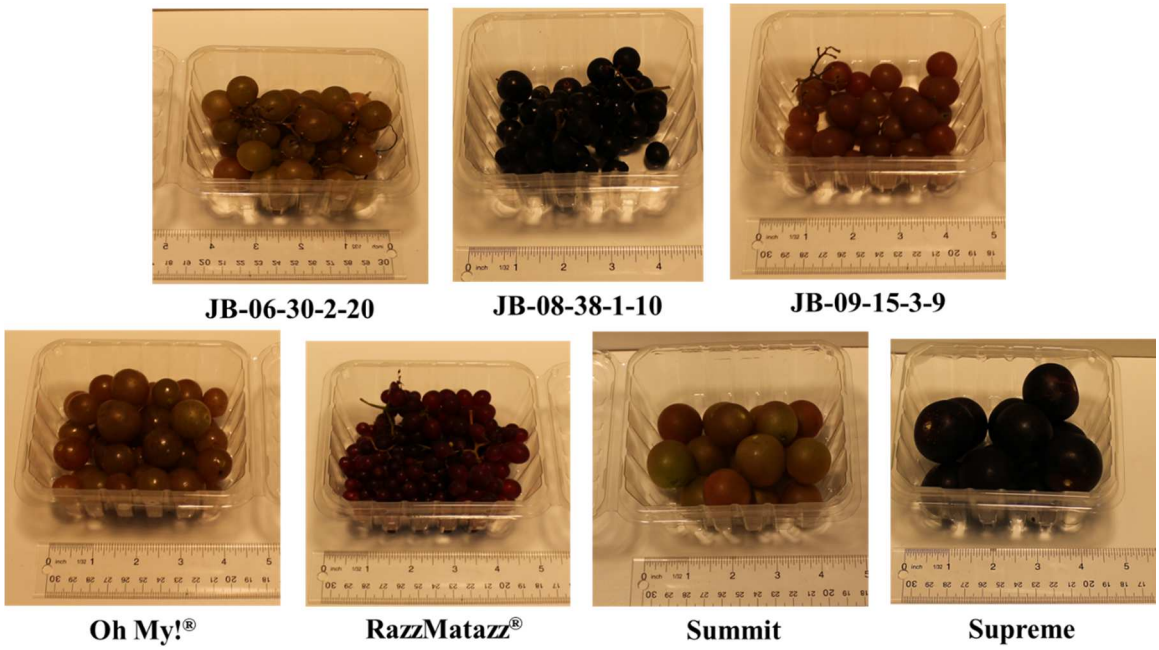


Fig. 2. Photo at harvest (day 0) of clamshells of muscadine grapes grown in Arkansas (A) and North Carolina (B) and evaluated at the University of Arkansas System Division of Agriculture (2020).

A. Arkansas

B. North Carolina

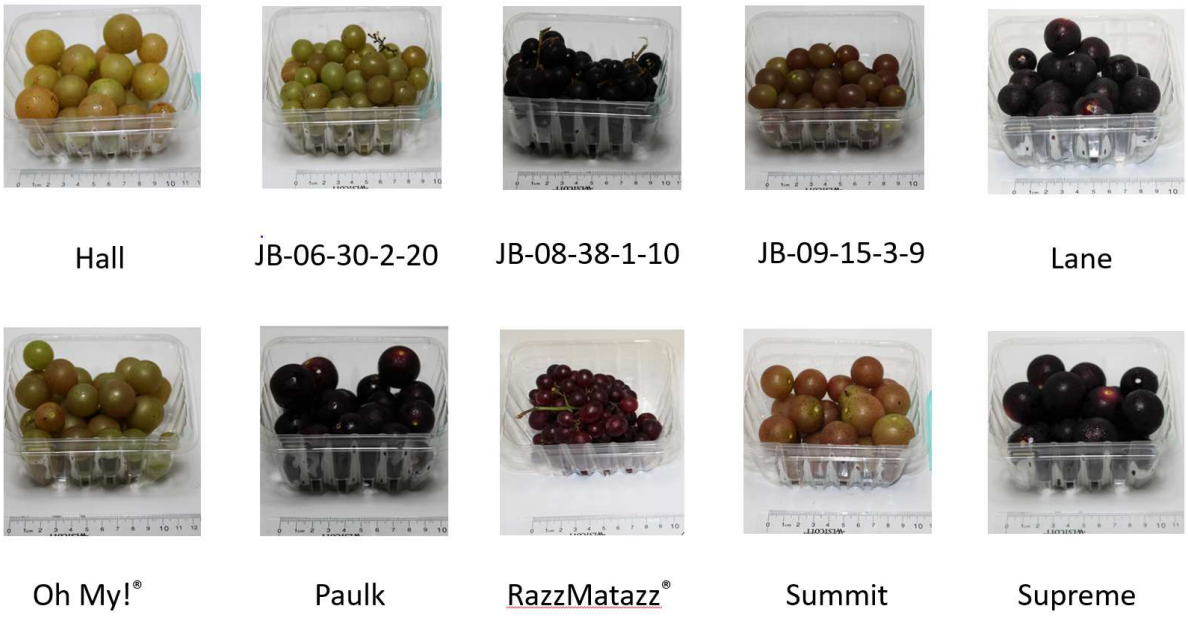


Fig. 3. Photo at harvest (day 0) of clamshells of muscadine grapes grown in Arkansas (A) and North Carolina (B) and evaluated at the University of Arkansas System Division of Agriculture (2021).

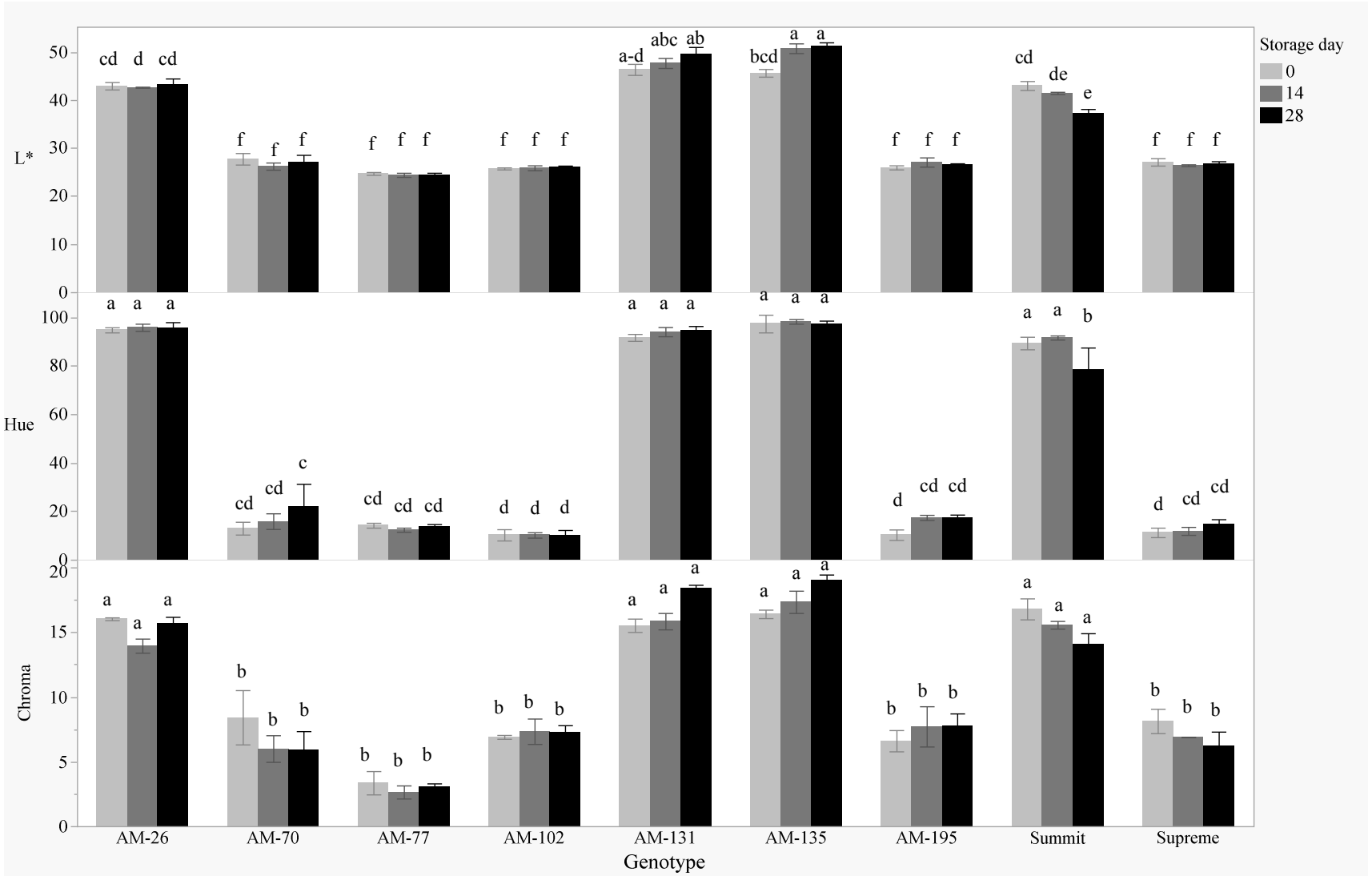


Fig. 4. Interaction effects on L*, Hue, and chroma values of muscadines grown in Arkansas (Clarksville, AR) and stored at 2 °C for 0,
Genotypes were evaluated in triplicate. Means with different letters for each attribute by location are significantly different ($p<0.05$) within each location using Tukey's Honestly Significant Difference test.

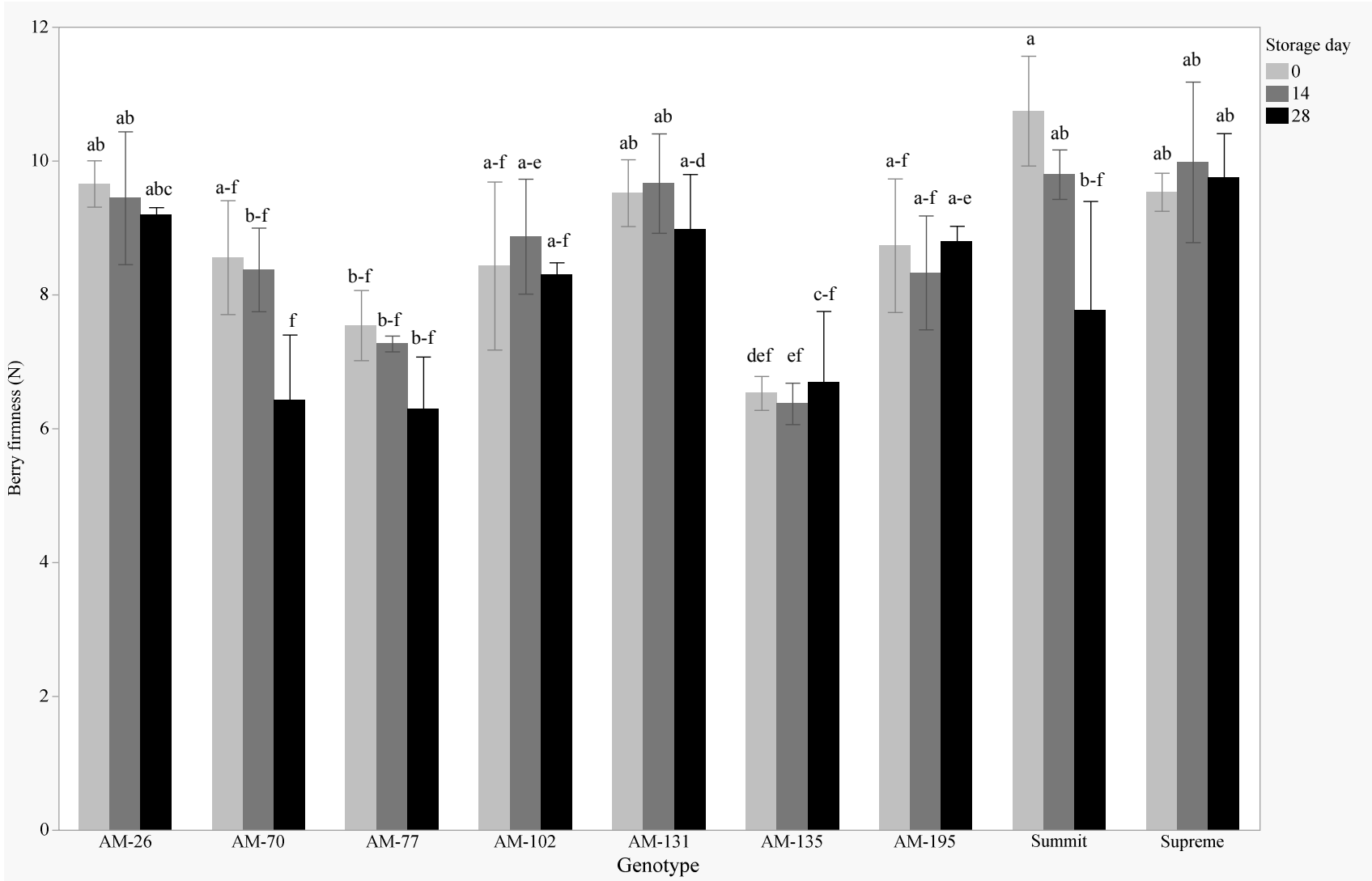


Fig. 5. Interaction effects on berry firmness of muscadines grown in Arkansas (Clarksville, AR) and stored at 2 °C for 0, 14, and 28 days at the University of Arkansas System Division of Agriculture (2020).

Genotypes were evaluated in triplicate. Means with different letters for each attribute by location are significantly different ($p<0.05$) within each location using Tukey's Honestly Significant Difference test

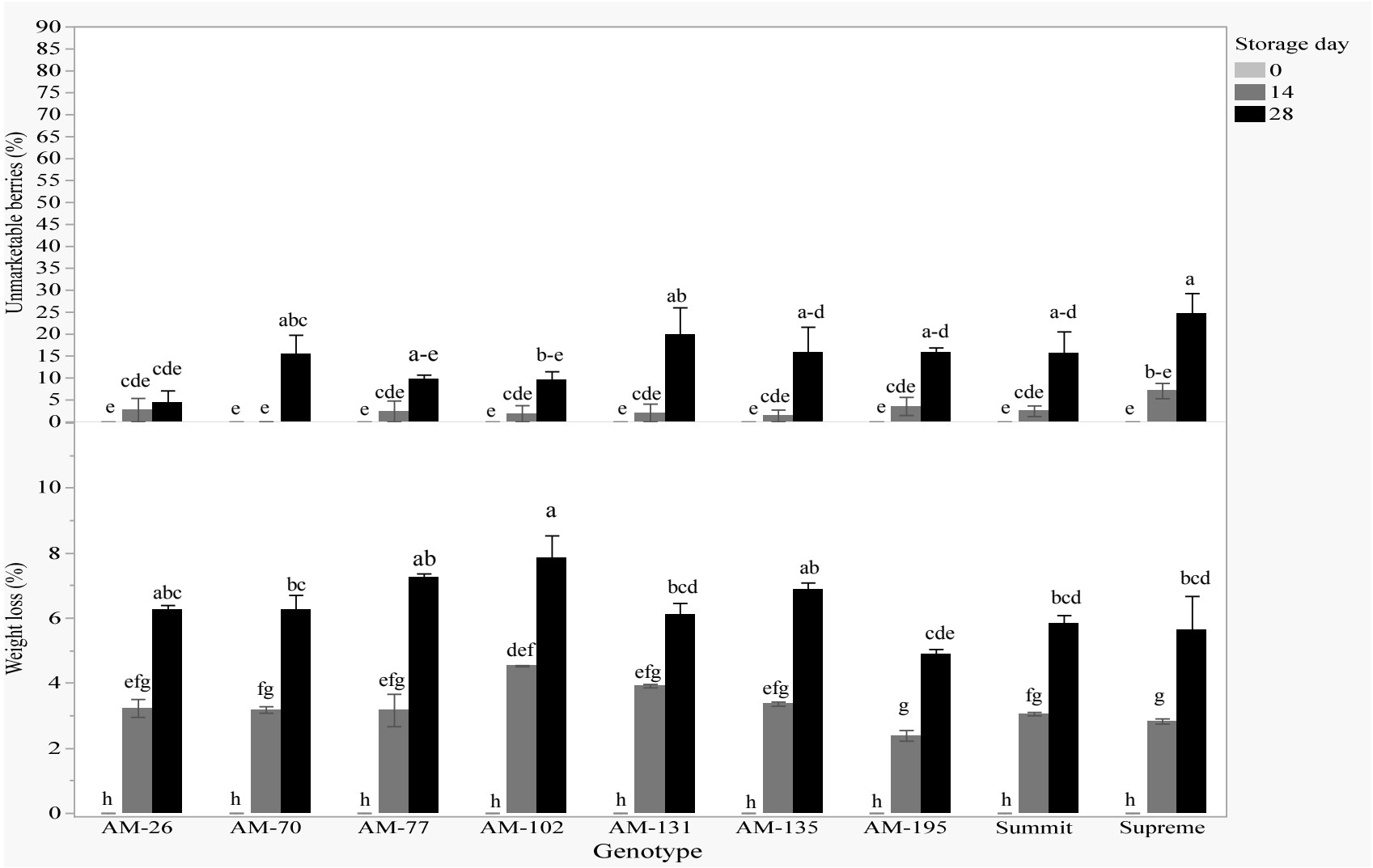


Fig. 6. Interaction effects on unmarketable berries and weight loss of muscadines grown in Arkansas (Clarksville, AR) and stored at 2 °C for 0, 14, and 28 days at the University of Arkansas System Division of Agriculture (2020).

Genotypes were evaluated in triplicate. Means with different letters for each attribute by location are significantly different ($p<0.05$) within each location using Tukey's Honestly Significant Difference test

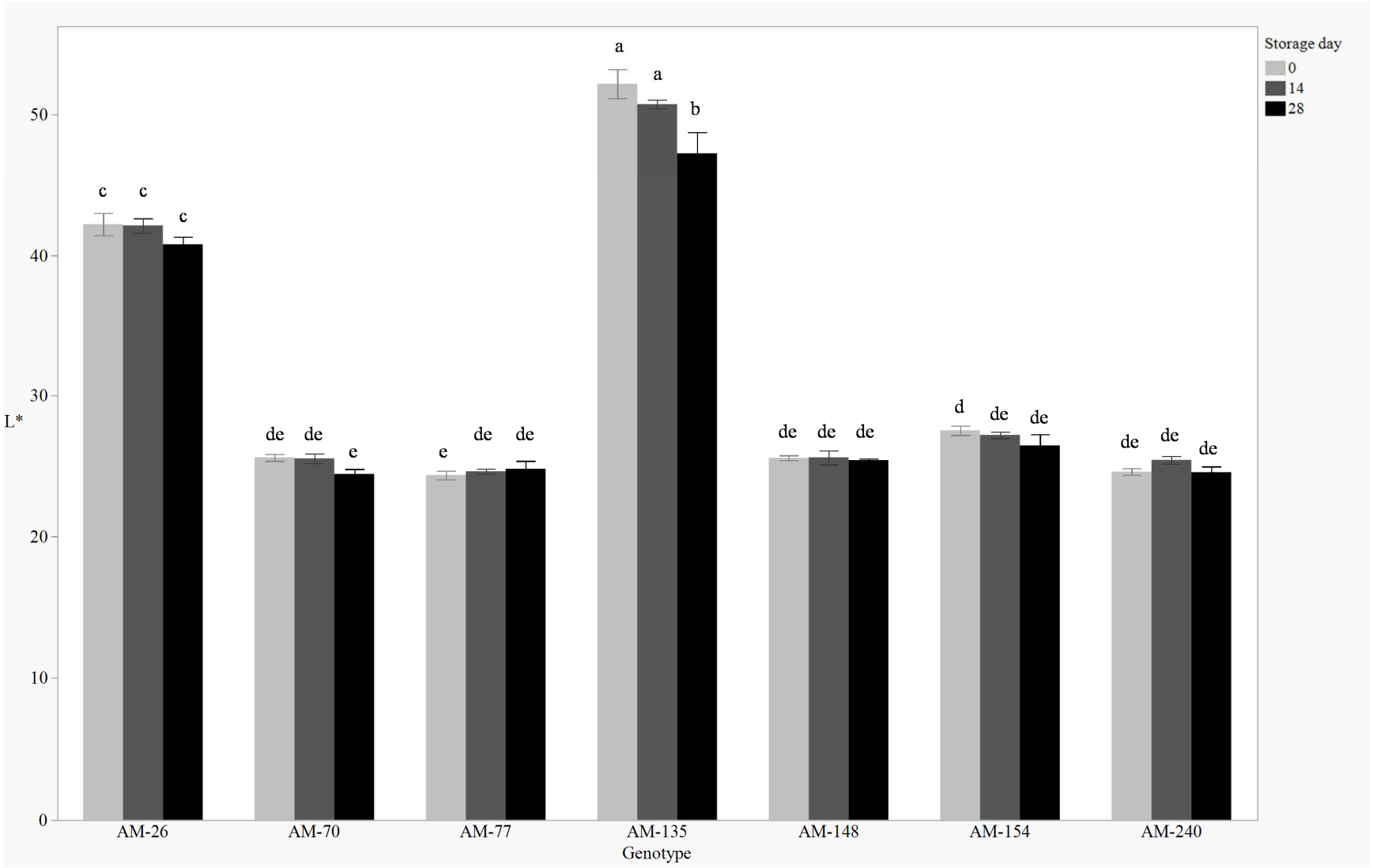


Fig. 7. Interaction effects on L* of muscadines grown in Arkansas (Clarksville, AR) and stored at 2 °C for 0, 14, and 28 days at the University of Arkansas System Division of Agriculture (2021).

Genotypes were evaluated in triplicate. Means with different letters for each attribute by location are significantly different ($p<0.05$) within each location using Tukey's Honestly Significant Difference test

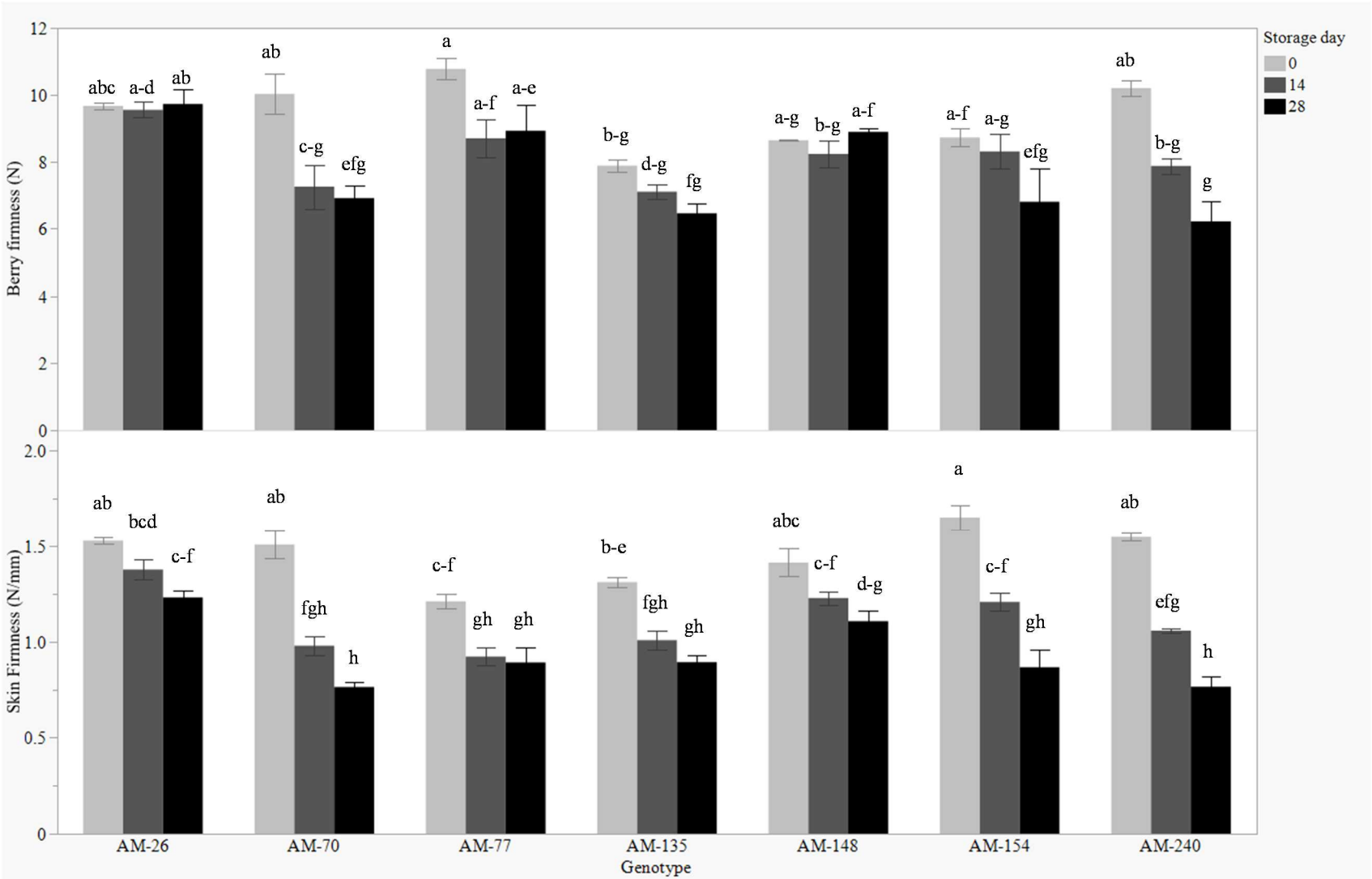


Fig. 8. Interaction effects on berry firmness and skin elasticity of muscadines grown in Arkansas (Clarksville, AR) and stored at 2 °C for 0, 14, and 28 days at the University of Arkansas System Division of Agriculture (2021).

Genotypes were evaluated in triplicate. Means with different letters for each attribute by location are significantly different ($p<0.05$) within each location using Tukey's Honestly Significant Difference test

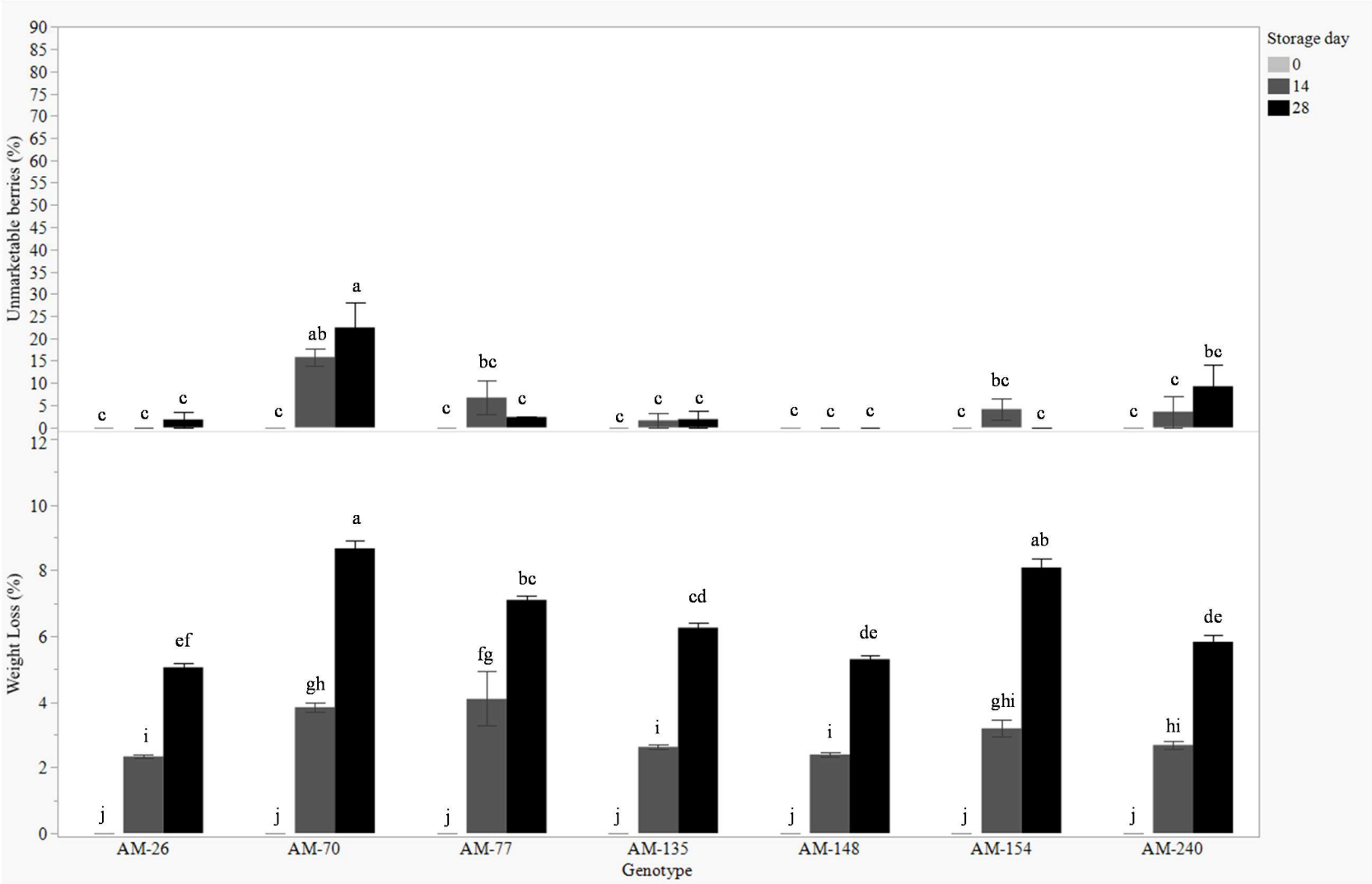


Fig. 9. Interaction effects on unmarketable berries and weight loss of muscadines grown in Arkansas (Clarksville, AR) and stored at 2 °C for 0, 14, and 28 days at the University of Arkansas System Division of Agriculture (2021).

Genotypes were evaluated in triplicate. Means with different letters for each attribute by location are significantly different ($p<0.05$) within each location using Tukey's Honestly Significant Difference test

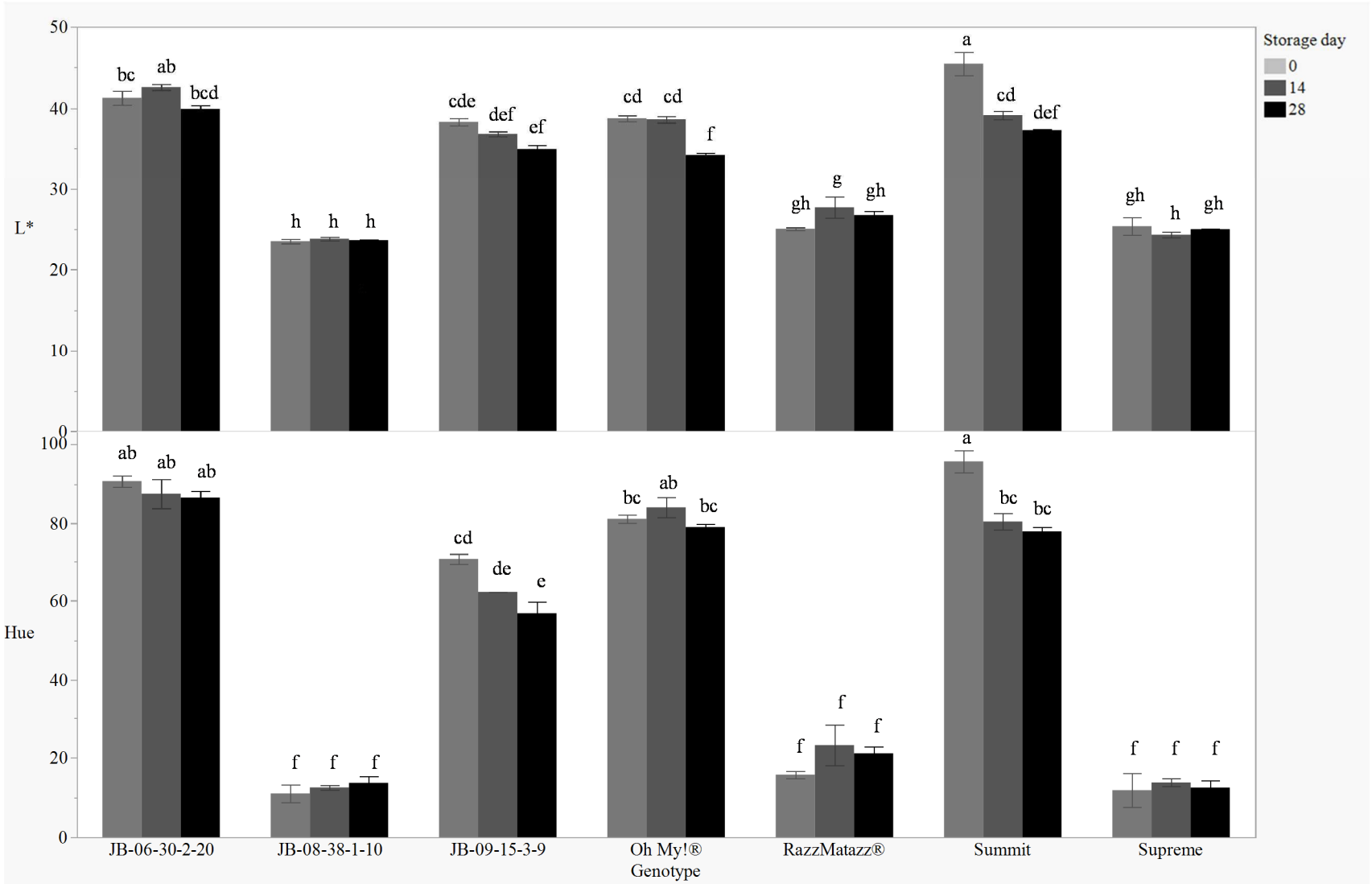


Fig. 10. Interaction effects on L* and hue of muscadines grown in North Carolina (Kings Mountain, NC) and stored at 2 °C for 0, 14, and 28 days at the University of Arkansas System Division of Agriculture (2020).

Genotypes were evaluated in triplicate. Means with different letters for each attribute by location are significantly different ($p<0.05$) within each location using Tukey's Honestly Significant Difference test

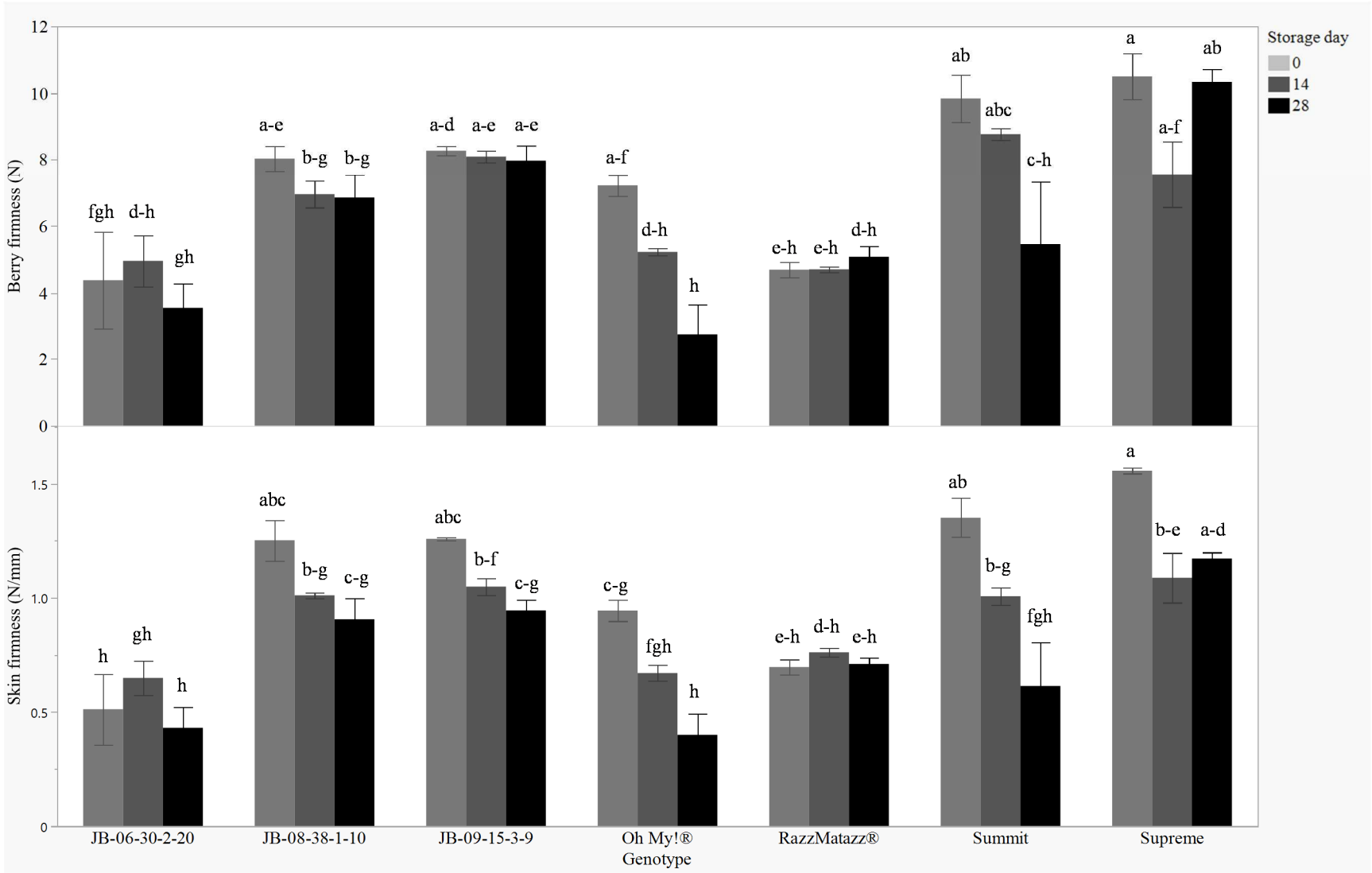


Fig. 11. Interaction effects on berry firmness and skin firmness of muscadines grown in North Carolina (Kings Mountain, NC) and stored at 2 °C for 0, 14, and 28 days at the University of Arkansas System Division of Agriculture (2020).

Genotypes were evaluated in triplicate. Means with different letters for each attribute by location are significantly different ($p<0.05$) within each location using Tukey's Honestly Significant Difference test

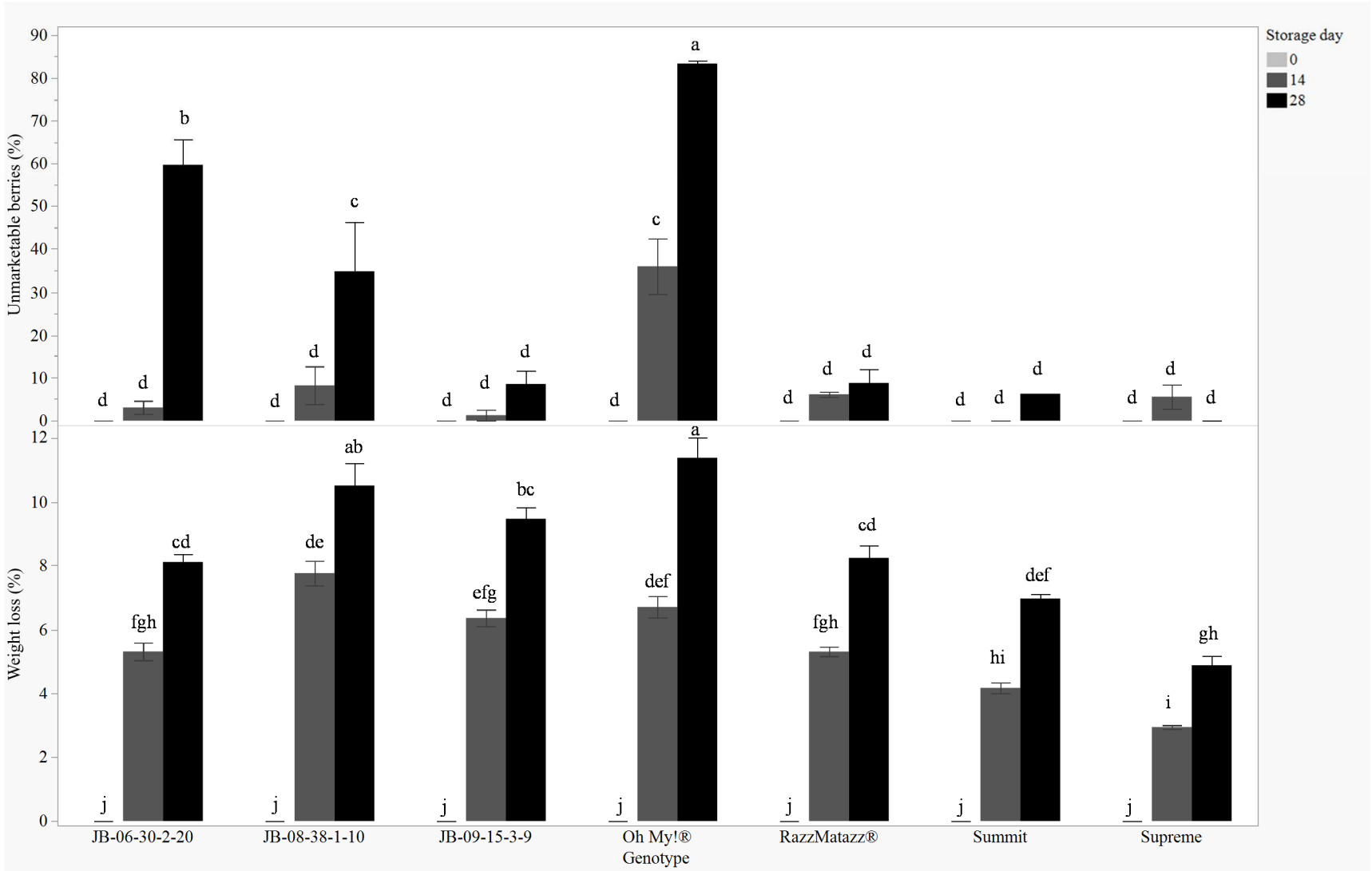


Fig. 12. Interaction effects on unmarketable berries and weight loss of muscadines grown in North Carolina (Kings Mountain, NC) and stored at 2 °C for 0, 14, and 28 days at the University of Arkansas System Division of Agriculture (2020).

Genotypes were evaluated in triplicate. Means with different letters for each attribute by location are significantly different ($p<0.05$) within each location using Tukey's Honestly Significant Difference test

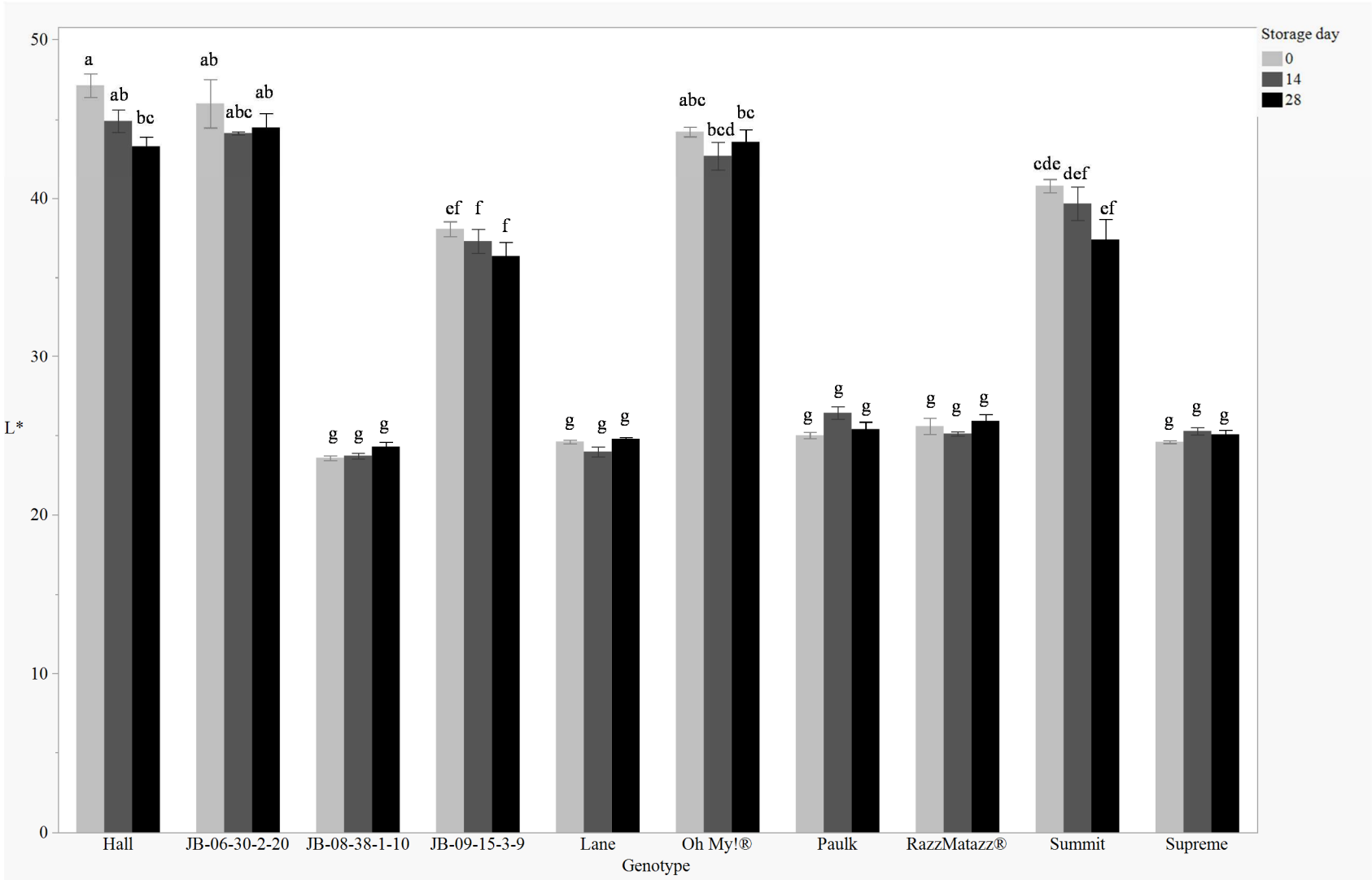


Fig. 13. Interaction effects on L* of muscadines grown in North Carolina (Kings Mountain, NC) and stored at 2 °C for 0, 14, and 28 days at the University of Arkansas System Division of Agriculture (2021).

Genotypes were evaluated in triplicate. Means with different letters for each attribute by location are significantly different ($p<0.05$) within each location using Tukey's Honestly Significant Difference test

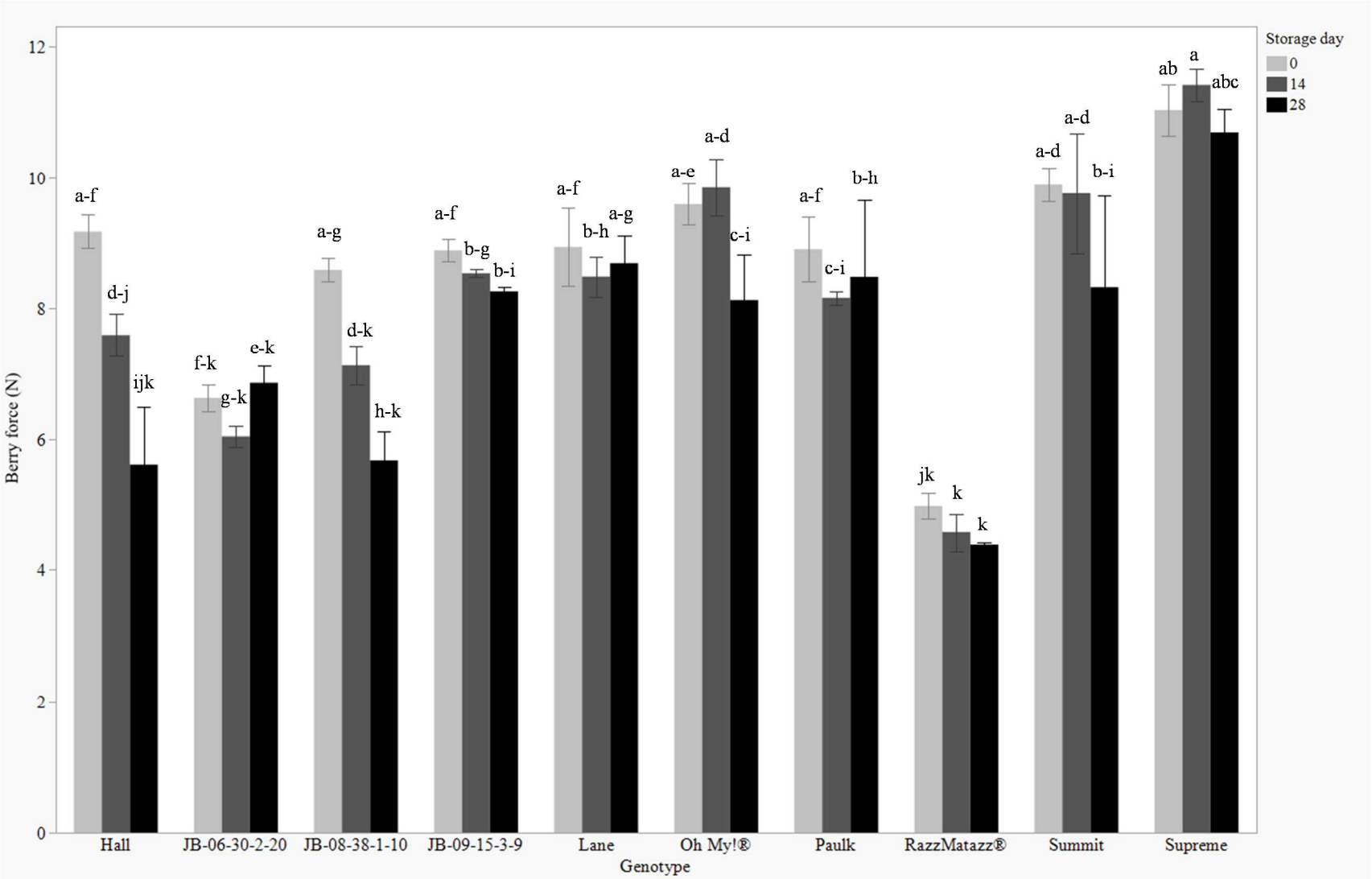


Fig. 14. Interaction effects on berry firmness of muscadines grown in North Carolina (Kings Mountain, NC) and stored at 2 °C for 0, 14, and 28 days at the University of Arkansas System Division of Agriculture (2021).

Genotypes were evaluated in triplicate. Means with different letters for each attribute by location are significantly different ($p<0.05$) within each location using Tukey's Honestly Significant Difference test

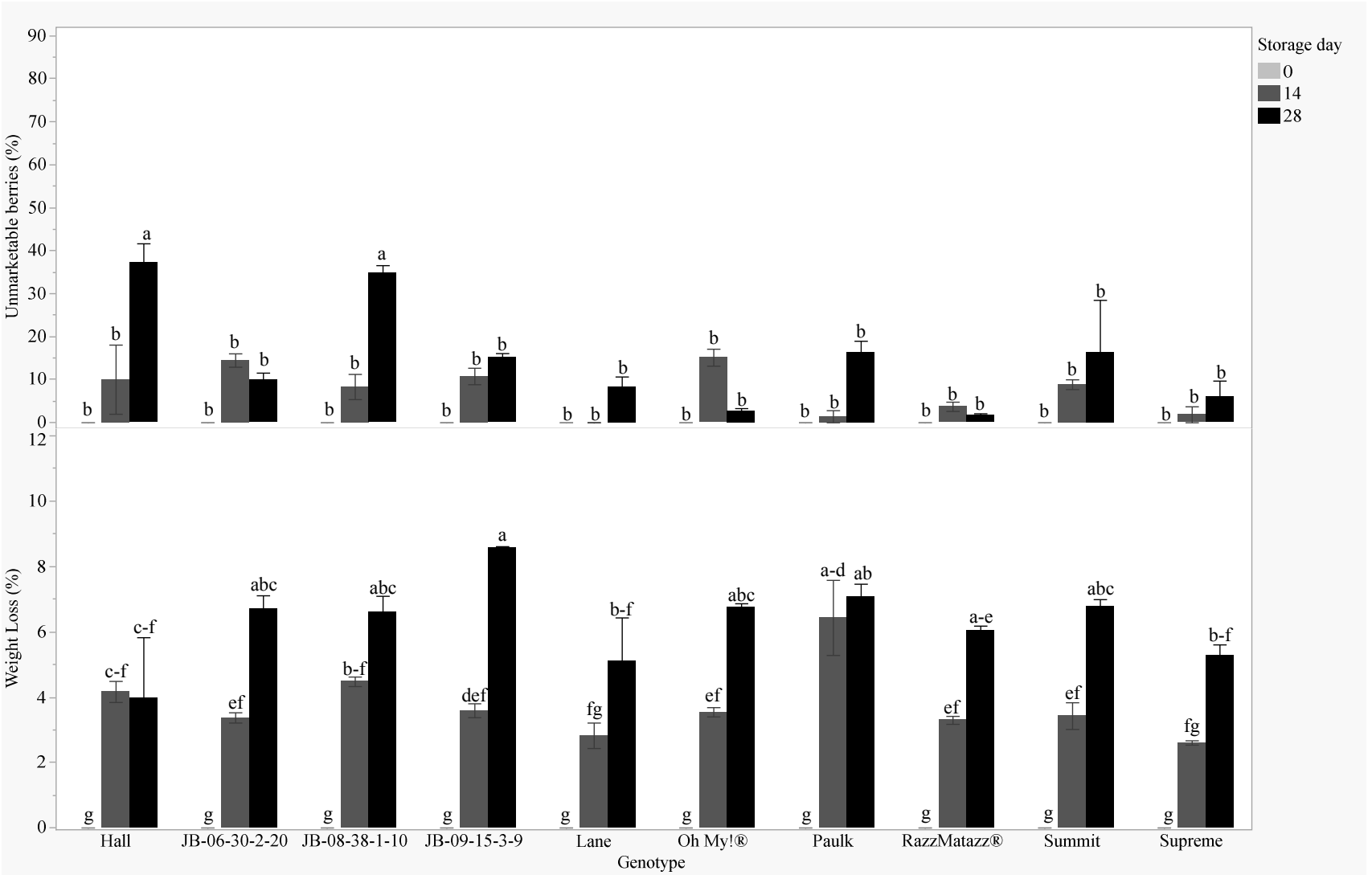


Fig. 15. Interaction effects on unmarketable berries and weight loss of muscadines grown in North Carolina (Kings Mountain, NC) and stored at 2 °C for 0, 14, and 28 days at the University of Arkansas System Division of Agriculture (2021).

Genotypes were evaluated in triplicate. Means with different letters for each attribute by location are significantly different ($p<0.05$) within each location using Tukey's Honestly Significant Difference test

Chapter II

Determining Impact of Skin Contact Time during Wine Production of 'Noble' and AM-77 Muscadine Grapes

Abstract

Muscadine grapes (*Vitis rotundifolia* Michx.) are a disease-resistant specialty crop native to the southeastern United States. There have been major advances in U.S. muscadine breeding efforts resulting in unique traits emerging that have the potential for commercial expansion. In 2020 and 2021, muscadines 'Noble' and AM-77 were evaluated at the University of Arkansas (UA) System Division of Agriculture Fruit Research Station and evaluated for wine production. The grapes were harvested in September/October, and the wine was produced at the UA System Department of Food Science with different skin contact times (0 and 3-days). The wines were analyzed for composition and color attributes at bottling for each year and during storage (0, 3, 6, 9, and 12 months at 15°C) for the 2020 wines. In addition, at 6-months storage, a consumer sensory evaluation (54 consumers) was done on the four wines using a nine-point hedonic scale to indicate overall liking of the wine attributes (color, aroma, flavor, mouthfeel, and overall) and a 5-point Just About Right (JAR) scale to evaluate color, aroma, flavor, and mouthfeel of the wines. At bottling for both years, there were ranges for the pH (2.86-3.13), titratable acidity (0.74-1.21%), ethanol (9.67-11.35%), as well as L* (3.50-14.22), a* (31.92), b* (14.61-41.76), hue angle (29.01-61.78), chroma (35.78), red color (1.86-3.98), brown color (0.07), and color density (1.89-3.69). In general, wines with 0-day skin contact had more red color, brown color, and color density than wine from the 3-day skin contact time. At bottling, AM-77 wine had lower pH, red color and color density and higher titratable acidity and L* than 'Noble' wine. The pH of wines increased during storage, and wines with 3-day skin contact times had higher

titratable acidity. In terms of the 0-day skin contact wine, there was not a difference in red color, brown color, and color density between AM-77 ‘Noble’, but in terms of the 3-day skin contact time wine ‘Noble’ wine had more red color, brown color, and color density. For composition during storage, all the attributes evaluated had significant interactions except L*, but the genotype x skin contact time x storage interaction was not significant for any attribute. For the sensory attributes of the four wines, consumers found differences in color, aroma, flavor, mouthfeel, and overall liking but not aroma. Although consumers tended to like the color of the 3-day skin contact wines more than 0-day wines, the consumers favored the flavor and overall liking of the 0-day skin contact time wine more than 3-day skin contact time wine. AM-77 0-day skin contact time wine had the highest liking for flavor, mouthfeel, and overall liking. Wine production using different skin contact time has shown the commercial potential for AM-77 as compared to ‘Noble’.

Introduction

Muscadine grapevines (*Vitis rotundifolia* Michx.) are plants that are disease and pest resistant and have a long history in the United States. The genus *Vitis* is commonly divided into *Euvitis* (bunch grapes) and *Muscadinia* (muscadine grapes). Of the three species of *Muscadinia*, only *V. rotundifolia* is cultivated commercially. The muscadine grape has been cultivated for about 200 years in the southern United States. Muscadine cultivation can be easier and yield a more abundant crop than *V. vinifera* because diseases resulting from humidity and pest pressures that devastate *V. vinifera* do not have the same deleterious effect on muscadine cultivars (Bouquet, 1981; Hopkins et al., 1974; Morris and Brady, 2004; Ren and Lu, 2002).

Muscadines are cultivated throughout the southeastern states from as far west as Texas to the eastern coast and as far north as Delaware. In 2019, more than 1,214 ha of muscadines were grown in Florida, Georgia, North Carolina, and South Carolina (Hoffman et al., 2020). North Carolina, Georgia, and Florida are the top three muscadine-producing states by acreage at 1,052, 688, and 486 hectares, respectfully in 2012 (Vilsack and Clark, 2014). In 2016, the Arkansas grape industry assessment survey conducted by University of Arkansas Department of Horticulture reported that muscadine grapes were the most common grape grown in the state (Alman, 2016), and economic analysis has indicated that muscadine grape production can be profitable for vineyards in Arkansas (Noguera et al., 2005).

Commercial vineyards grow muscadines for the production of juice, wine, and jelly/jam, and the majority of the commercial muscadine crop is used to produce wine in Arkansas (Sims and Morris, 1985). Muscadines are also grown for fresh-markets but mainly sold during peak muscadine season at commercial markets near the growing locations. In addition, muscadines

can be used to make other products like energy drinks, vinegars, grape seed oil, supplements, and lotions.

Muscadine grapevines typically flower in May to June, with harvest September to October. Muscadine grapevines are grown commercially on trellis systems including single wire, double wire, and Geneva Double Curtain systems. Muscadine vines can grow vigorously and may need canopy management, such as hedging, skirting, and fruit/shoot thinning to achieve the vines full potential for grape production (Anderson et al., 2020; Hoffman et al., 2020; Olien, 1990). With proper cultivation, the plant will typically produce 8-27 metric tons/hectare (Stanley, 1997). Morphologically, muscadines are drastically different than *V. vinifera* grapes. Muscadine grapes have thick skins, large seeds, small clusters, abscissions in between fruit and rachis, prominent lenticels, continuous piths, and a distinguishing aroma and flavor (Hickey et al., 2019; Hoffman et al., 2020). Characteristics common among processing cultivars include small to medium sized berries, high yield, even ripening, and higher sugar and acid levels. 'Carlos' (bronze) and 'Noble' (black) are the most common muscadine grapes for processing due to their high production amounts and are popular for juice and wine production (Anderson et al., 2020). Other processing cultivars include 'Alucha', 'Doreen', 'Magnolia', and 'Welder'.

Public breeding programs of muscadines across the southern United States include those at Florida A&M University, North Carolina State University, University of Arkansas, University of Florida, University of Georgia, and the United States Department of Agriculture (USDA) in Poplarville, MS (Olien, 2001). Previous advances in muscadine breeding include the development of perfect-flowered and self-fruitful cultivars, increased berry size and sugar content, presence of dry picking scars.(Conner, 2010). The first parthenocarpic seedless muscadine was 'Fry', but that was not really a major advance for breeders due to small berry size

and poor yield for commercial production (Hoffman, 2020). The first stenospermocarpic cultivars released in 2017. Other traits undergoing development include more cultivars with perfect flowers and large fruit, improved textures, thinner skins, and a broader range of ripening dates. Retaining the unique flavors and aromas of muscadines is a focus in creating new cultivars for commercial markets. The University of Arkansas System Division of Agriculture (UA System) Fruit Breeding Program began breeding muscadines in 2007 with a focus on vine cold tolerance, large fruit size, crisp texture, edible skin, self-fruitful flowers, seedlessness, and improved postharvest storability (Barchenger et al., 2015; Felts et al. 2018; Worthington, 2019). The muscadine breeding program is working to develop fresh-market muscadine grape and muscadine hybrids (crosses with *V. vinifera*) that have thinner more edible skins and no seeds and cultivars that can be used for commercial processing (Worthington, 2019).

Breeding cultivars of muscadines that result in new skin color components is important to breeding programs. Muscadine skin color is also important because color is extracted from the skin during juice and wine processing. Muscadine processers want deep, rich color and color stability in juice or wine that have an extended shelf life (Conner, 2010). The USDA (2006) has color standards regarding muscadines describing skin color in two categories, white or black/red. White muscadines have either a bronze or blush tone with shades of green, straw, amber, bronze, and some small amounts of red or blush. Black/red muscadines can include red, pink, purple, and black colors with an outer skin with at least 75% red, purple, or black tones. Black muscadines can be classified further to red and black categories. Black muscadines are typically very dark, and red muscadines can show lighter tones of red, pink, and purple. Muscadine color characteristics are important as they can change during ripening and during postharvest storage. It has been found that 90% of the total anthocyanins in muscadines were 3,5-diglucoside of

delphinidin, cyanidin and petunidin; the other 10% measured were 3,5-diglucoside of peonidin and malvidin in 'Carlos', 'Higgins', 'Jumbo', and 'Cowart' muscadines (Huang et al, 2009). Significant variation in total anthocyanin content among different cultivars of muscadine grapes has been documented with dark/purple skinned muscadine grapes having significantly higher levels of anthocyanins than bronze-skinned muscadine grapes (Huang, et. al. 2009). Connor and Mclean (2013) examined anthocyanin profiles and color of muscadines grown in Georgia and found that malvidin, an important anthocyanin for color stability, was only found in a few genotypes (cultivars and advanced breeding selections) but found positive correlations among other color parameters measured with anthocyanin content.

Muscadine grapes typically have three sections: the flesh (pulp), skins, and seeds. The flesh contains primary metabolites of the grape, such as water, sugar, acids, and pectin, whereas skins and seeds contain more secondary metabolites, such as phenolic and aroma compounds (Waterhouse et al., 2016). Mature grapes contain water, sugar, organic acids, and pectin. Sugars (glucose and fructose) make up a majority of grape carbohydrate content with muscadine grapes having 15-23% soluble solids. In grapes, the acidity attributes measured are pH and titratable acidity (% tartaric acid). Mature muscadine grapes grown in Arkansas typically have 0.50-0.70% titratable acidity and 3.0-3.3 pH (Barchenger et al., 2015. Felts, 2018; Felts et al., 2018).

Phenolic compounds have at least one 6-carbon aromatic ring and one or more hydroxyl groups and can be divided into two groups: non-flavonoids and flavonoids. Within the flavonoid category, compounds are further classified as anthocyanins, flavonols, or tannins. Anthocyanins are responsible for the red color of grapes and wine and are found primarily in the skin of red grape cultivars. *V. vinifera* grapes typically have monoglucosides, whereas muscadine grapes have diglucosides. Connor and MacLean (2013) evaluated the anthocyanin content and

composition of 22 muscadine grape genotypes and found delphinidin, cyanidin, petunidin, pelargonidin, peonidin, and malvidin in their 3,5-diglucosidic forms with delphinidin in the highest concentration, but found malvidin, the most important anthocyanin for muscadine wine and juice color stability, abundant in only a few clones. Pastrana-Bonilla et al. (2003) evaluated 10 cultivars of muscadine grapes grown in southern Georgia and found that in general across cultivars, the total phenolics in the seed, skin, pulp, and leaves was of 2,179, 375, 24, and 352 mg/g gallic acid equivalent, respectively.

Flavonols found in grapes include quercetin, kaempferol, myricetin, and isorhamnetin. Tannins, or flavan-3-ols, include catechin, epicatechin, epicatechin gallate, and epigallocatechin and are responsible for grape astringency and bitterness in both the skins and seeds of grapes. Threlfall et al. (2005) evaluated the pressing effects on the nutraceutical contents of seeds, skins, and juice of 'Black Beauty' and found that the juice generally had less total phenolics, total anthocyanins than the whole grapes. The juice from heated 'Black Beauty' musts had the total phenolics of 1,354 mg/L and anthocyanins of 414 mg/L, while dried seeds had more phenolics and less anthocyanins than the skins (Threlfall et al., 2005).

Previous research has shown that flavonols increase in grapes exposed to the sun prior to harvest (Price et al., 1995; Spayd et al., 2002). Spayd et al. (2002) found that the flavonol concentration was increased by 10-fold in 'Merlot' grapes that were exposed to the sun, relative to grapes that were shaded. Because flavonols are found mostly in the outer layer of cells in the grape skin and they absorb ultraviolet light strongly at 360 nm, it is believed that plants produce them as a form of protection. Flavonols are known to have a bitter taste, but it is unclear if, at the concentrations found in wine, they contribute to flavor. Sáenz-Navajas et al. (2010) found that there was no correlation between bitterness and flavonol concentration in red wines. However, it

was proposed that other compounds could have overpowered their effect. Preys et al. (2006) showed that when phenolic fractions were added back to wine, there was an association between bitterness and the fractions higher in flavonols. Hufnagel and Hofmann (2008) concluded that flavonols possess a 'velvety astringency'

Muscadine grapes have many nutraceutical impacts (foods containing health-giving additives and having medicinal benefit). Muscadines also have high amounts of healthy bioactive compounds including resveratrol, ellagic acid, anthocyanins, and proanthocyanidin phenolics (Ector et al., 1996; Lee and Talcott, 2004; Pastrana-Bonilla et al., 2003; Threlfall et al., 2005). Anthocyanin content is highest in the skin of dark berries (Striegler et al., 2005), and although found throughout berries, phenolic content is highest in the seeds (Ector et al. 1996; Pastrana-Bonilla et al., 2003; Sandhu and Gu, 2010; Threlfall et al., 2005). Kim et al. (2009) found that red muscadine juice had natural antibacterial properties by showing the inhibition of *Escherichia coli* growth when exposed to fresh or processed muscadine juice. Muscadine juice has lower amounts of anthocyanins and phenolics than whole berries (Threlfall et al., 2005), but muscadine juice has been shown to inhibit in vitro growth of leukemia cells (Merotens-Talcott, 2008). In addition, some cell culture studies (Mertens-Talcott et al. 2008, Yi et al. 2005) have indicated that muscadine polyphenols can inhibit proliferation of colon cancer cells and induce apoptosis. As consumers have become aware of these muscadine health benefits, the demand for fresh and processed muscadine products has increased.

In 2017, Arkansas was number 21 among U.S. states for total grapevine area, with 322 hectares. From 2008-2015, the number of grapes harvested and the price per tonne in Arkansas fluctuated. Grape production peaked in 2010 at over 2,300 tonnes, and the price peaked at about $1,290/tonne in 2012 (USDA NASS 2019). A majority of the commercial muscadine crop is

used to produce wine. The two most popular cultivars for processing are 'Noble', a black muscadine, and 'Carlos', a bronze muscadine. Sistrunk and Morris (1984) determined that 'Noble' muscadine grapes grown in Arkansas were excellent for juice and wine production. The production of grapes to wine involves a fermentation where grape sugars are converted to ethanol and carbon dioxide by yeast added to juice or must (skins, seeds, juice, and pulp). There are many other physical and biochemical changes occurring due to extraction and microbial metabolism of other grape compounds.

Muscadine wines can have poor color, color stability, and cloudiness/sediment. Muscadine grapes and wines contain only diglycosidic anthocyanins, which are unable to form stable polymeric pigment complexes (Sims and Morris, 1985). There have been several studies examining the attributes and quality of 'Noble' muscadine wines (Gürbüz et al., 2013; Lamikanra, 1987, 1997; Lamikanra et al., 1996; Nesbitt et al., 1974; Sims and Bates, 1994; Sims and Morris 1985, 1986; Sistrunk and Morris, 1984; Talcott and Lee, 2002). Research has shown that most of the phenolic compounds in muscadines are predominantly located in the skins (11.3%) and seeds (87.1%), the extraction and solubility of these compounds during wine and juice making are greatly influenced by the time (Baderschneider and Winterhalter, 2001; Huang et al., 2009, Pastrana-Bonilla et al., 2003, Sandhu and Gu 2010). Sims and Bates (1994) observed an increase in anthocyanin content with increasing skin contact time for 'Noble' muscadine wines, but also saw that longer skin fermentation times resulted in higher astringency and lower fruity and floral aromas. Mayfield (2020) evaluated 'Noble' muscadine wine with different enzyme treatments and skin contact times (0, 3, and 7 days) and found the longer skin contact times characterized wines with deeper, richer, spicier flavors, while wine from 0-day skin contact had light, fruity, floral characteristics.

The color instability of muscadine wines can be attributed to limited anthocyanin-tannin polymerization. Muscadines contain only diglucoside anthocyanins, which are unable to form stable polymeric pigment complexes like the monoglucoside anthocyanins in *V. vinifera* grapes and wine (Sims and Morris, 1985). Sims and Bates (1994) observed an increase in anthocyanin content with increasing skin contact time for 'Noble' muscadine wines, but also saw that longer skin fermentation times resulted in higher astringency and lower fruity and floral aromas.

Mayfield (2020) found only the diglucoside anthocyanins delphinidin-, malvidin-, petunidin-, peonidin-, and cyanidin-3,5-diglucoside in 'Noble' muscadine wines grown in Arkansas, and multiple studies have shown muscadine grapes with large amounts of malvidin-3,5-diglucoside produce wines and juices with the best color quality (Flora, 1979; Nesbitt et al., 1974). In addition, Mayfield (2020) found that increasing skin contact time also increased the red color, brown color, and color density of 'Noble' muscadine wines. Regardless of skin contact, the red color of wines increased slightly from 0- to 3-months storage, but then decreased from 3-months to 6-months storage. This decrease in red color can be attributed to degradation of the less stable diglucoside anthocyanins found in 'Noble' muscadine wine. While there were slight decreases in color density during storage, there was no increase in brown color observed (Mayfield, 2020). This was significant since muscadine wines typically experience browning during storage that negatively impacts their shelf-life and consumer acceptability (Sims and Morris, 1986).

Brown et al. (2016) evaluated the consumer acceptability of fresh-market muscadines and found flavor had the closest correlation to overall liking, which is promising since some of the muscadines were comparable to *V. vinifera* grapes in their flavor liking. Juices and wines produced from muscadine grapes have unique fruity and floral aromas and flavors. Baek et al.

(1997) investigated the dominant aromas compounds in muscadine juice and found that furaneol (strawberry or pineapple) and o-aminoacetophenone (fruity-grape like) are major characteristic contributing candy and foxy-like aromas. Furaneol exhibits a burnt sugar-like aroma at higher concentrations (Baek et al., 1997). Muscadine juices from Arkansas had cooked muscadine, apple, pear, cooked grape, green/unripe, and slightly musty aromas and flavors (Threlfall et al., 2007). Meullenet et al. (2008) found correlations between general muscadine flavor and musty flavor, general grape flavor and metallic flavor, green/unripe flavor and sourness/astringency, and sweetness and floral, apple, and pear flavors for Arkansas muscadine juice. Muscadine juice has shown promising results in consumer acceptance when blended with other fruit juice and juice cocktails (Flora et al., 1979; Trappey et al., 2007). Lamikanra (1987) determined that higher alcohols and fatty acid ethyl esters were the largest classes of volatile aroma compounds in 'Noble' muscadine wine with 2-phenylethanol (rose and honey aroma) responsible for the characteristic rose aroma of muscadine wines. Sims and Bates (1994) evaluated the effect of skin contact time (time that the wine is fermented with the juice, pulp, skins and seeds before pressing) on 'Noble' muscadine wines and found that wines with longer skin contact times had lower general muscadine aroma intensities. Regardless of the appealing aromas and flavors, muscadine wines, especially longer skin contact times during wine production, can have high bitterness and astringency due to their phenolic composition, poor color and color stability, and cloudiness/sediment caused by ellagic acid precipitation during storage (Sims et al. 1994, Sims and Morris 1985).

Since 'Noble' muscadines are the industry standard for juice and wine production, it is important to evaluate new, potential breeding lines and compare attributes to 'Noble'. The UA System, has bred a new muscadine genotype, AM-77, which could be the first muscadine grape

cultivar released from the UA System, and this genotype has the potential for wine production Thus, the objective of this research was to determine the impact of skin contact time during wine production of 'Noble' and AM-77 muscadine grapes.

Materials and Methods

Muscadine vineyards and harvest

In 2020 and 2021, 'Noble' grapes were grown and harvested from a commercial vineyard in Altus, AR, and AM-77 were grown and harvested from a commercial vineyard in Altus, AR and the UA System Fruit Research Station in Clarksville, AR (USDA hardiness zone 7b). The fruit was picked on the same harvest date, but from different locations due to a lack of available fruit. The soil type is Linker fine sandy loam (fine-loamy, siliceous, semi active, thermic Typic Hapludult). The grapes were grown on a single, high wire cordon system and a Geneva Double Curtain trellis system on own-rooted, variable-age vines. The grapes were hand harvested in September 24, 2020 and October 6, 2021. Harvest date was determined based on ideal composition attributes for muscadine grapes, as well as past harvest data, weather, and quality of the fruit. Approximately 128 kg of grapes from each genotype were used for wine production each year. The grapes were taken to the UA System Food Science Department in Fayetteville, AR and stored at 2 °C overnight for wine production the following day.

Wine production

For wine production, grapes from each genotype were split randomly into four 32 kg batches (0 days and 3 days skin contact time, in duplicate). Each batch of grapes was passed twice through a crusher/destemmer, and 30 mg/L sulfur dioxide (SO_2) as potassium metabisulfite was added at crush to inhibit the growth of wild yeast. The composition of the must (juice, skins, seeds, and pulp after crushing) was evaluated prior to, during, and at the end of fermentation, and

adjustments to sugars, acids, and SO_2 were made to the must to ensure a complete fermentation. The free SO_2 levels of the wine were evaluated and adjusted as needed. Soluble solids, pH, and titratable acidity of must was evaluated prior to fermentation. Musts was inoculated with Lalvin ICV D254® wine yeast (Lallemand, Inc., Montreal, Canada) at a rate of 0.26 g/L estimated juice in the must. Musts was fermented on the skins for zero days or three days at 15 °C. Residual sugars and ethanol levels were monitored using an EasyDens density meter (Anton Paar, Austria). After fermentation on the skins, the must was pressed with a 70-L Eno Agricola Rossi Hydropress (Calzolaro, Italy) using three 10-minute press cycles and a pressure of 207 kPa. The wines were collected in 11.4-L glass carboys fitted with fermentation locks filled with SO_2 solution to allow release of carbon dioxide and limit oxygen exposure. Wines were racked (wine removed from the sediment) several times as fermentation at 15 °C continued, and fermentation completed after approximately eight months. The free SO_2 content of wines was determined using the aeration-oxidation method (Iland et al., 1993) and adjusted to 10-20 mg/L depending on the pH of the wine. Wines were bottled into 125-mL 375-mL, and 750-mL glass bottles, sealed with plastisol-lined lug caps and screw caps, and stored at 15 °C until analysis. The wines were analyzed during storage (0, 3, 6, 9,and 12 months storage for 2020 wines and 0 months for 2021 wines for composition and color attributes. In addition, the 2020 wines were evaluated by consumer sensory panel at 6-months storage. Wines were stored at 15 °C for one week prior to the first analysis (month 0).

Composition attributes analysis

The composition attributes analysis of the wines included pH, titratable acidity, glycerol, ethanol, residual sugars, and organic acids. Other attributes of the juice, must, and wine were measured for winemaking adjustments. Analysis was done on each wine sample. The 2020 and

2021 wines were analyzed for composition attributes at 0-months storage at 15 °C, and 2020 wines were analyzed during (0, 3, 6, 9, and 12 months at 15 °C).

Soluble solids. The soluble solids (expressed as %) of the juice and must prior to inoculation was determined using a Bausch & Lomb Abbe Mark II refractometer (Scientific Instruments, Keene, NH).

Density. The density level of must during fermentation was determined using a EasyDens density meter (Anton Paar, Austria) expressed as g/cm^3.

pH. The pH of juice, must, and wines was measured using a PH700 pH meter (Apera Instruments, Columbus, Ohio). The pH was measured after the probe has been in the sample for 2 min. Wine was degassed prior to analysis.

Titratable acidity. The titratability acidity of juice, must, and wines (expressed as % tartaric acid or g tartaric acid /100 mL) was measured using a Metrohm 862 Compact Titrosampler. Six grams of sample was added to 50 mL degassed, deionized water and titrated with 0.1 N sodium hydroxide to an endpoint of pH 8.2. Wine was degassed prior to analysis.

Glycerol, ethanol, residual sugars, and organic acids. The glycerol, ethanol, residual sugars, and organic acids in wines were identified and quantified using High Performance Liquid Chromatography (HPLC) procedures described in Walker et al. (2003). Samples were passed through a 0.45 μm polytetrafluoroethylene (PTFE) syringe filter (Varian, Inc., Palo Alto, CA) before injection onto an HPLC system consisting of a Waters 515 HPLC pump, a Waters 717 plus autosampler, and a Waters 410 differential refractometer detector connected in series with a Waters 996 photodiode array (PDA) detector (Water Corporation, Milford, MA). Analytes were separated with a Bio-Rad HPLC Organic Acids Analysis Aminex HPX-87H ion exclusion column (300 x 7.8 mm) connected in series with a Bio-Rad HPLC column for fermentation

monitoring (150 x 7.8 mm; Bio-Rad Laboratories, Hercules, CA). A Bio-Rad Micro-Guard Cation-H refill cartridge (30 x 4.5 mm) were used as a guard column. Columns were maintained at a temperature of 65 ± 0.1°C by a temperature control unit. The isocratic mobile phase consisted of pH 2.28 aqueous sulfuric acid at a flow rate of 0.45mL/min. Injection volumes of both 10 µL (for analysis of organic acids and sugars) and 5 µL (for ethanol and glycerol) were used to avoid overloading the detector. The total run time per sample was 60 minutes. Citric, tartaric, malic, lactic, and succinic acids was detected at 210 nm by the PDA detector, and glucose, fructose, ethanol, and glycerol were detected at 410 nm by the differential refractometer detector. Analytes in samples were identified and quantified using external calibration curves based on peak area estimation with baseline integration. Results were expressed as milligrams analyte per 100 mL wine for organic acids and residual sugars, grams per liter wine for glycerol, and % v/v (alcohol by volume, ABV) for ethanol. Total residual sugars were calculated as the sum of glucose and fructose, and total organic acids were calculated as the sum of tartaric, malic, lactic, citric, and succinic acids.

Color attributes analysis

The color attributes analysis of the wines included L*, a*, b*, hue angle, chroma, red color, and color density. The 2020 and 2021 wines were analyzed for color attributes at 0-months storage at 15 °C, and 2020 wines were analyzed during (0, 3, 6, 9, and 12 months at 15 °C).

L*, a*, b*, hue angle, and chroma. Wine color analysis was conducted using a ColorFlex system (HunterLab, Reston, VA). The ColorFlex system uses a ring and disk set (to control liquid levels and light interactions) for measuring translucent liquids in a 63.5-mm glass sample cup with an opaque cover to determine CIELab transmission values of L*=100, a*=0, and b*=0 ((CIE, 1986).

Red color and color density. Color of wines was measured spectrophotometrically as absorbance at 520 nm (red color) and 420 nm (brown color), and color density (red color + yellow/brown color (Iland et al., 1993). Absorbance values were measured using a Hewlett-Packard 8452A Diode Array spectrophotometer equipped with UV-Visible ChemStation software (Agilent Technologies, Inc., Santa Clara, CA). Samples were diluted with deionized water as needed prior to analysis and measured against a blank sample of deionized water. A 1-cm cell was used for all spectrophotometer measurements.

Sensory attributes analysis

The consumer sensory attributes of the 2020 wines were evaluated. There were four wines evaluated (2 genotypes x 2 skin contact times) at 6-months storage at 15 °C. For the sensory evaluations, the replications of each treatment were combined. The consumer sensory panel (n=54) was conducted at an annual meeting of the Arkansas Association of Grape Growers (AAGG) and other wine tasting events. Panelists evaluated the wines for intensity and liking of muscadine wine attributes. Panelists evaluated 30-mL of each wine, and each wine was evaluated one time. The wines were served at room temperature (25 °C) in wine glasses labeled with three-digit codes. Serving order was randomized among panelists to prevent presentation order bias. Each wine glass was covered with a food-grade plastic disc to prevent dissipation of aromas and flavors. Panelists were instructed to remove the disc before evaluating each sample, and then replace the disc before evaluating the next sample. The panelists used a nine-point hedonic scale (1 = dislike extremely and 9 = like extremely) to indicate their overall liking of the wine attributes (color, aroma, flavor, mouthfeel, and overall). Panelists evaluated color, aroma, flavor and mouthfeel of the wines using a 5-point Just About Right (JAR) scale (1 = much to low; 2 = too low; 3 = JAR; 4 = too much; 5 = much too much) collapsed to too low, JAR, and

too much. In addition, panelists were instructed to.leave a comment about positive and negative attributes of the wine and which of the four wines they preferred. Sensory methods used as described in Meilgaard et al. (2007).

Design and statistical analysis

After harvest, muscadine grapes from each genotype were randomized for skin contact treatments (0 and 3 days) in duplicate. The wines were bottled (125-mL, 375-mL, and 750 mL bottles) and stored in glass bottles at 15 °C. The 2020 and 2021 wines were analyzed for composition and color attributes at 0-months storage at 15 °C, and 2020 wines were analyzed during (0, 3, 6, 9, and 12 months at 15 °C). For composition and color attributes, samples were taken from one 125-mL bottle. Bottles of wine were treated as individual experimental units in a full factorial design. Statistical analyses were conducted using JMP® Pro statistical software (version 16.2.0, SAS Institute, Cary, NC). For sensory analysis, replications of the wines were combined. In addition, the 9-point hedonic scales were converted to numerical values (dislike extremely = 1, dislike very much = 2, dislike moderately = 3, dislike slightly = 4, neither like nor dislike = 5, like slightly = 6, like moderately = 7, like very much = 8, like extremely = 9) for statistical analysis. For JAR-scaled attributes, a collapsed scale was used (too low, JAR, and too much), and the percent of responses for each wine were tabulated.

Results and Discussion

Average monthly temperature and rainfall at the Fruit Research Station in Clarksville, AR and Altus, AR were recorded from January to September (start of muscadine harvest) through reports generated by the Southern Regional Climate Center (Texas A&M University) and with a Nimbus Digital Thermometer (Sensor Instrument Co. Inc., Center Point, OR). The 2020 muscadine season Arkansas was relatively mild in terms of temperature and rainfall. The

2021 season had notable weather events included -26 °C with 178 mm of snow in February of 2021 followed by a freeze in late April (-1 °C). The average high temperature was 22 °C and low temperature was 12 °C in both years. Average (January-September) rainfall in 2021 (103 mm) was less than rainfall in 2020 (139 mm).

In 2020, the must of AM-77 0 and 3-day skin contact time had initial soluble solids 14.0% and 13.9%, respectively, pH of 3.01 and 3.03, respectively, and titratable acidity of 0.53% and 0.56%, respectively. In 2020, the must of 'Noble' 0 and 3-day skin contact time had initial soluble solids 16.3% and 16.2%, respectively, pH of 3.21 and 3.27, respectively, and titratable acidity of 0.37% and 0.36%, respectively. In 2021, the must of AM-77 0 and 3-day skin contact time had initial soluble solids 14.9% and 14.3%, respectively, pH of 3.28 and 3.30, respectively, and titratable acidity of 0.39% and 0.33%, respectively. In 2021, the must of 'Noble' 0 and 3-day skin contact time had initial soluble solids 17.2% and 17.4%, respectively, pH of 3.40 and 3.42, respectively, and titratable acidity of 0.27% and 0.23%, respectively. Wines were considered dry if the total residual sugars were <1.0%. The soluble solids of the musts in both years were adjusted to 20% prior to fermentation. Campbell et al. (2021) evaluated 90 muscadine genotypes, including 21 cultivars, 60 breeding lines, and 9 *Vitis x Muscadinia* hybrids and found soluble solids about 10% and titratable acidity about 0.2% had a modest diversity among genotypes.

Wine composition at bottling

In both years, genotype impacted the pH and titratable acidity of the wines at bottling (Table 1). The free sulfur dioxide of the wines and had acceptable ranges at bottling. In 2020, AM-77 and 'Noble' wines had 15 and 17 mg/L, respectively, and in 2021 the wines had 7 and 18 mg/L. Initial ethanol levels of the wine, and in 2020 and 2021 were 11% ethanol. In both years, there were ranges for the pH (2.86-3.13), titratable acidity (0.74-1.21%), glycerol (0.60-0.73%),

ethanol (9.67-11.35%), glucose (0.30-0.54%), fructose (0.04-1.59%), total residual sugars (0.41-2.13%), tartaric acid (0.08-0.21%), malic acid (0.03-0.24%), citric acid (0.06-0.14%), succinic acid (0.31-0.38%), and total organic acids (0.51-0.80%). Lamikanra et al. (1997) analyzed the concentration of organic acids during muscadine grape fermentation and wine aging identifying the acids as tartaric, succinic, malic, lactic, and citric. Typically, non-*rotundifolia* wines have tartaric and malic acid as 90% of the total organic acid content, but tartaric and succinic acids are the predominant acids of the muscadine wine (Lamikanra et al., 1997). Gürbüz et al. (2013) compared the effect wine made with skin contact time to the initial juice and found that the sulfur compounds increased 400% in the skin-contact wine compared to the initial juice. In addition, there were 42 aroma-active volatiles in the initial juice versus 48 in the wine.

2020. The genotype x skin contact time interaction and the skin contact time were not significant for any of the composition attributes. Genotype only impacted pH, titratable acidity, and malic acid. 'Noble' wine had higher pH (2.91), lower titratable acidity (0.84%) and malic acid (0.07%) than AM-77. For the other composition attributes glycerol was 0.61%, ethanol was 11.12%, glucose was 0.48%, fructose was 1.15%, total residual sugars were 1.62%, tartaric acid was 0.14%, citric acid was 0.10%, succinic acid was 0.36%, and total organic acids was 0.75%.

2021. The genotype x skin contact time interaction was not significant for any of the composition attributes except for fructose and total residual sugar. 'Noble' 0-day wine (0.22%) had a higher amount of fructose at bottling than 'Noble' 3-day wine (0.09%), AM-77 0-day wine (0.02%), and AM-77 3-day wine (0.07%) (Fig. 1). 'Noble' 3-day wine (0.49%) had a higher about of total residual sugars than AM-77 0-day wine (0.36%). However, all of these wines were dry (< 1.0%), Genotype only impacted pH and titratable acidity. 'Noble' wine had higher pH (3.13) and lower titratable acidity (0.74%) than AM-77. For the other composition attributes glycerol was 0.72%,

ethanol was 10.06%, glucose was 0.30%, total residual sugars were 0.44%, tartaric acid was 0.20%, malic acid was 0.04%, citric acid was 0.07%, succinic acid was 0.36%, and total organic acids was (0.67%). Skin contact time impacted pH, titratable acidity, ethanol, tartaric acid, malic acid, succinic acid, and total organic acid. As compared to the 0-day skin contact wine, the wine with 3-day skin contact had higher titratable acidity (0.86%), glycerol (0.76%), tartaric acid (0.30%), malic acid (0.05%), succinic acid (0.41%), and total organic acids (0.83%), but had the lowest pH (3.03), ethanol (9.67%). Mayfield (2020) investigated the skin contact of wines made from Arkansas-grown 'Noble' with 0-day and 3-day skin contact times and found that the wine from the 0-day skin contact time had a lower tartaric acid content (0.26%) than wines with 3-day skin contact time (0.34%). The glucose (0.34%) and citric acid (0.07%) levels of the wines were not impacted by skin contact time.

Wine color at bottling

In both years, genotype and skin contact time impacted L*, b*, and hue angle (Table. 2). There where ranges from L* (3.50-14.22), a* (31.92), b* (14.61-41.76), hue angle (29.01-61.78), chroma (35.78), red color (1.86-3.98), brown color (0.07), and color density (1.89-3.69). Mayfield (2020) evaluated L*(4.9-24), hue angle (360-361), chroma (30-64), red color (1.5-4.0), brown color (4.1-12.7), and color density (4.1-12.7) of 'Noble' muscadine wines with different skin contact times (0, 3, and 7 days) at bottling and found similar ranges to this research except for brown color.

2020. In 2020, the genotype x skin contact time was not significant for any of the wine color attributes. All attributes for color where affected by skin contact time in 2020, and L*, b*, hue angle, red color, and color density were impacted genotype. The wine with 0-day skin contact time had higher L* (14.22), a* (39.43), b* (23.64), hue angle (61.78), and chroma (45.99)

values, but wine with the 3-day skin contact time had lower L*(8.92), a* (34.78), b* (14.61), hue angle (45.16), and chroma (37.77). Nesbitt et al. (1974) found that red muscadine wines with lower L* and a redder hue angle were judged as having more desirable color. Therefore, the color of the 3-day skin contact wines could be visually preferred over that of the 0- days skin contact wines. The wine with the 0-day skin contact time had lower levels of red color (1.86), brown color (0.04), and color density (1.89) than the wine with 3-day skin contact time that had red color of 2.95, brown color of 0.08, and color density of 3.02. AM-77 had the highest L*(12.36), b*(20.96), hue angle (57.56), and lower red color (1.96) and color density (2.01). 'Noble had the lowest L* (10.51), b* (17.29), hue angle (49.39), and highest red color (2.84) and color density (2.90). The a* (37.10), chroma (41.88), and brown color (0.06) of the wines were not impacted by genotype. Dooley et al. (2012) compared descriptive sensory and consumer sensory analysis on three *V. vinifera* grape cultivars to compositional and color analysis. Finally, to descriptive analysis, red color density, and depth of color was positively correlated with clarity, flavor intensity, red color density, L*, chroma, total anthocyanin content, and polymeric pigment content. Consumer acceptance of the wine's appearance where positively correlated with red color density, total anthocyanins, percent polymeric color and negatively correlated with L*, chroma, and hue (Dooley et al., 2012).

2021. In 2021, the genotype x skin contact time interaction was significant for a*, chroma, red color, brown color, and color density. Skin contact and genotype impacted the L*, b*, and hue angle. The wine with 0-day skin contact time had higher L* (12.01), b* (41.76), and hue angle (56.08) values than the wine with 3-day skin contact time with L* of 3.50, b* of 17.59, and hue angle of 29.01. The genotype AM-77 had higher L*(9.23), b*(34.92), and hue angle (46.65) than 'Noble' with L* of 6.27, b* of 24.44, and hue angle of 38.34. Each genotype by skin contact

combination significantly impacted a* and chroma. For both a* and chroma, the wines from AM-77 0-day were the highest, followed by 'Noble' 0-day, AM-77 3-day, and 'Noble' 3 day. In general, the higher a* values indicate higher red color, but the intensity/shade of the red is impacted by b* values. 'Noble' 3-day skin contact wine had the highest red color (5.00), brown color (0.17), and color density (5.17), followed by AM-77 3-day wine with red color (2.97), brown color (0.09), and color density (3.06) (Fig. 3). Wines from both genotypes at the 3-day skin contact time were higher than the wines at 0-day skin contact time. AM-77 and 'Noble' 0-day wines had the lowest values for red color (1.58 and 2.17, respectively), brown color (0.03 and 0.04, respectively), and color density (1.61 and 2.21, respectively). In general, the wines with 0-day skin contact had more red color, brown color, and color density than the wine from the 3-day skin contact time. In terms of the 0-day skin contact wine, there was not a difference in red color, brown color, and color density between AM-77 and 'Noble', but in terms of the 3-day skin contact time wine 'Noble' wine had more red color, brown color, and color density. Mayfield (2020) found similar results when analyzing skin contact times on 'Noble' muscadine wines with the 0-days skin contact wine at 0-months storage having the lowest red color (1.50), and the 7-days skin contact wine with at 3-months storage having the highest (4.11), and during storage the red color of wines increased slightly from 0- to 3-months storage, but then decreased from 3- months to 6-months storage regardless of skin contact time.

Wine composition during storage

The pH, titratable acidity and color attributes for wines made from 2020 Arkansas-grown Noble and AM-77 muscadine grapes with different skin contact times (0 or 3 d) during fermentation were evaluated at 0, 3, 6, 9, and 12 months storage at 15°C. All of the attributes

evaluated had significant interactions except L*, but the genotype x skin contact time, x storage interaction was not significant for any attribute (Fig. 3-6).

The genotype x storage interaction was significant for pH (Fig. 4). 'Noble' wine at 12-months storage had the highest pH, and AM-77 at 0-months storage (2.86) had the lowest pH. In each genotype, the pH of the wine at 12-month storage was higher than the wine at 0-month storage. The genotype x skin contact time interaction, the genotype x storage interaction, and the skin contact time x storage interaction were significant for titratable acidity. For genotype x skin contact time interaction, the wines for both skin contact times for AM-77 were higher in titratable acidity than 'Noble', and the wine from the 3-day skin contact time within each genotype were higher in titratable acidity than the wine from the 0-day skin contact time (Fig. 6). For genotype x storage interaction, AM-77 was higher in titratable acidity than 'Noble' at each storage time, and for AM-77 the wine at 0-months storage had a higher titratable acidity than the wine at 12-months storage (Fig. 4). For the skin contact time x storage interaction (Fig. 5), the wine with 3-day skin contact time at 3, 6, 9, and 12-month storage was higher in titratable acidity then the wine with 0-day skin contact time. Lamikanra et al. (1997) found that tartaric acid decreased during storage and succinic acid increased for muscadine wines.

The interactions for L* were not significant, but all main effects (genotype, skin contact, and storage) were significant. Wine from AM-77 had a higher L* (14.91) than 'Noble', and the wine with 0-day skin contact time (16.76) higher than the 3-day skin contact time. For the storage date, the wine with 0-month storage had the lowest L* (11.57) than the 12-month storage (18.33). AM-77 wine was lighter in color than 'Noble', the wine with 0-day skin contact time was lighter than wine from the 3-day skin contact time. During storage, the color of the wines lightened. Mayfield (2020) evaluated 'Noble' wine with different skin contact times and

identified the diglucoside anthocyanins, delphinidin-, malvidin-, petunidin-, peonidin-, and cyanidin-3,5-diglucoside with 0-days skin contact wines having lower individual and total anthocyanins (142 mg/100 mL) than wines with 3-days (278 mg/100 mL) or 7-days (290 mg/100 mL) skin contact at bottling, and similar patterns were seen at other storage tines.

The genotype x skin contact time interaction was significant for hue and chroma. The hue of AM-77 wine at 0-day (71.25) was higher than the other genotype/skins contact times. In addition, within each genotype, the 0-day skin contact time was higher in hue. Within in the same skin contact time, AM-77 was higher than 'Noble'. A higher hue value indicates a lighter color of red/orange wine than the lower hue values which appear more magenta colored. The AM-77 and 'Noble' 0-day skin contact wines (47.81 and 47.62, respectively) had higher chroma values than the 3-day skin contact wines. Chroma indicated the intensity of the wine color meaning that the 0-day wines had more intense color than 3-day wines.

The genotype x skin contact time, genotype x storage date, skin contact time x storage date interactions where significant for red color, brown color, and color density. For the genotype x skin contact interaction, 'Noble' 3-day skin contact time had higher red color (3.42), brown color (0.10), and color density (3.52), 'Noble' 0-day skin contact time, and wine from AM-77 with both skin contact times (Fig. 3). In terms of AM-77, the 3-day skin contact time had higher red color, brown color, color density than the 0-day skin contact time. For the genotype x storage interaction, within each genotype, the wines at 0-month storage were higher in red color, brown color, and color density, then the wines at 12-month storage. At 12-months storage, 'Noble' wine had a higher red color than AM-77, but there was not a difference in brown color or color density. For the skin contact time x storage date interaction, within each skin contact time, the wines at 0-month storage were higher in red color, brown color, and color density, then

the wines at 12-month storage (Fig. 5). Mayfield (2020) also found a decrease in total and individual anthocyanin content and color density over 6-months storage, but brown color did not increase.

Sensory analysis

Sensory research pertaining to new genotypes or cultivars of muscadines juice or wine is limited. Consumers with prior experience/knowledge of muscadine wine and an understanding of its positive health implications was positively correlated to the liking of muscadine wine (Canziani et al., 2018). Wines made from Arkansas-grown AM-77 and 'Noble' muscadine grapes with different skin contact times (0 or 3 d) during fermentation were evaluated at 6-months storage at 15 °C by consumer (n=54) using a 9-point hedonic scale and a JAR scale. The four wines (AM-77 0-day, AM-77 3-day, 'Noble' 0 day, and 'Noble 3-day) were evaluated by the consumers. Color, aroma, flavor, mouthfeel, and overall liking of the wines were evaluated by the consumers using the 9-point hedonic scale (Table 4). Consumers could significantly differentiate the wines for color, flavor, mouthfeel, and overall liking, but not aroma with a liking score of 6.0. Wine from 'Noble' 3-day skin contact time had the highest liking (7.11) for wine color and was significantly higher in liking than the 0-day skin contact time for both 'Noble' and AM-77. Wine from AM-77 0-day skin contact time had the highest liking for flavor (6.50), mouthfeel (6.28), and overall liking (6.33). Regardless of genotype, the flavor and overall liking of the wine from the 0-day skin contact time was higher than the 3-day skin contact time.

For data analysis, the JAR data were collapsed to ''Too Low,'' JAR, and ''Too Much'' (Table 5). Ideally for JAR evaluations, at least 75% of participants should consider an attribute JAR. Previous consumer sensory research (Threlfall et al., 2007) has shown that consumers prefer red-colored muscadine juice more than bronze-colored juice. This trend was shown in our

research in that the consumers preferred the deeper color of the wine with 3-day skin contact time. Consumers found that AM-77 (77%) and 'Noble' (85%) wines with 3-day skin contact were JAR for color, but the color was not enough for the wines from AM-77 (43%) and 'Noble' (41%) 0-day skin contact time. Mayfield (2020) evaluated the aroma and overall liking of 'Noble' muscadine wine with 0, 3, and 7-day skin contact time, and found that consumers like the aroma of the 3 and 7-day skin contact wines more than the 0-day skin contact wine. However, consumers did not detect differences in the aroma of the four wines in our study, but the aroma of AM-77 0-day skin contact time wine and 'Noble' 3-day skin contact time wine had the highest liking (6.11) but not significantly higher. Consumers found that the aroma was not enough (35-42%) for all of the wines, but AM-77 0-day skin contact time wine (58%) had the highest percent for JAR. Commercially-produced muscadine wine is often produced in a sweeter style (higher residual sugar) with robust, fruity flavors, but 3-day skin contact time wines had deeper, dark-fruit flavors. Wine from AM-77 0-day skin contact time (69%) had the highest percent of consumers that found flavor JAR, but the consumers found that the 3-day skin contact wines for both genotypes (40-47%) had too much flavor. This may be because of higher acid contents, like succinic acid, which can impart salty/bitter flavors (Thoukis et al., 1965). Wine from AM-77 0-day skin contact time (75%) had the highest acceptance for mouthfeel, but AM-77 3-day skin contact time wine (39%) had the highest percent of too much mouthfeel.

Volatile aroma compounds identified in Arkansas-grown 'Noble' muscadine wines included floral alcohols, roasted and caramelized aldehydes, fruity and floral esters, and floral, herbal, and spicy terpenes, and in addition, wines with greater skin contact times were associated with herbal and green/unripe aroma compounds, whereas wines with 0-days skin contact were associated with fruity, roasted, caramelized aromas (Meullenet et al., 2008 ;Mayfield, 2020).

Mayfield (2020) found the most commonly-used descriptors for muscadine wine aroma were fruity, floral, earthy, and candy with higher skin contact times described as having spicy, dark-fruit aromas typical of red wines, whereas wines with 0-days skin contact were described as having strawberry, candy, and artificial fruity aromas characteristic of muscadine grape juice.

In an informal tasting 2020 (1 year) and 2021 (3 months) the wines from 'Noble' and AM-77, and there were distinguishable varietal characteristics. The color and aromas of the 3-day skin contact wines in both years was more intense. In both years the color of 'Noble' wine was a more pinkish red color, and wine from AM-77 had a tawny red color. The aroma of 'Noble' had fruity notes, and AM-77 had floral notes. The mouthfeel of AM-77 was thicker than that of 'Noble'. The wines had a range of tasting notes, but in general the 3-day wines had more body, mouthfeel, flavor, but they lacked balance of other attributes. The consumer evaluation showed that the wines made from AM-77 and 'Noble' 0-day skin contact times were liked more than the 3-day skin contact times, with AM-77 slightly higher than 'Noble' but not significantly. According to a preference test, the consumers found AM-77 0-day skin contact wine was the most preferred (58%), and followed by Noble 0-day skin contact time (15%), and Noble 3-day skin contact time (15%) AM-77 3-day skin contact wine (11%)

Conclusions

In 2020 and 2021, wine from AM-77 and 'Noble' muscadines with 0-day and 3-day skin contact times during fermentation had composition and color values at bottling within typical ranges for dry red table wines, remaining mostly stable throughout storage for 12-months at 15 °C. At bottling, the genotype and skin contact impacted most composition and color attributes. At bottling, wine with the 0-day skin contact time had lower red color, brown color, and color density and higher L* than wine with 3-day skin contact time. At bottling, AM-77 wine had

lower pH, red color and color density and higher titratable acidity and L* than ‘Noble’ wine. The pH of wines increased during storage, and wines with 3-day skin contact times had higher titratable acidity. The red color and color density of muscadine wines decreased during storage, but brown color did not drastically increase or decrease. The differences in pH and color attributes of AM-77 and ‘Noble’ wine at bottling were the same during storage. The consumer sensory panelist found differences among the four wines (AM-77 and ‘Noble’ wines with 0 and 3-day skin contact times) for the sensory attributes except aroma. AM-77 0-day skin contact time wine was had the highest liking score for flavor, mouthfeel, and overall liking. The consumers generally liked the deeper color of the wines from the 3-day skin contact time more than 0-day, but the flavor, mouthfeel, and overall liking of the wines from the 0-day skin contact wines were liked more than wines from the 3-day skin contact time. Therefore, genotype and skin contact time impacted the composition, color, and sensory attributes of wines produced from Arkansas-grown AM-77 and ‘Noble’ muscadine grapes. AM-77 has potential as a new cultivar for commercial production of muscadine wine.

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Table 1. Composition attributes for wines at bottling made from Arkansas-grown AM-77 and Noble muscadine grapes with different skin contact times (0 or 3 d) (2020 and 2021).

Effects[z]	pH	Titratable acidity (%)[y]	Glycerol (g/L)	Ethanol (% v/v)	Glucose (%)	Fructose (%)	Total residual sugars (%)	Tartaric acid (%)	Malic acid (%)	Citric acid (%)	Succinic acid (%)	Total organic acids (%)
2020												
Genotype (G)												
AM-77	2.86 b	1.21 a	0.60 a	11.35 a	0.54 a	0.70 a	1.11 a	0.15 a	0.24 a	0.06 a	0.36 a	0.80 a
Noble	2.91 a	0.84 b	0.62 a	10.88 a	0.41 a	1.59 a	2.13 a	0.12 a	0.07 b	0.14 a	0.35 a	0.70 a
P-value	*0.0402*	*0.0002*	0.5062	0.4913	0.3406	0.2299	0.2431	0.2260	*0.0158*	0.2926	*0.5429*	0.3585
Skin contact (SC)												
0 days	2.91 a	1.03 a	0.60 a	10.99 a	0.43 a	1.50 a	2.02 a	0.12 a	0.13 a	0.12 a	0.34 a	0.75 a
3 days	2.86 a	1.02 a	0.61 a	11.23 a	0.52 a	0.79 a	1.22 a	0.15 a	0.18 a	0.08 a	0.37 a	0.76 a
P value	*0.0528*	*0.6364*	0.8529	0.7135	0.4705	0.3237	0.3421	0.2125	0.2852	0.5400	*0.4039*	0.9172
G x SC												
P-value	*0.4601*	*0.2449*	0.4182	0.3980	0.6752	0.6530	0.6552	0.9578	0.2860	0.7869	0.1663	0.2950
2021												
Genotype												
AM-77	2.96 b	0.89 a	0.71 a	10.10 a	0.37 a	0.04 b	0.46 a	0.18 a	0.04 a	0.06 a	0.38 a	0.67 a
Noble	3.13 a	0.74 b	0.73 a	10.01 a	0.30 a	0.15 a	0.41 a	0.21 a	0.04 a	0.07 a	0.34 a	0.66 a
P-value	*<0.0001*	*<0.0001*	0.4053	0.6995	0.0887	*0.0130*	0.1106	0.3262	0.9097	0.5987	0.2366	0.7828
Skin contact												
0 days	3.03 b	0.77 b	0.68 a	10.44 a	0.37 a	0.08 a	0.42 a	0.08 b	0.03 b	0.07 a	0.31 b	0.51 b
3 days	3.06 a	0.86 a	0.76 a	9.67 b	0.30 a	0.12 a	0.45 a	0.30 a	0.05 a	0.07 a	0.41 a	0.83 a
P-value	*0.0341*	*0.0002*	0.0631	*0.0150*	0.0700	0.1745	0.2754	*0.0022*	*0.0386*	0.9623	*0.0193*	*0.0010*
G x SC												
P-value	0.0647	0.7247	0.3120	0.1396	0.8836	*0.0262*	*0.0194*	0.4364	0.7001	0.9033	*0.3933*	0.2632

[z] Means with different letters for each attribute within effects of each year are significantly different ($p<0.05$) according to Student's T test, significant p-values are highlighted.

[y] Titratable acidity expressed as percent tartaric acid

Table 2. Color attributes for wines at bottling made from Arkansas-grown AM-77 and Noble muscadine grapes with different skin contact times (0 or 3 d) (2020 and 2021).

Effects[z]	L*	a*	b*	Hue angle	Chroma	Red color[y]	Brown color[x]	Color density[w]
2020								
Genotype (G)								
AM-77	12.63 a	37.78 a	20.96 a	57.56 a	43.27 a	1.96 b	0.05 a	2.01 b
Noble	10.51 b	36.42 a	17.29 b	49.39 b	40.49 a	2.84 a	0.06 a	2.90 a
P-value	*0.0459*	*0.0978*	*0.0415*	*0.0146*	*0.0728*	*0.0074*	0.1160	*0.0081*
Skin contact (SC)								
0 days	14.22 a	39.43 a	23.64 a	61.78 a	45.99 a	1.86 b	0.04 b	1.89 b
3 days	8.92 b	34.78 b	14.61 b	45.16 b	37.77 b	2.95 a	0.08 a	3.02 a
P value	*0.0020*	*0.0018*	*0.0019*	*0.0011*	*0.0020*	*0.0033*	*0.0013*	*0.0033*
G x SC *P-value*	*0.1883*	*0.0570*	*0.2013*	*0.1256*	*0.1345*	*0.6064*	*1.0000*	*0.6451*
2021								
Genotype								
AM-77	9.23 a	31.25 a	34.92 a	46.65 a	34.92 a	2.27 b	0.06 b	2.33 b
Noble	6.27 b	22.47 b	24.44 b	38.34 b	24.44	3.58 a	0.10 a	3.69 a
P value	0.0025	*0.0001*	0.0015	0.0045	*0.0002*	*0.0012*	*0.0146*	*0.0013*
Skin contact								
0 days	12.01 a	36.23 a	41.76 a	56.08 a	41.76 a	1.87 b	0.3 b	2.33 b
3 days	3.50 b	17.00 b	17.59 b	29.01 b	17.59 b	3.98 a	0.13 a	3.69 a
P value	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*0.0002*	*0.0007*	*0.0002*
G x SC *P-value*	*0.2075*	*0.0008*	*0.2019*	*0.0572*	*0.0044*	*0.0108*	*0.0220*	*0.0113*

[z] Means with different letters for each attribute within effects of each year are significantly different ($p<0.05$) according to Student's T test, significant p-values are highlighted.
[y] Red color was calculated as absorbance of wine at 520 nm.
[x] Brown color was calculated as absorbance of wine at 420 nm.
[w] Color density was calculated as absorbance 520 nm + absorbance 420 nm.

Table 3. The pH, titratable acidity, and color attributes for wines made from Arkansas-grown Noble and AM-77 muscadine grapes with different skin contact times (0 or 3 d) during fermentation and evaluated at 0, 3, 6, 9, and 12 months storage at 15°C (2020).

Effects [a]	pH	Titratable acidity (%)[y]	L*	Hue angle	Chroma	Red color[y]	Brown color[x]	Color density[w]
Genotype (G)								
AM-77	2.88 b	1.09 a	14.91 a	64.52 b	44.66 a	1.85 b	0.05 b	1.80 b
Noble	2.97 a	0.82 b	12.87 b	57.12 a	42.78 b	2.74 a	0.07 a	2.82 a
P-value	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*0.0196*	*<0.0001*	*<0.0001*	*<0.0001*
Skin contact (SC)								
0 day	2.96 a	0.89 b	16.76 a	68.66 a	47.71 a	1.74 b	0.04 b	1.77 b
3 day	2.90 b	1.02 a	11.01 b	52.99 b	39.73 b	2.86 a	0.08 a	2.95 a
P-value	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*
Storage (S)								
Month 0	2.89 c	1.03 a	11.57 c	53.47 c	41.88 bc	2.40 b	0.06 b	2.46 b
Month 3	2.89 c	0.99 ab	12.61 bc	56.67 b	43.21bc	2.80 a	0.10 a	2.90 a
Month 6	2.94 b	0.93 c	13.64 b	59.00 b	44.26 b	1.75 c	0.04 b	1.78 c
Month 9	2.97 a	0.88 d	13.31 b	57.23 b	41.32 c	2.93 a	0.10 a	3.02 a
Month 12	2.97 ab	0.96 bc	18.33 a	77.75 a	47.92 a	1.61 c	0.03 b	1.64 c
P-value	*<0.0001**	*<0.0001*	*<0.0001*	*<0.0001*	*0.0001*	*<0.0001*	*<0.0001*	*<0.0001*
G x SC (P-value)	0.1799	*0.0420*	0.1184	*0.0288**	*0.0337*	*0.0002*	*0.0078*	*0.0003*
G x S (P-value)	*0.0378*	*0.0006*	0.6637	0.7208	0.7778	*0.0013*	*0.0117*	*0.0015*
SC x S (P-value)	0.2371	*<0.0001*	0.4371	0.0520	0.2252	*0.0002*	*<0.0001*	*<0.0001*
G x SC x S (P-value)	0.3921	*0.0677*	0.2921	0.2381	0.5785	0.1087	0.1709	0.1128

[z] Means with different letters for each attribute within effects are significantly different ($p<0.05$) according to Student's T test, significant p-values are highlighted.

[y] Red color was calculated as absorbance of wine at 520 nm.

[x] Brown color was calculated as absorbance of wine at 420 nm.

[w] Color density was calculated as absorbance 520 nm + absorbance 420 nm.

Table 4. Consumer sensory (n=54) of wines made from Arkansas-grown AM-77 and Noble muscadine grapes with different skin contact times (0 or 3 d) during fermentation and evaluated at 6 months storage at 15 °C using a 9-point hedonic scale (1=dislike extremely; 5 = neither like nor dislike; 9 = like extremely).

Genotype	Skin contact time (d)	Color	Aroma	Flavor	Mouthfeel	Overall liking
AM-77	0	5.77 b[z]	6.11 a	6.50 a	6.28 a	6.33 a
AM-77	3	6.50 ab	5.81 a	4.26 b	4.59 c	4.28 b
Noble	0	6.20 b	6.02 a	5.69 a	5.91 ab	5.67 a
Noble	3	7.11 a	6.11 a	4.70 b	5.46 b	4.72 b
P-value		*0.0002*	*0.6833*	*<0.0001*	*<0.0001*	*<0.0001*

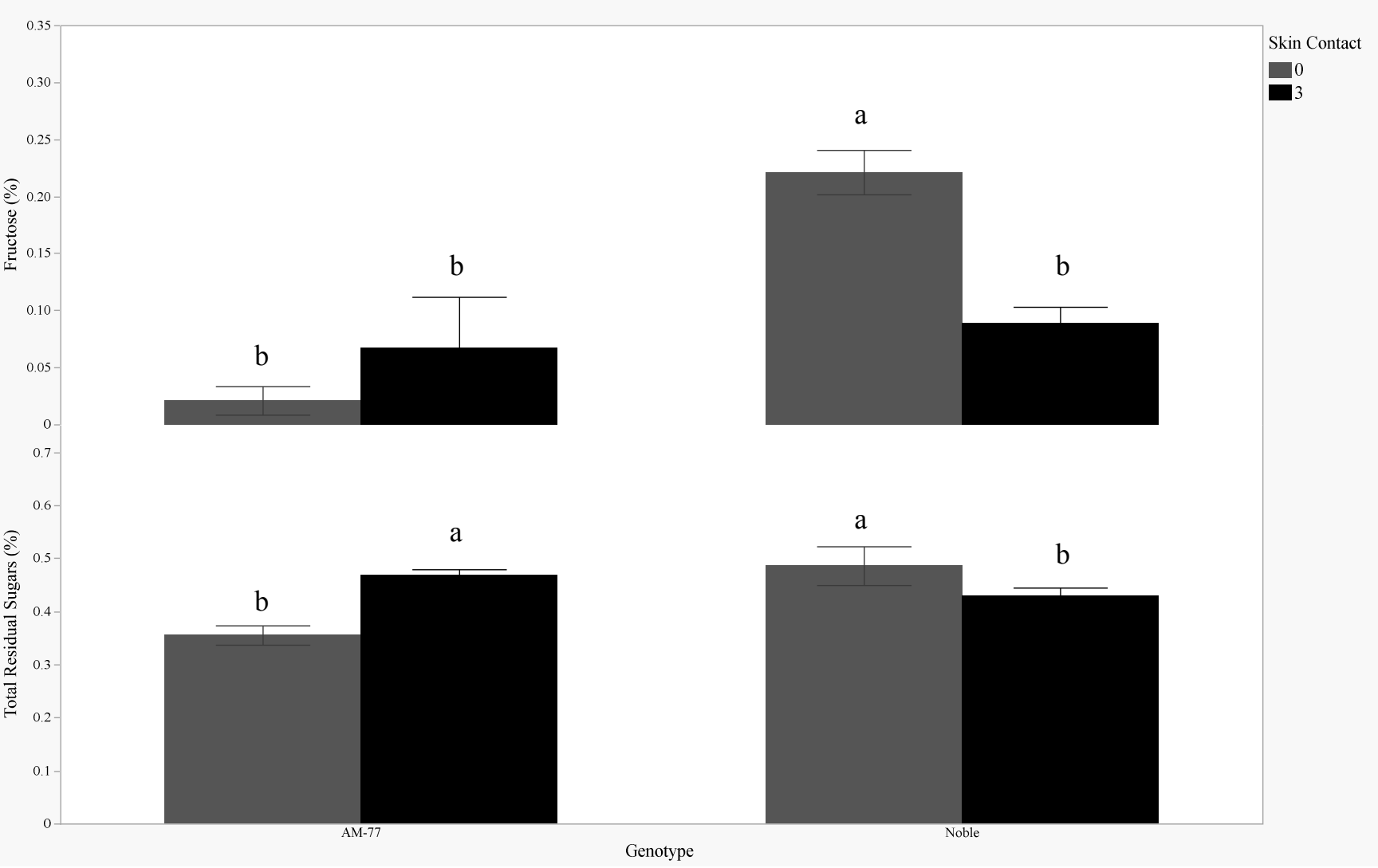
[z] Means with the different letters for each attribute are significantly different ($P<0.05$) using Tukey's honestly significant difference test., significant p-values are highlighted.

Table 5. Percent (%) of consumer (n=54) sensory attributes for wines made from Arkansas-grown AM-77 and Noble muscadine grapes with different skin contact times (0 or 3 d) during fermentation evaluated using a on a collapsed 5-point Just About Right (JAR)[z] scale at 6-months storage at 15 °C.

		Color			Aroma			Flavor			Mouthfeel		
Genotype	Skin contact time (d)	Not enough	JAR	Too much	Not enough	JAR	Too much	Not enough	JAR	Too much	Not enough	JAR	Too much
AM-77	0	43	48	9	36	58	6	10	69	21	8	75	17
AM-77	3	9	77	13	42	49	9	18	35	47	18	43	39
Noble	0	41	55	4	35	56	9	26	49	25	24	59	17
Noble	3	2	85	13	40	54	6	19	41	40	24	49	27

[z] The 5-point Just About Right (JAR) scale (1 = much to low; 2 = too low; 3 = JAR; 4 = too much; 5 = much too much) was collapsed to too low, JAR, and too much.

Fig. 1. Effect of genotype and skin contact time on fructose and total residual sugars of wines at bottling made from Arkansas-grown AM-77 and 'Noble' muscadine grapes fermented with 0-day and 3-day skin contact times (2021).



[z] Means with different letters for each attribute within effects of each year are significantly different ($p<0.05$) according to Student's T test, significant p-values are highlighted.

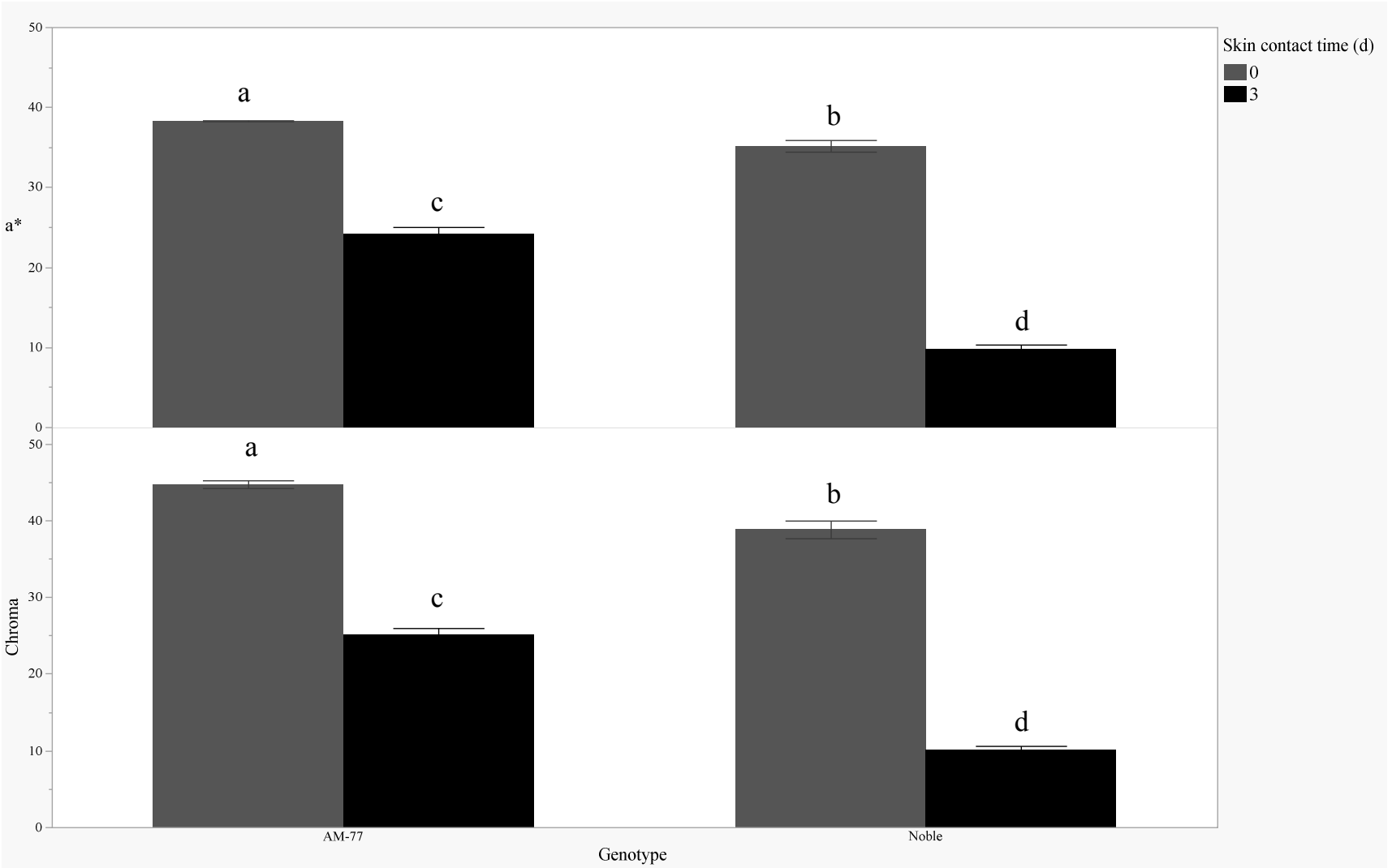


Fig. 2. Effect of genotype and skin contact time on a* and chroma of wines at bottling made from Arkansas-grown AM-77 and 'Noble' muscadine grapes fermented with 0-day and 3-day skin contact times (2020).

[z] Means with different letters for each attribute within effects of each year are significantly different ($p<0.05$) according to Student's T test, significant p-values are highlighted.

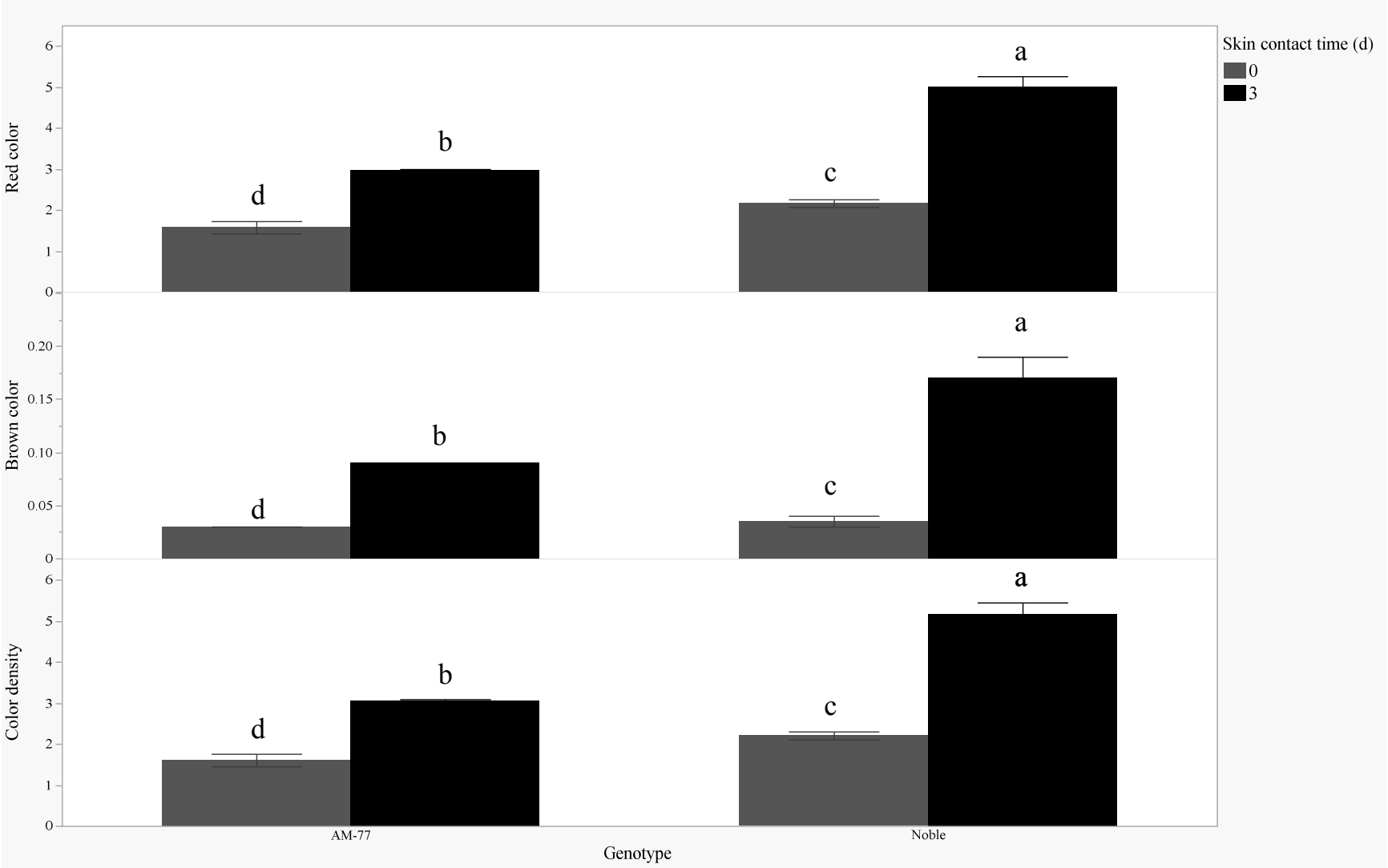


Fig. 3. Effect of genotype and skin contact time on red color, brown color, and color density of wines at bottling made from Arkansas-grown AM-77 and 'Noble' muscadine grapes fermented with 0-day and 3-day skin contact times (2020).

[z] Means with different letters for each attribute within effects of each year are significantly different ($p<0.05$) according to Student's T test, significant p-values are highlighted.

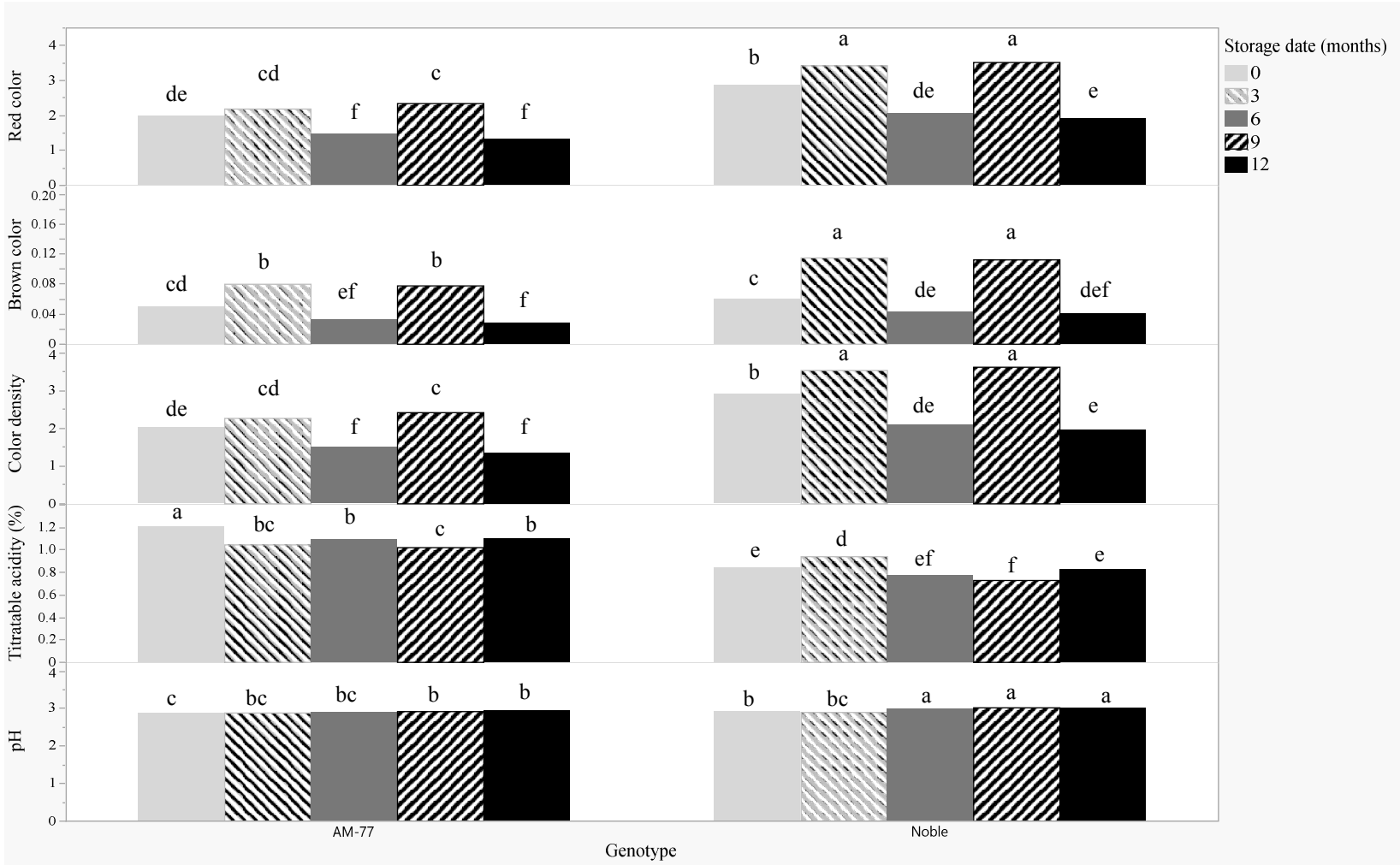


Fig. 4. Effect of genotype and storage on red color, brown color, color density, titratable acidity, and pH of wines made from Arkansas-grown AM-77 and 'Noble' muscadine grapes fermented with 0-day and 3-day skin contact times during 12-month storage at 15 °C (2020).

[z] Means with different letters for each attribute within effects of each year are significantly different ($p<0.05$) according to Student's T test, significant p-values are highlighted.

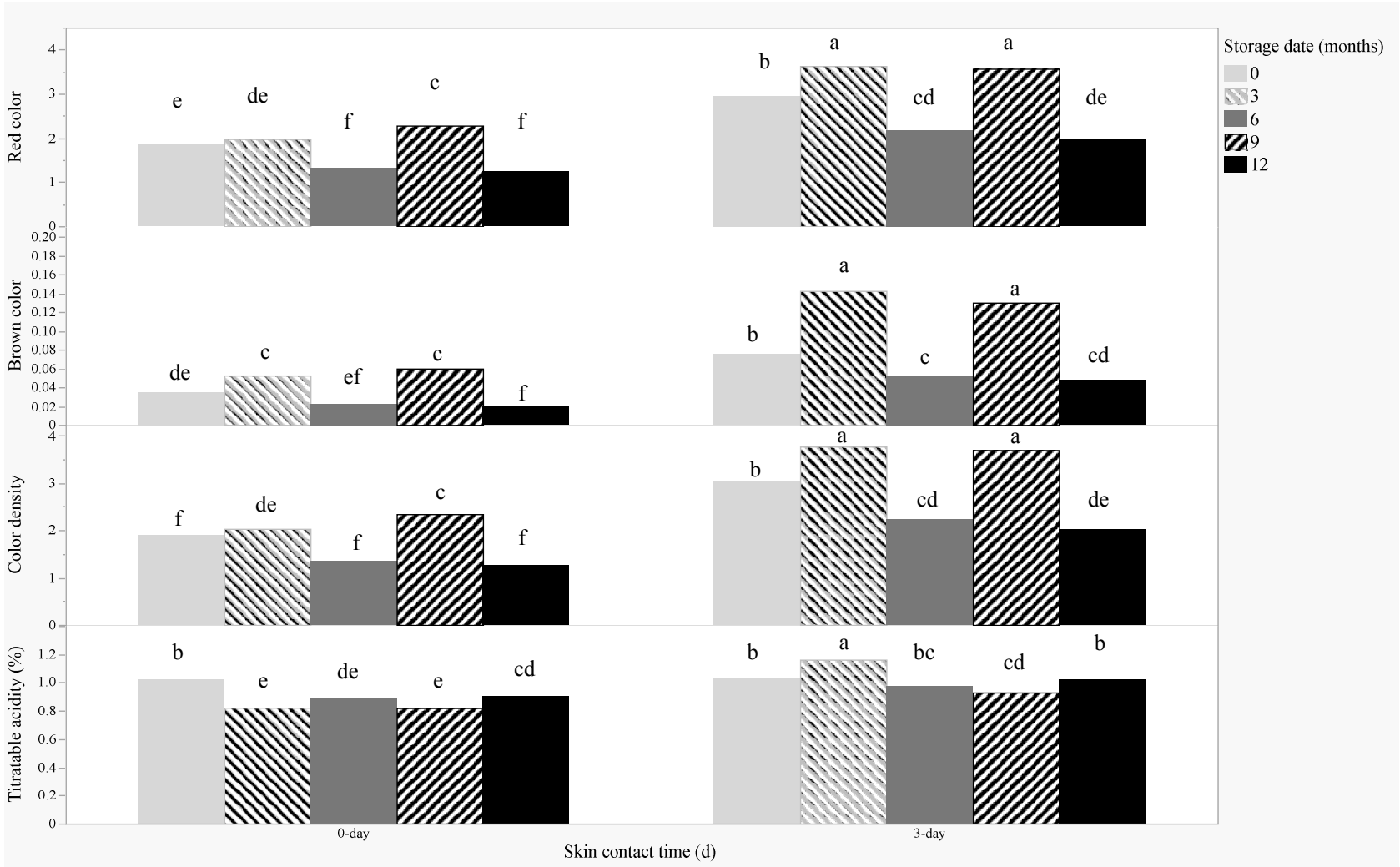


Fig. 5. Effect of skin contact time and storage on red color, brown color, color density, and titratable acidity of wines made from Arkansas-grown AM-77 and 'Noble' muscadine grapes fermented with 0-day and 3-day skin contact times during 12-month storage at 15 °C (2020).

[z] Means with different letters for each attribute within effects of each year are significantly different ($p<0.05$) according to Student's T test, significant p-values are highlighted.

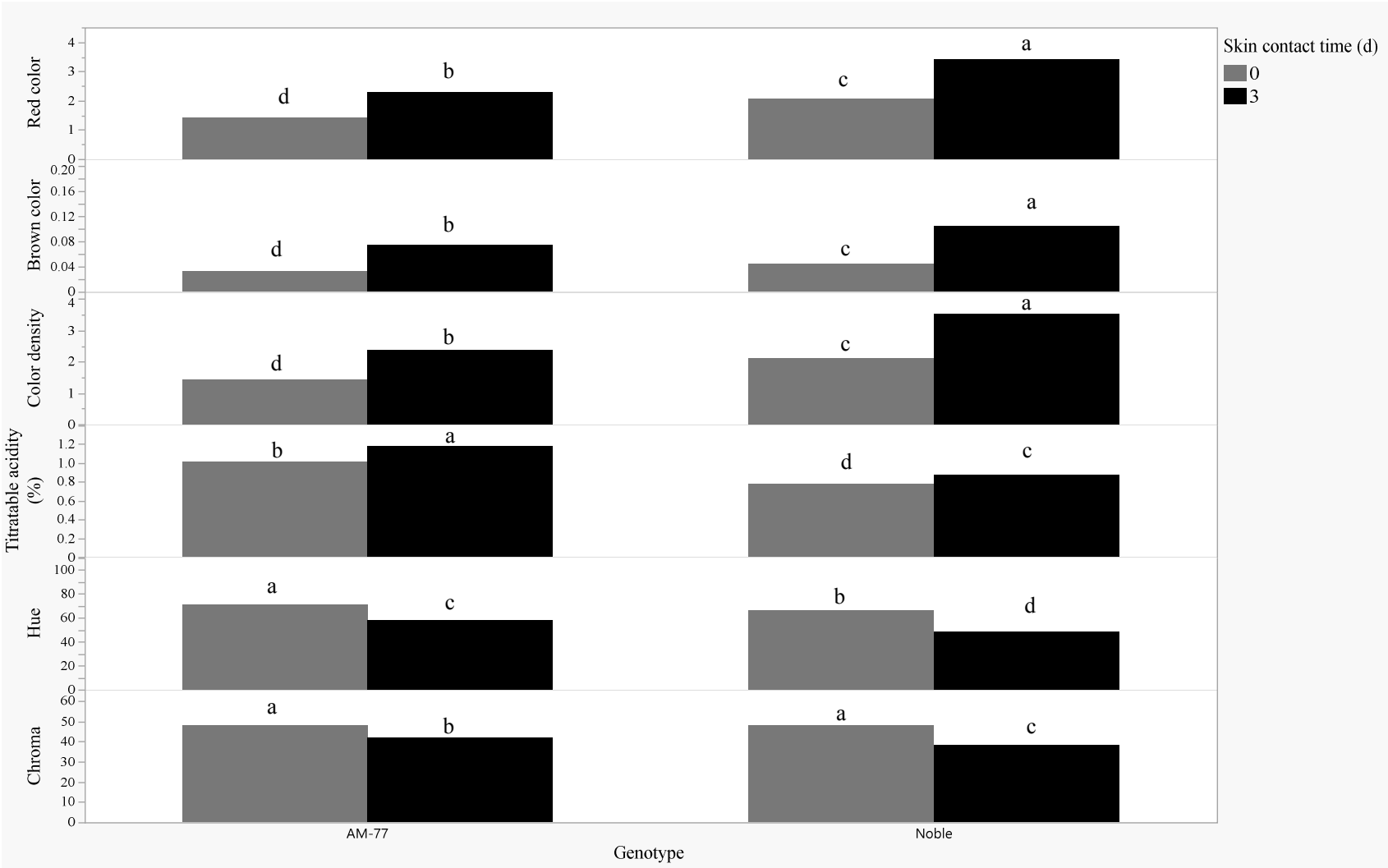


Fig. 6. Effect of genotype and skin contact time on red color, brown color, color density, titratable acidity, hue, and chroma of wines made from Arkansas-grown AM-77 and 'Noble' muscadine grapes fermented with 0-day and 3-day skin contact times during 12-month storage at 15 °C (2020).

[z] Means with different letters for each attribute within effects of each year are significantly different ($p<0.05$) according to Student's T test, significant p-values are highlighted.

OVERALL CONCLUSION

Identifying the unique attributes and postharvest practices of muscadine grapes is important to growth of the muscadine industry. For this research in 2020 and 2021, the postharvest quality attributes of fresh-market muscadine grapes from Arkansas and North Carolina were evaluated, and the impact of skin contact time during wine production of 'Noble' and AM-77 muscadine grapes was determined.

The postharvest quality attributes of fresh-market muscadine grapes from Arkansas and North Carolina were evaluated to provide data to improve the USDA standards and grades for muscadine grapes and determine the postharvest potential of both seeded and seedless muscadines. In the two-year study, 33 genotypes (cultivars and breeding selections) were evaluated. Overall, genotype had the most impact on the postharvest quality of fresh-market muscadine grapes grown in Arkansas and North Carolina in 2020 and 2021. Most genotypes had good storability with low weight loss (<9%) after 28 d even though berry firmness tended to decrease and weight loss and unmarketable berries increased. Of the genotypes evaluated in each year and location, only seven of 33 had unmarketable berries greater than 10%. Additionally, evaluation of the fruit at 28 d postharvest storage at 2 °C indicated that while no one genotype performed well in all categories, most genotypes had good storability.

The impact of skin contact time during wine production of 'Noble' and AM-77 muscadine grapes was determined. Wine from AM-77 and 'Noble' muscadines with 0-day and 3-day skin contact times during fermentation had composition and color values at bottling within typical ranges for dry red table wines, remaining mostly stable throughout storage for 12-months at 15 °C. At bottling, wine with the 0-day skin contact time had lower red color, brown color, and color density and higher L* than wine with 3-day skin contact time. At bottling, AM-77

wine had lower pH, red color and color density and higher titratable acidity and L* than 'Noble' wine. The red color and color density of muscadine wines decreased during storage, but brown color did not drastically increase or decrease which is an important factor in red muscadine wines. The consumer sensory panelist found differences among the four wines (AM-77 and 'Noble' wines with 0 and 3-day skin contact times) for the sensory attributes except aroma. AM-77 0-day skin contact time wine was had the highest liking score for flavor, mouthfeel, and overall liking, and over half of the consumers preferred this wine. The consumers generally liked the deeper color of the wines from the 3-day skin contact time more than 0-day, but the flavor, mouthfeel, and overall liking of the wines from the 0-day skin contact wines were liked more than wines from the 3-day skin contact time.

Overall, this research demonstrated that there is significant diversity and potential for consumers and producers in the overall eating experience of muscadines based on composition, firmness, and size that have potential for storage. the potential for various viticultural and enological techniques to enhance the attributes of Arkansas wines. These findings can contribute to the improvement of the standards and grades for fresh-market muscadines, as well as expanding the knowledge of new muscadine genotypes for wine production.

UNIVERSITY OF ARKANSAS

To:	Renee Terrell Threlfall FDSC B-3
From:	Douglas James Adams, Chair IRB Committee
Date:	09/11/2019
Action:	**Exemption Granted**
Action Date:	09/11/2019
Protocol #:	1908209641
Study Title:	Impact of production techniques on wines produced from muscadine grapes

The above-referenced protocol has been determined to be exempt.

If you wish to make any modifications in the approved protocol that may affect the level of risk to your participants, you must seek approval prior to implementing those changes. All modifications must provide sufficient detail to assess the impact of the change.

If you have any questions or need any assistance from the IRB, please contact the IRB

Coordinator at 109 MLKG Building, 5-2208, or irb@uark.edu. cc: Sarah Mayfield, Key Personnel