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Evaluation of Fresh-market Potential of Arkansas-grown Fruit: Blackberries, Peaches, Table Grapes, and Muscadine Grapes

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Evaluation of Fresh-market Potential of Arkansas-grown Fruit: Blackberries, Peaches, Table Grapes, and Muscadine Grapes

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Overall Abstract

Fresh-market produce is a major component of commercial market sales. However, shelf-life of fresh-market produce is limited, so evaluating postharvest potential (time from harvest to consumption) is critical. Fresh-market fruit can be impacted by many factors that deteriorate the quality of the fruit. Understanding the postharvest physiology of fruit can lead to better handling and storage conditions for extended shelf life and enhanced quality for the consumer. This research project was a collaborative effort within the University of Arkansas System Division of Agriculture between the Food Science and Horticulture Departments to evaluate the fresh-market potential of Arkansas-grown fruit. Physiochemical and marketability attributes of fresh-market blackberries, peaches/nectarines, table grapes, and muscadine grapes were evaluated at harvest and during postharvest storage. Additionally, the peaches/nectarines and muscadine grapes were evaluated by a descriptive sensory panel at harvest. Genotype played a critical role in the fresh-market fruit evaluated in this study. Storage day and storage temperature also had an impact on postharvest quality of the nine fresh-market blackberry genotypes evaluated, but harvest time had minimal impact. Blackberries stored at a lower temperature (2 $^{\circ}$C) retained marketable attributes longer than fruit stored at 10 $^{\circ}$C. Descriptive sensory analysis of harvest attributes of nine peach/nectarine genotypes were correlated to many physiochemical attributes. The peaches/nectarines had strong fresh-market potential after 21 d storage at 2 $^{\circ}$C. The table grape production method (four high tunnel grown cultivars and six traditionally-grown genotypes) did not impact physiochemical attributes, but had a greater impact on marketability attributes. Grapes grown in the high tunnel had more marketable berries and longer shelf life. Descriptive sensory analysis of six muscadine grape genotypes described appearance and basic taste attributes and correlated to many physiochemical attributes. The six muscadine grape genotypes

had good retention of composition and marketability attributes indicating potential for fresh-market after 21 d storage at 2 ˚C. The fresh-market attributes evaluated for these fruits will assist in fruit breeding efforts at the University of Arkansas, as well as provide insight into the commercial potential for growers for these advanced selections and cultivars.

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Dedication

This thesis is dedicated to my friends and family who have supported me through my studies. First, my husband William "Taylor" Felts, for all of his love, generosity, and support during this journey. My best friend, Genesis Storms, for being my biggest cheerleader and pushing me through the difficult days. My undergraduate advisor, Dr. Daniel T. Glatzhofer, for showing me there is so much more to chemistry than meets the eye. And finally, my mother Amy Retherford, for her motivation, encouragement, and instilling me with a passion for education. She showed me that learning is not a chore, but rather a gift to cherish every day and for that I am forever grateful.

Table of Contents

Overall Introduction

Consumer demand for locally-grown produce has sharply increased across the United States with increasing economic growth and self-sustaining food systems. Local food is defined as farmers selling directly to consumers (Martinez, 2010). The United States Department of Agriculture (2015), reported the increased importance of local sales including direct-to-consumer (farmer's markets) and intermediated marketing channels (sales to institutions or regional distributers). In this report, 85% of farms participating in local food sales were small-scale farms (<$75,000), and it was found that direct-to-consumer farming led to an increased likelihood to remain in business. In addition, Martinez (2010) found that local foods in the United States have the potential to reduce food safety risks, help preserve farmland, develop social capital, and preserve cultivar genetic diversity.

In Arkansas, agriculture is the largest industry contributing $16 billion annually to the state's economy (Farm Bureau of Arkansas, 2016). Within the fresh-market sector, produce such as tomatoes, melons, peaches, grapes, blueberries, and many more enhance the commodity diversity. In 2015, these commodities earned $17 million dollars for the state (Arkansas State Agriculture Overview, 2015), showing the economic importance of fresh-market produce. There were 107 local farmer's markets in Arkansas which help stimulate and contribute to the local economy and of these markets, 53 offered fresh fruits and vegetables to their customers (USDA, 2016).

The University of Arkansas System Division of Agriculture supports research and outreach in locally-produced fruits. In 1964, the University of Arkansas began its Fruit Breeding Program directed by Dr. James N. Moore. Over the past five decades, the program has led to the development of over 50 different fruit cultivars including: blackberries, table grapes, wine

grapes, peaches, strawberries, and blueberries (Barchenger, 2014; Clark, 1998; Clark, 2002). The program focuses on developing fruit cultivars for local fresh-markets, but use of many of the cultivars has extended far beyond Arkansas to other states and countries. One of the most successful achievements in the program has been the blackberry breeding efforts, with Arkansas considered a world leader in the development of new blackberry cultivars for shipping, fresh market, and home gardeners. The fruit breeding program primarily utilized classical breeding techniques, but has implemented more molecular breeding (Clark, 2011).

Postharvest storage is critical for fresh-market fruit. Postharvest can be defined as the period of time from harvest to consumption (Florkowski et al., 2014). Postharvest attributes of fresh-market produce can be related to texture, flavor, nutraceutical composition, and food safety of the product. From the moment a fruit or vegetable is picked, the product has a long journey to the consumer with many critical points where the produce can become unacceptable due to over-ripening, decay, and handling damage (Florkowski et al., 2014). Understanding postharvest physiology can lead to better handling and storage conditions for extended shelf life and better quality produce for the consumer. Cultivars and selections of blackberries, peaches, table grapes, and muscadines from the University of Arkansas Fruit Breeding Program need to be evaluated after harvest.

Objectives

1) Effects of harvest time and storage temperature on postharvest quality of Arkansas blackberry genotypes
2) Physiochemical, marketability, and sensory analysis of Arkansas-grown peaches and nectarines for fresh-market

3) Physiochemical and marketability analysis of traditional and high-tunnel grown Arkansas table grapes for fresh-market
4) Physiochemical, marketability, and sensory analysis of Arkansas muscadine grapes for fresh-market

Literature Review

For all horticulture fruit crops, postharvest handling is important, as roughly one-third of fresh produce is lost at various points in the distribution system (Kader, 2002). In addition, improving the understanding of the physiochemical and marketability of the fruit aids in identification of breeding advancements and postharvest handling procedures. In the United States, fruit is graded on the basis of appearance, texture, composition, and marketability (USDA, 2018). Enhancement in these categories is an important aspect for the fruit breeder sincethis improves the overall quality of the fruit and enhances the profit obtained by the grower.

Blackberries

Over the last 20 years, blackberry cultivation has rapidly increased worldwide. North America is the largest producer by weight of blackberries, whereas Europe has more acreage of production (~7,700 ha) (Finn and Clark, 2011; Kaume et al., 2011; Strik et al., 2012). In North America, there is roughly ~7,200 ha of commercially cultivated blackberries, with Central and South America producing substantially less, ~1,600 ha and ~1,600 ha, respectively. This increase in popularity has caused a surge of new blackberry breeding plantings, and research. As indicated by Finn and Clark (2011), worldwide raspberry production paved the way for blackberry production in the 21st century due to similar characteristics between the fruit. Blackberries have lower production costs, increased vigor of plants, and greater disease tolerance than raspberries. Blackberries are now ranked fourth as the most important berry, behind

strawberries, blueberries, and red raspberries. Blackberry popularity with consumers continues to increase due to more commercial availability, sweeter cultivars, and knowledge of health benefits (Barnett, 2007; Finn and Clark, 2011).

Physical characteristics

Blackberries come in many sizes and shapes due to variations in the genetic makeup of cultivars. In a study by Threlfall et al. (2016), significant variation with respect to weight, length, width, and number of drupelets per berry was found between multiple genotypes. In contrast to wild blackberries, cultivated blackberries had greater size but lower soluble solids, titratable acidity, and pH (Yilmaz et al., 2009). With the rise of blackberry breeding efforts, advancements in cultivated blackberries have occurred such as the development of thornless plants, erect cane architecture, increased fruit firmness, and development of primocane-fruiting cultivars (Clark and Moore, 1999; Clark, 2005; Moore, 1984; Moore and Clark, 1993). Of the three cane types (erect, semi-erect, and trailing), erect blackberries are grown for fresh-market systems, and they are easier to harvest by hand (Strick and Finn, 2011). In 2005, the first commercial primocane-fruiting cultivars, 'Prime-Jim®' and 'Prime-Jan®', were released from the University of Arkansas's Fruit Breeding Program (Clark et al., 2005). Primocane-fruiting blackberries produce fruit on both current-season canes (primocanes) and second-season canes (floricanes). Primocane-fruiting blackberries can produce larger and firmer berries from the primocanes versus floricanes (Segantini et al., 2018). However, when both crops are harvested in a season, yield and berry size were substantially less for the primocanes (Clark and Perkins-Veazie, 2011)

Postharvest handling

Another important aspect of blackberries is the effect that storage has on the marketability of the fruit. Caneberries, such as blackberries, have extremely perishable

characteristics that can be affected by poor harvest and handling procedures; as well as improper storage temperatures, leading to fruit deterioration and decreased marketability (Kader, 2002). Mold growth is a primary concern on fresh-market berries during postharvest storage of which *Botrytis cinerea* Pers. and *B. caroliniana,* also known as gray mold, are the predominant species (Li et al., 2012). *B. cinerea* kills host cells before colonizing dead tissue on the fruit. Although optimum growth of *B. cinerea* is at 20 °C, its ability to grow at colder temperatures (as low as 0 °C) leads to slow decay during storage of fresh-market fruit (Bautista-Baños, 2014). Modified atmosphere packaging can improve storage potential of fruit. In addition, type of storage container, packing procedures, storage temperature, and humidity affect marketability of the fruit (Joo et al., 2011). Kim et al. (2015) found that fruit stored at 1 °C retained a consistent marketability, however when removed from cold storage and placed in room temperature, fruit deterioration rapidly increased. Other research has shown storage temperature was directly related to degree of deterioration (de Arruda Palharini et al., 2015; Perkins-Veazie et al., 1999; Perkins-Veazie and Clark, 2005; Segantini et al., 2018).

Firmness and composition

Blackberry composition varies by genotype. A study by Carvalho and Batancur (2015) on two Andean blackberry cultivars, 'Pantanillo' and 'Guapante', found that the firmness of the fruit was 0.1-0.3 N when the fruit was at a maturity stage of 5 and 6, e.g. ready for consumption. In that study, the texture was analyzed by compression using a texture analyzer. A study on 52 cultivated and wild blackberry cultivars in the United States, indicated that the soluble solids, titratable acidity, and pH ranged between 6.88%-16.83%, 0.52%-2.24%, and 2.65-3.61 respectively (Fan-Chiang and Wrolstand, 2010). Threlfall et al. (2016) found, using descriptive and consumer sensory analysis, that a desired blackberry should have a berry weight of 8-10 g,

soluble solids of 9%-11%, titratable acidity of 0.9%-1.0%, and a soluble solids/titratable acidity ratio of 10-13. Organic acids and sugars in blackberries grown in Turkey and Spain had equal amounts of glucose and fructose as well as small amounts of sucrose in the fruit. Additionally, malic acid was the predominant acid with ascorbic acid in some cultivars and no citric acid present (Kafkas et al., 2006; Romero Rodriguez et al., 1992; Yin, 2017). However, studies in Solvenia and the United States have shown citric acid in equal or greater amounts than malic acid (Fan-Chiang and Wrolstad, 2010; Mikulic et al., 2012; Segantini et al., 2018)

Nutraceuticals

Nutraceuticals are a food or part of a food that can provide extra health benefits in addition to the basic nutritional value of the food. They can help prevent chronic diseases and improve different facets of health by working in with other vitamins and nutrients naturally present in fruits and vegetables (Kaur, 2016). Blackberries have numerous nutraceutical compounds. Anthocyanins, phenols such as ellagic acid, catechin, quercetin, and ferulic acid, as well as polymeric phenols such as ellagitannins and proanthocyanidins are present (Lee et al., 2012). Genetics, growing conditions, and maturation influence blackberry phenolic composition (Kaume et al., 2011). In a study by Ali et al. (2011), antioxidant levels were influenced by both pre- and post- harvest factors and total anthocyanin and phenolic content decreased during postharvest storage at 2 °C while ellagic acid content remained the same. Cavender et al. (2014) found that certain cultural practices, such as weed management, had a significant effect of the antioxidant properties of the fruit.

Sensory

Sensory analysis is a useful tool for identifying various qualities of a fruit that may otherwise be difficult to quantify. In a study by Perkins-Veazie and Collins (2002), consumer

sensory analysis was used as a tool for identification of off-flavors in fresh-market blackberries stored in a controlled atmosphere. In the study, they found that while monomeric anthocyanin content was decreasing, no off-flavors were detected with 3 or 7 d of storage in the controlled atmosphere. In a study by Segantini et al. (2017), a combination of physiochemical and descriptive sensory analyses showed promise in assisting blackberry breeders in developing superior fruit with extended postharvest storage.

Peaches/Nectarines

Peaches have been grown worldwide for centuries. Cultivation of the fruit began around 6050 BC in an eastern province of China and recently fossilized peach pits have been found dating back 2.5 million years to the late Pliocene, in southwest China (Feltman, 2015; Zheng et al., 2014). In 1997, peaches were the second most-grown fruit crop in the world, behind apples, at roughly 9.1 million metric tons (Fideghelli et al., 1997). Peach and nectarine production has doubled with roughly 22 million metric tons produced, with 45% of the production occurring in China (Food and Agricultural Organization, 2016). In 2016, the United States was ranked 4th in world peach production behind China, Spain, and Italy (Food and Agricultural Organization, 2016). The United States Department of Agriculture (2017) indicated 721,783 metric tons of peaches and 152,361 metric tons of nectarines were produced in 2016. Of that production, 305,757 metric tons of peaches and 147,145 metric tons of nectarines were produced for fresh-market consumption.

Physical characteristics

Peaches and nectarines have a wide variety of characteristics across genotypes. According to Brovelli et al. (1999), the fruit is usually classified as round, flat, or beaked; pubescent or smooth-skinned; freestone or clingstone; white, yellow, or red-flesh; sweet, sour, or

astringent; and melting or non-melting flesh. Classifications such as melting and non-melting flesh, or pubescent and smooth-skinned are defined by the genetic makeup of the fruit. Peaches and nectarines have a similar genetic framework, however, nectarines are smooth-skinned, where peaches have a pubescent, or fuzzy exterior. This is due to a single recessive allele in the fruit, but peaches and nectarines are categorized similarly in regards to many common traits (Layne and Bassi, 2008). The main difference in melting and non-melting peaches is increased enzymatic capacity for pectin degradation in melting-flesh types. The tertiary ripening phase is generally called the 'melting' stage (Ghiani et al., 2011; Maw et al., 2003). Melting-flesh peaches are used in fresh-markets. Flesh color and stone type (freestone vs. clingstone) are also a commonly used to distinguish between genotypes. The production of white-flesh fruit has increased since 1997, while canning clingstone fruit decreased (Fideghelli et al., 1997).

Postharvest handling

When looking at postharvest attributes in peaches, texture, color, and flavor are some of the most important attributes to maintain. Fully-ripe peaches deteriorate at ambient temperature. Chilling injury is common in peaches and nectarines and is influenced by storage temperature and storage period (Lurie and Crisosto, 2005). Cold storage causes damage to fruit quality (chilling injury) by initiating browning (both internal and external), flesh breakdown, loss of juiciness (mealiness or woolliness), discoloration, and loss of flavor (Lauxmann et al., 2014; Delgado et al., 2013). Enzymatic browning of the peach flesh is a common physiological disorder related to the activation of polyphenoloxidase (Cheng and Crisosto, 1995). Polyphenoloxidase activity is related to the available substrates, the pH, and the temperature. With respect to peaches, catechol, catechin, and pyrogallol are the predominant substrates for polyphenoloxidase, and a pH of 5 is optimal for maximum activity. Lower temperatures decrease

the kinetic energies of the reactant molecules slowing polyphenoloxidase activity (Yoruk and Marshall, 2003). Loss of juiciness in peaches has been attributed to reduced pectinesterase and polyglacturonase activities in ripe fruit. This chilling injury only occurs in the fruit as it is ripening in storage. The adequate levels of pectinesterase and polyglacturonase for ripening to occur are not available, due to the low temperature, leading to an undesirable texture of the fruit (Buescher and Furmanski, 1978; González-Agüero et al., 2008).

Firmness and composition

According to Crisosto and Mitchell (2002a), the texture of peaches directly relates to when the fruit is ready to buy and eat. Fruits that reach 27-36 N are considered ready-to-buy and fruits that reach approximately 9-14 N are considered ready to eat. In a study by Infante et al. (2008), the cultivars 'Ryan Sun', 'Autumn Red', 'September Sun', and 'Tardibelle' had flesh firmness ranging from 59-64 N at harvest. In addition to firmness, the pH, soluble solids, and titratable acidity of the fruit are important factors to consider when breeding and growing peaches and nectarines, as they affect how we perceive the fruit. Fruit composition is dependent of a variety of different traits and external factors. In a study by Cantín et al. (2009), differences in sugar concentrations were found between peaches and nectarines, white and yellow-flesh fruit, freestone, and clingstone, as well as by growing year. Additionally, growing location including weather, soil type, and crop load had an effect on fruit composition (Day, 1997). Research at the University of Florida showed that the cultivar 'Tropic Beauty', a melting-flesh cultivar, had a pH of 3.86, soluble solids of 10.5%, and titratable acidity of 2.06%. Whereas the non-melting flesh genotypes 'Oro A' and FL 86-28C, had soluble solids of 12.0% and 11.9%, respectively (Brovelli et al., 1999).

Nutraceuticals

The peach is a source of many nutraceuticals. Prior research has shown the importance of understanding the role of phenolic compounds in fruit. Senter et al. (1989) evaluated the phenolic compounds in 'Cresthaven' peaches grown in Georgia. The peaches were evaluated at various postharvest ripening times, and the prominent phenolic compounds did not vary significantly during storage. Peach cultivars rich in phenolic compounds indicated a positive correlation with high antioxidant capacity, color stability, and antimicrobial activity (Cevallos-Casals et al, 2006). From that, Cevallos-Casals et al. (2006) proposed that fruit high in phenolic compounds have potential breeding for enhanced levels. The nutraceuticals in the exocarp, mesocarp, and endocarp varied. An investigation on 'Golden', 'Shireen', and 'Shahpasand' peach cultivars found that the skin had higher levels of minerals, antioxidant capacity, and phenolics than the flesh (Manzoor et al., 2012). This was demonstrated again by Gil et al. (2002), where the total phenolics, vitamin C, and carotenoids were greater in the skin than flesh. The total phenolic content is important in fruit breeding because the content is linked to higher antioxidant potential. Findings from a team at Texas A&M University found that the peach genotype, BY94P7552, had 46% of the antioxidant capacity of a blueberry, a fruit known to have an exceptionally high antioxidant activity (Cevallos-Casals et al., 2006). In a study by Thomàs-Barberàn et al. (2001), no trend was found between peach flesh type and phenolic content. Rather, the phenolic content was cultivar dependent and as with other studies, the flesh contained less phenolics than the skin.

Sensory

Sensory analysis is a useful tool for the evaluation of fruit. A study in Brazil compared eleven peach cultivars using a trained descriptive panel (n=30) to evaluate appearance, aroma,

flesh color, flesh firmness, flavor, and juiciness to create a sensory profile (Cuquel et al., 2012). Comparison of the maturity of peaches at harvest showed that maturity did not affect sensory quality despite recognizable differences in aroma (Infante et al., 2012). The effects of cold storage on the 'Douradão' peach cultivar was analyzed by a panel of fourteen, and after 28 d storage at 1 °C, mealiness was identified by the panelists (Santana et al., 2011).

Table Grapes

Grapes have had a long history in human culture. Grapes were widely cultivated in the Middle East and played a role in religion (Fuller, 1996). The first wine from grapes discovered has been dated to 8500-4000 BC during the Neolithic period (Cocke, 2004). It is thought that the first domestication of wild grape cultivars began near modern-day Turkey. Over the years, grapes have had many uses including wine, juice, raisins, and table grapes. One of the most widespread table grape cultivars is 'Thomson Seedless' or 'Sultana' which was thought to have originated in Asia as a raisin grape and was introduced to the United States in 1872 (Bioletti, 1919). Table grape production in the United States in 2016 was around 7.3 million metric tons. California is the major producer with roughly 907,000 metric tons of table grape production (USDA, 2017). Overall, the United States is the sixth largest producer of table grapes after China, India, Turkey, the European Union (EU-27), and Brazil as of 2017 (USDA, 2017).

Physical characteristics

Table grapes have a variety of unique physical characteristics. Grape clusters have berries attached to a rachis and can be classified as small to large ranging from 113-680 g (USDA, 1999). Fruit breeding efforts have led to significant genetic variation of grapes including: color, shape, flavor, texture, and aroma. Commercial table grapes such as 'Cotton Candy', with a unique aroma and flavor, and 'Witch's Fingers' grapes, with a unique shape, are prime examples

of how fruit breeding has changed the public perception of table grapes. Table grapes, depending on the cultivar, are generally seedless in United States markets with about 15%-18% soluble solids. Certain characteristics such as skin friability, thickness, and flesh firmness can be used to define table grape cultivars (Cliff et. al., 1996). Aroma is another key attribute in table grape cultivars and is directly related to how the consumer perceives the product (Lung et al., 2016).

Postharvest handling

In table grapes, growth of mold and texture loss are the primary concerns of extended postharvest storage (Gandara-Ledezma et al., 2015). Table grapes are a non-climacteric fruit and do not ripen further after harvest, meaning deterioration begins immediately after the fruit is harvested (Piazzolla et al., 2016). One of the predominant concerns in storage is the decay of the berries due to *Botrytis cinerea* or gray mold. Gray mold can be controlled with ethanol, sulfur dioxide, hot water, ultraviolet irradiation, and edible coatings. Commonly, sulfur dioxide pads are used inside the clamshell with the grapes to inhibit mold growth (Smilanick et al., 1990; Palou et al., 2002). Other treatments such as dipping the grape clusters in ethanol were as effective without impairing the appearance of the bunch, berry firmness, or organoleptic ratings (Lichter et al., 2002; Karabulut et al., 2004). The identification of gray mold inhibitors that stimulate the production of bioactive compounds has grown in interest in the last 20 years with treatments such as ultraviolet irradiation and chitosan used for this purpose. Ultraviolet irradiation increased the resveratrol content of ‘Napoleon’ table grapes and decreased the presence of gray mold (Cantos et al., 2000; Cantos et al., 2001; Nigro et al., 1998). Studies indicated chitosan application on grapes decreased the incidence of gray mold, but also increased the presence of phenylalanine ammonia-lyase, an enzyme which stimulates the production of polyphenol compounds (Romanazzi et al., 2002).

Firmness and composition

In table grapes, these same physiochemical properties are important in understanding the postharvest physiology of the fruit. According to Crisosto and Mitchell (2002b), the maturity of the berries can be indicated by the sugar to titratable acidity ratio. For example, 'Thomson Seedless' is considered ripe when it has an 18:1 sugar to acid ratio. Wu et al. (2016) used soluble solids, total acidity, and pH to estimate the maturity of 20 table grape cultivars. In these cultivars, titratable acidity ranged from 2.5%-4.0%, pH ranged from 3.56-4.35, and soluble solids ranged from 15.0%-21.5%. Research done on 'Semillon' reported a pH of 3.97, soluble solids of 24%, and titratable acidity of 2.72% (Lohitnavy et al., 2010). In a consumer acceptability test, the soluble solids/titratable acidity ratio of 'Crimson Seedless' table grapes was optimal from 35-40 (Jayasena and Cameron, 2008). Texture analysis of table grapes has been conducted since the 1980s with pulp and skin properties analyzed. Commonly, three methods are used in the evaluation of the table grape, compression, penetration, and traction (Rolle et al. 2012). Penetration (puncture) tests are commonly used to study the pulp and skin mechanical characteristics. Lee and Bourne (1980) found that penetration force of the skin was highly correlated with soluble solids during maturation on northeastern United States table grape cultivars. Using a penetration test, Sato and Yamada (2003) found that table grape cultivars had larger maximum force values than wine grapes, and *V. vinifera* L. cultivars had smaller maximum forces than *V. labruscana* L. cultivars where the average force was 0.57 N for *V. vinifera* cultivars and 0.76 N for *V. labruscana* cultivars.

Nutraceuticals

Grapes and grape products have beneficial health effects due to the unique polyphenolic compounds. Current trends in leading a healthy lifestyle could help the table grape industry

capture an increased component of the nutraceutical market (Crupi et al., 2015). Crupi et al. (2015) found that table grapes have high levels of flavonoids, with darker grape cultivars showing higher amounts due to higher anthocyanin levels. A study by Mildner-Szkudlarz et al. (2013) incorporated white grape pomace into wheat flour biscuit and increased the phenolic compounds and enhanced antioxidant properties of the biscuit. In a study by Mattivi et al. (2006), 91 grape varieties (*V. vinifera*) were analyzed and the predominant flavonol was quercetin in both red and white grapes, 44% and 81%, respectively. In a study by Cantos et al. (2002), total phenolic contents were found in both red and green table grape cultivars regardless of the lack of anthocyanins in green table grapes. This phenomenon was offset by a higher amount of flavon-3-ols in the green cultivars compared to red. Additionally, this study indicated the use of total phenolic quantification using the sum of all nutraceutical constituents over the Folin-Ciocalteu method since overestimation is common due to interference of sugars, ascorbic acid, and aromatic amines.

Sensory

A trained panel at the University of Foggia evaluated seven table grape cultivars using quantitative descriptive sensory analysis. Overall, changes in composition (titratable acidity, soluble solids, and pH) were distinguishable across the different cultivars (Baiano et al., 2012). Another study by Cliff et al. (1996), used descriptive profiling to describe the visual and flavor/texture characteristics of new table grape cultivars. Their work indicated that attributes such as color, shape, skin friability, skin thickness, seediness, flesh firmness, and many more were evaluated and distinguishable among the 12 cultivars profiled. Of the attributes evaluated, seediness and the skin and flesh attributes were beneficial for the evaluation of grape genotypes.

Muscadine Grapes

Native to the southern United States, the muscadine grape (*Vitis rotundifolia* Michx.) was first discovered in 1584 by Sir Walter Raleigh, an English explorer, who found the fruit in abundance off the coast of North Carolina (Stanley, 1997). While native cultivation and consumption most likely occured far earlier than 1584, this was the first documented account of the unique grape. Since the resurgence of interest in muscadine production in the United States, the University of Georgia has released of over 30 cultivars from their fruit breeding program (Conner, 2006). In 2005, the University of Arkansas initiated a muscadine breeding program with a focus on improved texture, thinner skins, seedlessness, and dry stem scar (Barchenger, 2014). Currently, muscadines are used for both processing (baking, jellies, jams, juice, and wine) and fresh-market consumption (Flora, 1977). Muscadines have great fresh-market potential if limiting factors such as uneven ripening, seediness, low postharvest storability, and short harvest season are addressed (Barchenger et al., 2015; James et al., 1999; Morris 1980; Perkins-Veazie et al., 2012).

Physical characteristics

Muscadines have a unique flavor and are classified as either bronze, red, or black; slipskin or non-slipskin; as well as, by their shape and berry size (Barchenger et al., 2015; Brown et al., 2016). The berries grow in small clusters (5-10 berries) and unlike bunch grapes, fall from the vine (shatter) when ripe (Conner, 2009). This native grape is known for its strong musky flavor and thick skin, which leads to varying acceptability among consumers. Muscadines can also have 2-4 seeds present in the berry. First time consumers may have a lower acceptability than repeat consumers who like the unique attributes (Barchenger, 2014; Brown et al., 2016; Degner and Mathis, 1980). In order to achieve a greater consumer acceptability, muscadine grape

breeders have been working on seedless varieties. In a study by Ren et al. (2014), new seedless muscadine grapes had similar soluble solids and titratable acidities to 'Fry', a well-known cultivar, but the berries were very small 1.4-3.4 g. In 2015, the first seedless muscadine, 'RazzMatazz' was released by Scarlet Tanager LLC (Bloodworth, 2015). Unlike traditional muscadines, 'RazzMatazz' berries grow in clusters of ~50 berries and are relatively small (8 mm wide).

Postharvest handling

Muscadines are known for having a short shelf life due to a loss of texture, shriveling, browning, and overall weight loss (Walker et al., 2001). In a study done at the University of Arkansas, storage attributes (percent weight loss and percent unmarketable berries) were affected by the genotype (Barchenger et al., 2015). The decay of muscadines during postharvest storage is directly related to storage temperatures. With extended cold storage (<20 °C), negative attributes such as visible tissue deterioration and rapid decay occur, especially when the temperatures are increased (Takeda et al., 1983). Saunders et al. (1981) indicated that at 1 °C with 85% relative humidity, muscadine grapes lasted 14 d with no visible signs of tissue deterioration, however, a slight softening occurred. Postharvest storage is of critical importance for shipment of the fruit to distant markets. In a study by James et al. (1999), the efficacy of shipment of muscadines was evaluated and showed that while the composition remained fairly consistent, texture was affected. Additionally, shipment increased the rate of texture loss by about two-thirds as compared to an in-lab study (James et al., 1999). Controlled atmosphere storage retarded respiration of the fruit leading to decreased cell wall degradation and decreased titratable acidity as compared to traditional cold storage (Basiouny, 1996).

Firmness and composition

In a study done at the University of Arkansas, physiochemical attributes (penetration force, titratable acidity, pH, soluble solids, and color) of muscadines were affected by the fruit's genotype; however, titratable acidity, pH, soluble solids, and color remained fairly constant throughout storage (Barchenger et al., 2015). 'Fry' muscadine had an average soluble solids of 14% and titratable acidity of 0.6% (Takeda et al., 1983). A study by Threlfall et al. (2007) looked at the composition of five black muscadine cultivars (Black Beauty, Ison, Nesbitt, Southern Home, and Supreme) and three bronze cultivars (Carlos, Granny Val, and Summit). Soluble solids ranged between 12.6% to 14.6%, pH ranged between 3.09 to 3.42, and the titratable acidity ranged between 3.35-6.00 g/L depending on the cultivar. As the berries matured on the vine, the weight and sugars (glucose, fructose, and sucrose) increased, and the organic acids (tartaric and malic acid) decreased leading to an increase in soluble solids and pH, and a decreased titratable acidity by harvest (Carroll and Marcy, 1982).

Nutraceuticals

Muscadine grapes have some of the highest antioxidant levels among fruits (Greenspan et al., 2005). Powdered muscadine puree has more dietary fiber than oat or rice bran, are a great source of resveratrol, and have anti-carcinogenic properties (Stanley, 1997). A study done on the anti-inflammatory effects of muscadine grape skins found that they had *in vitro* and *in vivo* anti-inflammatory properties, and the polyphenols in muscadines have also shown anticarcinogenic properties (Greenspan et al., 2005; Yi et al. 2005). Research by Wang et al. (2010) confirmed that muscadine pomace is rich in phenolics, flavonoids, and anthocyanins. In a study by You et al. (2012) total phenolic content and total anthocyanin content had strong

linear correlations, indicating that the phenolics and anthocyanins contributed to the total antioxidant potential.

Sensory

Few consumer sensory studies have been done on fresh-market muscadines, and no published work has been done using a trained descriptive panel. In a study by Brown et al. (2016), consumer acceptability of muscadines was correlated with thinner skin and higher pH grouped with overall liking and flavor. Similarly, in a study by Threlfall et al. (2007), consumers showed preference for high soluble solid muscadine juice (14%) and juice with a soluble solids/titratable acidity ratio of 26 to 31. In a descriptive analysis of the muscadine juice, overall liking was positively correlated to sweetness and caramelized flavors, whereas, overall liking was negatively correlated to sour and green and unripe flavors. A consumer panel evaluated 'Fry' and found that muscadines could be distinguished by increasing sweetness, related to sugar to acid ratio and maturity differences were distinguishable within the cultivar (Walker et al., 2001). As previous research is lacking with respect to descriptive analysis of fresh-market muscadines, a generalized understanding of grapes can be gained from looking at results from descriptive analysis of table grapes.

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Chapter I

Effects of Harvest Time and Storage Temperature on Postharvest Quality of Arkansas Blackberry Genotypes

Abstract

Postharvest storage performance in fresh-market fruits is extremely important to fruit breeders, growers, and consumers. In blackberries (*Rubus* subgenus *Rubus* Watson), postharvest quality relies on the capacity of the berries to maintain composition and firmness and resist leakage, decay, and development of red drupelets (reversion) before reaching the consumer. Four cultivars (Natchez, Osage, Ouachita, and Prime-Ark® Traveler) and five advanced breeding selections (A-2428, A-2444, A-2453, A-2526, and APF-268) were harvested from the University of Arkansas Fruit Research Station, Clarksville, AR at 7:00 $_{AM}$ and 12:00 $_{PM}$ at the shiny-black stage of ripeness. After harvest, berries were randomized and placed in 125-g vented clamshells in duplicate and stored at 2 °C and 10 °C for both physicochemical analysis (soluble solids, pH, and titratable acidity) and marketability analysis (firmness, weight loss, leakage, decay, and red drupelet reversion). Berries were evaluated at harvest (day 0) and after 7 and 14 days at 2 °C and 10 °C. At harvest (day 0) these genotypes had a berry weight of 3.50-10.32 g, soluble solids of 6.40%-11.50%, pH of 2.34-3.67, titratable acidity of 0.48%-1.62%, and firmness of 3.05-13.69 N. A-2444 had the highest soluble solids (10.85%) and pH (3.50). 'Prime-Ark® Traveler' and A-2453, a novel "crispy" genotype, had firmer fruit than the other genotypes at both harvest times, and A-2453 was more firm at 12:00 $_{PM}$ than 7:00 $_{AM}$. 'Natchez' had the highest berry weight, and A-2453 the smallest. There was less weight loss at 2 °C (2.52%) than at 10 °C (6.35%) during storage regardless of harvest time. A-2444 had the greatest weight loss after 14 days storage at both temperatures. 'Natchez' had the highest red drupelet reversion at 7:00 $_{AM}$ on day 7 for both storage temperatures and after 14 days storage at 2 °C, and red drupelet reversion in 'Prime-

Ark® Traveler' harvested at $12{:}00_{PM}$ increased (9.75%) as compared to day 0. Harvest time had minimal impact on blackberry marketability after 14 days storage. In general, most berries were less firm after 14 days storage at 10 °C as compared to 2 °C and leakage, decay, and weight loss were greater. However, red drupelet reversion was not impacted by storage temperature after 14 days storage. After 14 days storage, A-2453 had the least leakage (13.67%) at 2 °C, and 'Osage' had the least leakage (16.04%) at 10 °C. In addition, during storage 'Ouachita' and APF-268 had the least decay at 2 °C and 10 °C, respectively. Overall, greater impact on postharvest quality of Arkansas-grown blackberries was due to the effects of storage temperature and genotype rather than harvest time.

Introduction

Blackberries (*Rubus* L. hybrids) are an aggregate fruit native to regions of Europe and North America, but grown worldwide for processing and fresh-markets. According to the United States Department of Agriculture (2017), 1,620 ha of blackberries were harvested in the United States with ~2,740,000 kg for fresh market, though this data is primarily from Oregon. In 2016, U.S. blackberry production was valued at $26.4 million with $5.0 million from fresh-market sales and $21.4 million from processed sales (USDA, 2017). Though the total sales were down 36% from 2015, the reduction was mainly due to a decrease in sales of processed blackberries as value of fresh-market sales remained $5-6 million each year from 2011 to 2016.

Barnett (2007) attributed increased fresh-market blackberry sales in the United Kingdom to increased availability of sweeter cultivars and awareness of health benefits associated with the fruit. Blackberries are known to have excellent health benefits attributed to high antioxidant capacity and presence of various bioactive compounds such as phenolic acids, anthocyanins, flavonoids, and ellagitannins (Machado et al., 2015). In addition, blackberries are rich in vitamins (C, A, E, B6), folic acid, dietary fiber, potassium, phosphorous, magnesium, calcium, and iron, which contribute to other health benefits such as skin, bone, heart, and brain heath (Lee, 2017).

Blackberry production methods vary by region, and the plants can be erect (self-supporting), trailing, or semi-erect. A survey in 2005 indicated that half of the cultivars in production were semi-erect and the remaining half evenly split between erect and trailing types (Strik et al., 2007). Erect and semi-erect plants are grown primarily for fresh-market production and are usually hand harvested.

In the United States, both public and private blackberry breeding programs have been working on the development and release of new fresh-market blackberry cultivars. The University of Arkansas Fruit Breeding Program routinely evaluates blackberry selections at the Fruit Research Station in Clarksville, AR and has released many fresh-market cultivars with unique traits. In 2004, the University of Arkansas released the first commercial primocane-fruiting blackberries (Clark et al., 2005). Most blackberry plants are biennial, meaning first-season canes grow (primocanes), and in the second season plants, produce fruit on the floricanes. Primocane-fruiting plants can increase fruit production per plant, but also impact fruit seasonality. Another advancement from this program is the development of "crispy" blackberry selections with firm textures to improve postharvest shipping capability and shelf life (Salgado and Clark, 2016). Currently, the breeding program is focused on improving the understanding of postharvest quality and releasing new fresh-market cultivars (Clark and Finn, 2011; Clark, 2015)

During postharvest shipping and storage, blackberries are susceptible to many conditions which lower marketability, shelf life, and fruit quality. Due to their soft skin and fragile nature, blackberries have a relatively short postharvest shelf-life (de Arruda Palharini et al., 2015). Softening, leakage, mold development, and weight loss are common postharvest problems in blackberries and other soft fruit. Another postharvest issue, red drupelet reversion, is when the black drupes on mature berries turn red during or after cold storage (Salgado and Clark, 2016; Segantini et. al., 2018). The cause of this injury has not been determined, however it was shown that "shiny" black berries placed in cold storage then removed can develop red drupelets and genotypes vary in susceptibility. It is hypothesized that the temperature the fruit is picked or stored may influence the extent and severity of red drupelet reversion. Previous studies at the University of Arkansas by Yin (2017) and McCoy et al. (2016) found significantly less red

drupelet reversion of fruit harvested early in the morning than fruit harvested in the afternoon indicating a potential environmental effect. The “crispy”, firm blackberries had less red drupelet reversion during storage (McCoy et al., 2016; Segantini et. al, 2017; Salgado and Clark, 2016; Yin, 2017), suggesting that firmness can also impact red drupelet reversion.

By understanding how harvest and storage temperatures affect blackberries, we can provide information to growers to broaden postharvest potential. The purpose of this study was to evaluate the effects of different harvest times and storage temperatures on the postharvest quality of Arkansas-grown fresh-market blackberries.

Materials and Methods

Blackberry plants and culture

Nine blackberry genotypes (*Rubus* subgenus *Rubus Watson* L.) were evaluated in this study, including four cultivars (Natchez, Osage, Ouachita, Prime-Ark® Traveler) and five advanced selections (A-2428, A-2444, A-2453, A-2526, and APF-268). The plants were grown at the University of Arkansas Research Station in Clarksville, AR (West Central Arkansas, lat. 35 ˚31'58"N and long. 93 ˚24'12"W). Plants were trained to a T-trellis with two lower wires ~0.5 m from the soil surface spaced 0.5 m apart and two upper wires ~1.0 m high spaced 0.8 m apart. The blackberry plants that were harvested for this project were in three plots with five plants per plot, and the plots were established in 2013, 2015 and 2016. Standard cultural practices for erect blackberry production were used including annual spring nitrogen fertilization (56 kg·ha^{-1} N) using ammonium nitrate. The plants were irrigated as needed using trickle irrigation. Dormant pruning consisted of removing dead floricanes and removing primocane tissue to a point below the flowering area on the primocanes. The plants received a single application of liquid lime sulfur (94 L·ha^{-1}) at budbreak for control of anthracnose (*Elsinoë veneta* [Burkholder] Jenk.). Raspberry crown borer (*Pennisetia marginata* [Harris]) was controlled by a single application of a labeled insecticide with bifenthrin as the active ingredient in October of each year. Insecticides labeled for commercial use in Arkansas were used for spotted wing drosophila (*Drosophila suzukii* Matsumura) control.

Blackberry harvest

Blackberries were hand harvested from the floricanes at 7:00 AM and 12:00 PM. The fruit was harvested at the "shiny" black stage of ripeness and were free of major blemishes, flaws, or damage. About 4 kg of blackberries were harvested for each genotype and harvest time into 150-

g vented clamshells and placed in an ice chest chilled with ice packs. ‘Natchez’, ‘Osage’, Prime-Ark® Traveler’, A-2428, and A-2444 were harvested on 8 June 2017, and ‘Ouachita’, A-2453, A-2526, and APF-268, were harvested on 20 June 2017 (Table 1). There were no rain events within 12 h of either harvest. Air temperature in the plots was measured using AcuRite Digital Humidity and Temperature Comfort Monitor (Primax Family of Companies, Geneva, WI) at the start and completion of harvest for each genotype. Fruit for this study was transported from Clarksville, AR to the Food Science Department, Fayetteville, AR (~2 hrs travel time) after both the 7:00 $_{AM}$ and 12:00 $_{PM}$ harvests were completed. After the fruit was harvested at 7:00 $_{AM}$, the closed coolers were placed at 4 °C until the 12:00 $_{PM}$ harvest was complete. The blackberries were then gently removed from the clamshells, randomized by genotype and harvest time, and placed into new 150-g ventilated clamshells. The fruit was placed in two different cold storage temperatures (2 $^{\circ}$C and 10 $^{\circ}$C) with 85% to 89% relative humidity and evaluated for physiochemical and marketability attributes at day 0, 7, and 14.

Physiochemical analysis

Physiochemical analysis was performed on fruit in two replicate clamshells. The physiochemical analysis included berry attributes and composition evaluated at 0, 7, and 14 d at 2 °C and 10 °C for each harvest time and genotype.

Berry attributes. Five berries per genotype and replication were removed to analyze berry attributes (weight, drupelets/berry, red drupelet reversion (RDR), and firmness). Berry weight was measured on a digital scale (PA224 Analytic Balance, Ohaus Corporation, Parsippany, NJ). The total drupelets and total red drupelets were counted on each berry using a paint pen, and then the percent RDR was calculated.

Firmness. Five berries per genotype and replication were removed to analyze firmness using a Stable Micro Systems TA.XT.plus Texture Analyzer (Texture Technologies Corporation, Hamilton, MA.). Fruit compression was performed by placing individual berries horizontally on a flat surface using a cylindrical and plane probe of 7.6 cm diameter at a rate of 2 mm/s with a trigger force of 0.02 N. Force to compress the berry was measured in Newtons (N).

Composition. Five berries per genotype and replication were frozen (-10 ˚C) for compositional analysis (soluble solids, pH, titratable acidity, organic acids, and sugars). The five berries in each sample were thawed and squeezed through cheese cloth to extract juice. The pH and titratable acidity were measured using the Titrino plus 862 compact titrosampler (Metrohm AG, Herisan, Switzerland) with the electrode standardized to pH 4.00, 7.00, and 10.00 buffers. Titratable acidity was determined using ~3 g of juice diluted with deionized, degassed water with a titration using 0.1 N sodium hydroxide to an endpoint of pH 8.2. Titratable acidity was expressed as percentage of citric acid. Soluble solids (expressed as percent) was measured using an Abbe Mark II refractometer (Bausch and Lomb, Scientific Instrument, Keene, NH).

Organic acids and sugars. Organic acids and sugars were determined using high performance liquid chromatography (HPLC) in duplicate for each genotype and replication. 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, isocitric, isocitric lactone, and malic acids of blackberries were measured using previously established HPLC procedures (Walker et al., 2003; Segatini et al., 2018). 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 0.45 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 35 min. A Waters 410 differential refractometer to measure refractive index connected in series with a Waters 996 photodiode array detector monitored the eluting compounds. Isocitric, isocitric lactone, and malic 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 (isocitric + isocitric lactone + malic acid) were expressed as g/100 g.

Marketability analysis

Marketability analysis was performed on fruit in two replicate clamshells. The marketability analysis included total decay, total leakage, and weight loss evaluated at 0, 7, and 14 d at 2 °C and 10 °C for each harvest time and genotype.

Total decay and total leakage. The total decay (visible mold or rot) and leakage (berries with juice visible) of the berries in the clamshell was calculated as (number of decayed or leaking fruit/number of total fruit) × 100 and expressed as percent.

Weight loss. The weight loss of the clamshell was calculated as the weight decrease of the total blackberries in the clamshell expressed as percent.

Design and statistical analysis

After harvest, the fruit from each of the nine genotypes was completely randomized for each harvest time (7:00 $_{AM}$ and 12:00 $_{PM}$). The fruit was stored at two storage temperatures (2 $^{\circ}$C and 10 $^{\circ}$C) for 0, 7, and 14 d. Statistical analyses were conducted using JMP® (version 13.2.0; SAS Institute, Cary, NC). A univariate analysis of variance (ANOVA) was used to determine the significance of main factors (genotype, harvest time, storage temperature, and storage day) and interactions. Tukey's Honestly Significant Difference (HSD) test was used to detect significant differences ($p < 0.05$) among means and verify interactions at 95% significance level. Figures were created with each standard error bar constructed using 1 standard error from the mean.

Results and Discussion

Overall, the 2017 blackberry harvest season was relatively mild at the Fruit Research Station, with average high temperature of 28.4 $^{\circ}$C and a low of 19.4 $^{\circ}$C during the month of June. Significant rain events occurred through April to June (Fig. 1). Air temperature for fruit harvested at 7:00 $_{AM}$ was cooler (5 to 10 $^{\circ}$C) than fruit harvested at 12:00 $_{PM}$ (Table 1). In addition, the temperature of the fruit harvested on 8 June was cooler than fruit harvested on 20 June at both harvest times. At harvest (day 0), the blackberries were within a commercially acceptable range for berry weight (3.50-10.32 g), soluble solids (6.40%-11.50%), pH (2.34-3.97), and titratable acidity (0.48%-1.62%) (data not shown). The blackberries were evaluated for physiochemical attributes at harvest and physiochemical and marketability attributes during postharvest storage. At harvest there were significant two-way interactions (harvest time x genotype) and during postharvest storage there were significant two-, three-, and four-way interactions (harvest time x storage day x storage temperature x genotype).

Physiochemical attributes at harvest

The blackberries from the nine genotypes were harvested at 7:00 $_{AM}$ and 12:00 $_{PM}$ and evaluated for physiochemical attributes (berry weight, drupelets/berry, firmness, soluble solids, pH, titratable acidity, total organic acids, and total sugars). There was no significant harvest time x genotype interactions for drupelets/berry, soluble solids, pH, titratable acidity, total organic acids, or total sugars (Table 2), and main effect of harvest time did not impact these attributes. There were significant differences among genotypes for drupelets/berry, soluble solids, pH, and titratable acidity, but not total organic acids or total sugars. 'Natchez' had the most drupelets/berry (102), and the lowest soluble solids (7.65%) of the genotypes. A-2453 had the fewest drupelets/berry (36) and the lowest titratable acidity (0.74%). A-2444 had the highest soluble solids (10.85%) and pH (3.50) of the genotypes. Segantini et al. (2017) found similar levels of soluble solids and titratable acidity in blackberries at harvest, ranging from 6.60%-10.90% and 0.50%-1.50%, respectively. However, in the cultivar release description of 'Natchez' it was noted to have a soluble solids content of 8.70%, which was slightly higher than seen in this study (Clark, 2010).

There were no differences among genotypes for total organic acids (0.52-1.35 g/100 g) and total sugars (2.87-6.06 g/100 g). Individual organic acids and sugars were evaluated, but there were no significant main effects or interactions. The berries contained isocitric acid (0.32-0.80 g/100 g), isocitric lactone (0.08-0.13 g/100 g), malic acid (0.12-0.43 g/100 g), glucose (1.36-2.99 g/100 g) and fructose (1.42-3.07 g/100 g) (data not shown). Since fructose is characteristically sweeter than glucose, its concentration is desirable, as the majority of consumers prefer sweeter fruit (Wang et al., 2009). Glucose and fructose levels in the berries were predominantly in a 1:1 ratio. A ratio of 1:1 glucose to fructose was also observed by Fan-

Chiang and Wrolstad (2010). Isocitric acid was the predominant acid and isocitric acid and malic acid had a ~2:1 ratio. Yin (2017) found Arkansas blackberries, when grown in Clarksville, to be malic acid predominant; whereas, Segantini et al. (2018) noted Arkansas blackberries to be isocitric acid predominant. These differences may be genotype specific as Yin's results were on various blackberry populations, whereas, Segantini et al. reported on eleven specific genotypes, of which six were the same as in this study. Kafkas et al. (2006) reported malic acid to be the predominant acid with no citric acid present in blackberries grown in Turkey, suggesting growing conditions may have an effect on acid composition of blackberries.

Berry weight and firmness had significant genotype x harvest time interactions (Table 2). Although berry weights varied by genotype (4.20-9.10 g), the berry weights at both harvest times were similar for all genotypes except A-2428, which had a larger berry weight at 12:00 $_{PM}$ than 7:00 $_{AM}$ (Fig. 2). This indicated an overall uniform harvest and proper randomization prior to analysis. Firmness of blackberries at harvest ranged from (3.05-13.69 N). Segantini et al. (2017) found similar firmness levels of 4.90-9.00 N. 'Prime-Ark® Traveler' and A-2453 harvested at 12:00 $_{PM}$ had firmer fruit than the fruit of the other genotypes at both harvest times (Fig. 3). A-2453, a novel "crispy" genotype, was more firm at 12:00 $_{PM}$ than 7:00 $_{AM}$. The other genotypes had similar berry firmness for both harvest times. In terms of temperature at both harvest days, the 7:00 $_{AM}$ harvest had average ambient temperature that was ~6.9 $^{\circ}$C cooler than the 12:00$_{PM}$ harvest time. Overall, harvest time had a minimal effect on the initial physiochemical attributes of blackberries. Significant main effects were predominantly due to genotype, and interactions between harvest time x genotype were generally significant due to one or two outlier values for limited genotypes.

Physiochemical and marketability attributes during postharvest storage

The nine blackberry genotypes harvested at 7:00 $_{AM}$ and 12:00 $_{PM}$ were stored at two different temperatures (2 °C and 10 °C) and evaluated at 0, 7, and 14 d. Significant two-, three-, and four-way interactions were found for many of the attributes (Table 3). Postharvest storage results were analyzed by storage temperature to demonstrate how different genotypes harvested at different times performed as storage progressed (Tables 4 and 5).

Berry weight ranged from 2.92-10.50 g during postharvest storage. There was a significant harvest time x genotype interaction for berry weight at both storage temperatures, but berry weight was not impacted by harvest time (Fig. 4). 'Natchez' had the highest berry weight, and A-2453 the smallest. There was also an interaction between storage day x genotype at 10 °C (Fig. 5). Most of the genotypes lost berry weight as storage progressed, but the reduction was not significant except 'Natchez', which had lower berry weight on day 14 than day 0. 'Natchez' was the largest berry and its size might have contributed to greater weight loss. The berry weights in this study were typically smaller than those found in 2015 (6 to 14 g) for Arkansas-grown blackberries (Segantini et al., 2017; Threlfall et al., 2016).

Soluble solids ranged from 6.20%-12.20% during storage. Soluble solids of blackberries at 2 °C were impacted by storage day x genotype, but storage day did not have an effect on soluble solids (Fig. 6). A-2444 had the highest soluble solids at all storage times. Although, soluble solids of blackberries at 10 °C had a significant three-way interaction (harvest time x storage day x genotype), harvest time and storage day did not greatly impact soluble solids (Fig. 7).

The pH of the berries ranged from 2.34-4.31 during storage. There was an interaction between storage day x genotype for pH at both storage temperatures (Fig. 8). The pH was higher

at day 14 than day 0 for A-2453, A-2526, APF-268, and 'Ouachita' at both temperatures. As storage progressed, the pH increased for the genotypes, which has also been observed in previous studies on blackberries (Tosun et al., 2008).

During storage, titratable acidity ranged from 0.30%-1.62%. There was an interaction between storage day x genotype at 2 °C, but titratable acidity was not impacted by storage day (Fig. 9). There was an interaction between harvest time x storage day at 2 °C, but titratable acidity was not impacted by storage day at either harvest time (Fig. 10). As with berry weight, there was a general trend for decreased titratable acidity after 14 d storage but was not significant. At 10 °C, there were no significant interactions for titratable acidity. For the blackberries stored at 10 °C, fruit harvested at 12:00 PM had slightly higher titratable acidity (0.77%) than fruit harvested at 7:00 AM (0.68%). Additionally, after 14 d storage, the titratable acidity was lower (0.54%) than day 0 (0.93%) or day 7 (0.72%). A-2453 had the lowest titratable acidity (0.61%) during storage, and 'Ouachita' had the highest (0.95%) (Table 5).

Weight loss of the blackberry-filled clamshells during storage ranged from 0.00%-22.14% and was affected by a storage day x genotype and harvest time x genotype interactions at both temperatures (Tables 4 and 5 and Figs. 11 and 12). When examining the effects of storage day on weight loss, weight loss increased for all genotypes regardless of storage temperature, but there was less weight loss at 2 °C (Fig. 11). A-2444 had the greatest weight loss after 14 d storage at 2 °C and 10 °C, 7.34% and 18.31%, respectively. A-2444 and A-2428 had larger drupelets than the other genotypes which could have led to increased weight loss (J. R. Clark, personal communication). There was less weight loss during storage at 2 °C than at 10 °C regardless of harvest time (Fig. 12). Weight loss at 2 °C during storage averaged 2.52% whereas

weight loss at 10 °C averaged 6.35%. During storage, berries harvested at 7:00 $_{AM}$ did not differ in weight loss from berries harvested at 12:00 $_{PM}$.

Leakage ranged from 0.00%-92.86% during storage. At 2 °C, there were no significant interactions for leakage; however, at 10 °C, leakage was impacted by storage day x genotype. At 2 °C, harvest time did not impact leakage of blackberries but storage day and genotype did. Leakage increased during storage at 2 °C with 8.41% at day 0 to 21.10% at day 14 (Table 4). 'Natchez' had the most leakage (18.91%) during storage at 2 °C, and A-2453 the least (5.60%) (Table 4). After 14 days storage at 10 °C, Natchez had the most leakage (67.78%), and Osage the least (16.04%) (Fig. 13). At both storage temperatures, generally, 'Natchez' had one of the highest incidences of leakage, which most likely attributed to the decreased berry weight mentioned previously. With the exception of 'Ouachita', storage at 10 °C resulted in increased leakage during storage.

At both storage temperatures, decay had no significant interactions (Tables 4 and 5). Decay ranged from 0% to 100% during storage. Harvest time did not impact decay at either storage temperature. Decay during storage increased at both storage temperatures. After 14 d storage at 2 °C and 10 °C, decay was 38.92% and 70.00%, respectively. A-2444 had the most decay at both storage temperatures although most genotypes were statistically similar, while 'Ouachita' had the least (12.45%) at 2 °C. There were no differences among genotypes for decay at 10 °C. In the release of 'Ouachita', it was reported to have very good storage potential, with a storage period longer than previously released cultivars, such as 'Navaho', which supports the low incidence of decay in this study (Clark and Moore, 2005).

Red drupelet reversion ranged from 0.00%-21.52% during storage and was impacted by harvest time x storage day x genotype interactions at both storage temperatures (Fig. 14).

However, harvest time had minimal impact on red drupelet reversion during storage at both 2 °C and 10 °C (Tables 4 and 5). Yin (2017) and McCoy et al. (2016) evaluated blackberries grown in Arkansas during 2016 and 2015, respectively, and found that blackberries harvested in the morning had less red drupelet reversion compared to fruit harvested in the afternoon. When comparing the 2016 versus 2017 harvest seasons, there were temperature and rainfall differences that might contribute to the differences between this study's results and results by the study by Yin (2016). Although the average temperatures in June were warmer in 2016 compared to 2017, the temperatures on the days of harvest in June were warmer in 2017 as compared to 2016 for both harvest times. On 9 June 2016, temperatures at 7:00 AM and 12:00 PM were 22 °C and 28 °C, respectively as compared to 26 °C and 32 °C on 8 June 2017 (Table 1). Similarly, on 21 June 2016, temperatures at 7:00 AM and 12:00 PM were 24 °C and 30 °C, respectively as compared to 29 °C and 39 °C on 21 June 2017. However, June minimum and maximum temperatures for 2016 and 2017 were 21-31 °C and 19-28 °C, respectively. In terms of rainfall, there was 43 mm in 2016 and 103 mm in 2017.

'Natchez' had the highest red drupelet reversion at 7:00 AM on day 7 for both storage temperatures (Fig. 14). Previous research has shown 'Natchez' had the lowest incidence of red drupelet reversion during storage as compared to 10 other genotypes (Segantini et al., 2017). As mentioned previously, 'Natchez' had one of the highest incidences of leakage, which potentially could increase red drupelet reversion. Additionally, in 2015, a week prior to harvest of 'Natchez', Segantini et al. (2017) noted 9.10 mm of cumulative rainfall; whereas, a week prior to the 2017 harvest, 'Natchez' experienced a 35.80 mm cumulative rainfall. However, 'Natchez' at 14 d storage had much lower reversion than after just 7 d storage although fruit was harvested on the same day. Most other genotypes had a gradual increase in reversion during storage. This

inconsistency is not easily explained, and it remains unclear why 'Natchez' harvested at 7:00 AM experienced such high levels of reversion after 7 d storage. 'Natchez' also had lower reversion for the 12:00 PM harvest compared to 7:00 AM.

Red drupelet reversion for A-2444, A-2453, APF-268, and 'Ouachita' was higher after 14 d of storage than 7 d of storage regardless of harvest time and storage temperature. After 14 d postharvest storage at 2 °C, red drupelet reversion in 'Prime-Ark® Traveler' harvested at 12:00PM significantly increased to 9.75% compared to no increase at 10 °C. As mentioned previously, fruit for this study was transported at harvest from Clarksville, AR to Fayetteville, AR (~2 hrs travel time) after both the 7:00 AM and 12:00 PM harvests were completed in pre-chilled ice chests with cooler packs. Red drupelet reversion could have been affected due to potential temperature acclimation from removing field heat gradually in the ice chest before placing the fruit at the final storage temperatures. This gradual transition would have allowed the fruit to acclimate to its conditions, thus minimizing red drupelet reversion as it has been shown to minimize chilling injury in other fruits such as peaches and plums (Sun et al., 2010; Tanou et al., 2017).

During storage, berry firmness ranged from 1.88-13.69 N. There was a significant harvest time x genotype interaction at both storage temperatures (Tables 4 and 5). In general, most berries were less firm when stored at 10 °C as compared to 2 °C. Studies by Mir et al. (2001) and NeSmith et al. (2005) also noted decreased firmness as a response to storage temperature in blueberries and apples. Harvest time did not impact firmness except for A-2453, which was firmer at 12:00 PM than 7:00 AM at both storage temperatures (Fig. 15). Salgado and Clark (2016) found that "crispy" genotypes, such as A-2453, were firmer than non-crispy genotypes. In this study, the "crispy" genotype was firmer at later harvest times. In a previous study by McCoy et

al. (2016), harvest time had a minimal effect on fruit firmness and berries harvested at 1:00$_{PM}$ were not softer than berries harvested at 7:00 $_{AM.}$ This finding is similar to the other eight genotypes included in this study.

Total organic acids and sugars ranged from 0.09-1.28 g/100g and 0.06-15.41 g/100g, respectively. At both storage temperatures, total organic acids were not impacted by harvest time, storage day, nor genotype and there were no significant interaction effects. At 2 $^{\circ}$C, total sugars were impacted by a harvest time x storage day interaction. After 14 days storage, fruit harvested at 7:00 $_{AM}$ had a higher total sugar content (4.87 g/100g) than fruit harvested at 12:00$_{PM}$ (2.49 g/100g) stored at 2 $^{\circ}$C (Fig. 16). However, at 10 $^{\circ}$C, there were no significant interactions or main effects of harvest time, storage day, or genotype for total sugars.

After 14 d of storage at 2 $^{\circ}$C and 10 $^{\circ}$C, the impact of the marketability attributes (leakage, decay, weight loss, red drupelet reversion, and firmness) of fresh-market blackberries was apparent. Storage temperature had a greater impact than harvest time on marketability attributes, after 14 d of storage, regardless of genotype (Fig. 17). Red drupelet reversion was not impacted by storage temperature. Leakage, decay, and weight loss were greater, and firmness lower, when the berries were stored at 10 °C versus 2 °C. A similar study by Palharini et al. (2015) found increased decay in blackberries when fruit was stored at higher temperatures (15 °C vs 2 °C or 5 °C). Similar trends were observed when looking at the effects of storage temperature and genotype on marketability attributes after 14 d storage, regardless of harvest time (Fig. 18). Genotypes stored at 10 °C had higher leakage, decay, and weight loss, and lower firmness after 14 d storage. A-2453 was the firmest and 'Ouachita' was the least firm at both storage temperatures. A-2526 had the least weight loss at both storage temperatures. At 2 $^{\circ}$C, A-2453 had the least leakage, and at 10 $^{\circ}$C 'Osage' had the least leakage. A-2453 had the least red drupelet

reversion at both storage temperatures. Overall, a greater impact on marketability was due to the effects of storage temperature over the effects of harvest time for these genotypes.

Conclusion

Overall, genotype and storage day had the most significant effects on the postharvest quality of fresh-market blackberries grown in Arkansas. Blackberry marketability attribute performance was directly related to storage temperature. Fruit stored at a lower temperature retained marketable attributes longer than fruit stored at the higher temperature. Red drupelet reversion was primarily attributed to genotypic effects, not harvest time nor storage temperature. A-2453 performed exceptionally well in this study with the least red drupelet reversion at both storage temperatures, less leakage after 14 d storage at 2 °C, and more firmness at both harvest times than the "non-crispy" genotypes. Additionally, 'Osage' had the least leakage at 10 °C after 14 d storage; and, 'Ouachita' and APF-268 had the least decay during storage at 2 °C and 10 °C, respectively.

Although the previously held theory was that harvest time would impact postharvest quality of fresh-market blackberries, minimal impact of harvest time was found in this study. On day 0, harvest time impacted blackberry firmness and berry weight of select genotypes, but in general did not impact physiochemical attributes. In addition, after 14 d storage, harvest time had no significant impact on the marketability of fresh-market blackberries. These findings may be partially attributed to how the harvested blackberries were placed into coolers and transported. In addition, rain events prior to harvest could have affected the overall fruit quality for example; berry weight and soluble solids were lower in this study than previously found in other research on these genotypes in Arkansas. For this reason, further analysis through a multi-year repeated

study is needed to investigate how harvest time affects the postharvest quality of Arkansas grown fresh-market blackberries.

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Tables

Table 1. Mean air temperature[z] on days of harvest of blackberry genotypes at 7:00 $_{AM}$ and 12:00 $_{PM}$, Clarksville, AR (2017)

		Harvest time	
Harvest date	**Genotypes harvested**	**7:00 AM**	**12:00 PM**
8 June 2017	Natchez, Osage, Prime-Ark® Traveler, A-2428, and A-2444	26.25 °C	31.58 °C
20 June 2017	Ouachita, A-2453, APF-268, and A-2526	28.83 °C	38.83 °C

[z] Air temperature was measured using AcuRite Digital Humidity and Temperature Comfort Monitor (Primax Family of Companies, Geneva, WI) at the start and completion of harvest for each genotype. Values were averaged for all of the genotypes for harvest date to obtain average air temperature.

Table 2. Main and interaction effects of harvest time and genotype on initial berry and composition attributes for fresh-market blackberry genotypes harvested at 7:00 AM and 12:00 PM, Clarksville, AR (2017)

Effects	Berry weight (g)	Drupelets/ berry	Firmness (N)	Soluble solids (%)	pH	Titratable acidity (%)[z]	Total organic acids (g/100 g)	Total sugars (g/100 g)
Harvest time								
7:00 AM	6.12 a[y]	59.82 a	5.83 b	8.90 a	3.11 a	0.89 a	0.87 a	3.62 a
12:00 PM	6.31 a	61.54 a	6.52 a	8.86 a	3.09 a	0.93 a	0.78 a	4.01 a
P value	*0.2701*	*0.2132*	*0.0048*	*0.7585*	*0.7000*	*0.4227*	*0.6112*	*0.5830*
Genotype								
A-2428	5.57 cd	49.22 e	5.30 c	9.55 b	3.38 ab	0.90 bcd	0.64 a	3.47 a
A-2444	7.26 b	51.17 de	5.20 c	10.85 a	3.50 a	0.74 cd	0.96 a	6.06 a
A-2453	4.20 e	35.80 f	8.52 a	9.82 ab	3.12 b	0.74 d	0.52 a	3.41 a
A-2526	5.51 d	44.45 ef	4.99 c	8.99 bc	2.52 c	1.03 abc	0.83 a	3.34 a
APF-268	6.68 bc	69.28 b	6.47 bc	7.77 de	2.54 c	1.09 ab	0.80 a	2.87 a
Natchez	9.10 a	101.85 a	5.82 c	7.65 e	3.46 a	0.77 cd	0.96 a	4.55 a
Osage	5.00 de	64.90 bc	5.86 c	8.22 cde	3.53 a	0.82 bcd	0.81 a	3.54 a
Ouachita	5.64 cd	59.38 cd	5.30 c	8.30 cde	2.57 c	1.26 a	1.35 a	4.33 a
Prime-Ark® Traveler	6.99 b	70.05 b	8.10 ab	8.76 bcd	3.27 ab	0.86 bcd	0.55 a	2.79 a
P value	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*0.3932*	*0.4914*
Harvest time x Genotype (P value)	*0.0104*	*0.2686*	*<0.0001*	*0.3376*	*0.1600*	*0.5364*	*0.8132*	*0.9587*

[z]Titratable acidity expressed as % citric acid.

[y]Genotypes were evaluated in duplicate (n=2). Means with different letter(s) for each attribute within effects are significantly different ($p<0.05$) using Tukey's Honestly Significant Difference test.

Table 3. F-test significance from ANOVA for fresh-market blackberry genotypes, harvest time (7:00 AM and 12:00 PM), storage day (0, 7, and 14), and storage temperature (2 °C and 10 °C), Clarksville, AR (2017)

Source	Berry weight (g)	Soluble solids (%)	pH	Titratable acidity (%)	Weight loss (%)	Leakage (%)	Decay (%)	Red drupelet reversion (%)	Firmness (N)	Total organic acids (g/100 g)	Total sugars (g/100 g)
Genotype (G)	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0192	<0.0001	<0.0001	0.0691	0.0093
Harvest time (H)	0.5173	0.7095	0.0026	0.0041	0.6373	0.9656	0.0323	0.8624	<0.0001	0.0495	0.0706
Storage day (D)	<0.0001	0.0018	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.2844	0.0827
Storage temperature (T)	<0.0001	<0.0001	<0.0001	0.0001	<0.0001	<0.0001	<0.0001	0.2584	<0.0001	0.5024	0.9606
G x D	<0.0001	0.0042	<0.0001	0.0010	<0.0001	0.0008	0.0414	<0.0001	0.6054	0.6922	0.3827
G x H	0.0001	0.0151	0.2996	0.5262	0.0119	0.1061	0.3271	0.0041	<0.0001	0.6843	0.2813
G x T	0.0545	0.3914	0.0002	0.0134	0.0001	0.3081	0.2688	0.0001	0.1853	0.8084	0.8486
H x D	0.0322	0.9443	0.1016	0.2850	0.7346	0.5955	0.3106	0.0703	0.8520	0.2821	0.0366
H x T	0.3843	0.1102	0.0973	0.1035	0.0759	0.4300	0.7269	0.6920	0.6752	0.7002	0.8815
D x T	0.0015	0.1772	<0.0001	<0.0001	<0.0001	0.0004	<0.0001	0.2023	<0.0001	0.4373	0.3632
G x H x D	0.2004	0.0070	0.0629	0.1412	0.3524	0.4174	0.2002	0.0106	0.0017	0.6630	0.8771
G x H x T	0.0075	0.0063	0.1479	0.1957	0.0017	0.9102	0.9393	0.7258	0.0062	0.2381	0.3980
H x D x T	0.4168	0.3353	0.3792	0.0573	0.2775	0.4312	0.7960	0.3749	0.2195	0.2493	0.5137
G x D x T	0.3638	0.0660	0.0035	0.3655	0.0111	0.1871	0.7566	<0.0001	0.6140	0.9576	0.4956
G x H x D x T	0.0358	0.0246	0.0544	0.6442	0.1726	0.9970	0.9697	0.5794	0.3870	0.3387	0.0085

Table 4. Main and interaction effects of blackberries for harvest time, storage day, and genotypes on physiochemical and marketability attributes of fresh-market blackberry genotypes harvested at 7:00 AM and 12:00 PM, and stored at 2 °C. Clarksville, AR (2017)

Effects	Berry weight (g)	Soluble solids (%)	pH	Titratable acidity (%)	Weight loss (%)	Leakage (%)	Decay (%)	Red drupelet reversion (%)	Firmness (N)	Total organic acids (g/100 g)	Total sugars (g/100 g)
Harvest time (H)											
7:00 AM	6.47 a[z]	8.82 a	3.31 a	0.79 a	2.60 a	9.13 a	17.90 a	4.12 a	5.86 b	0.90 a	4.21 a
12:00 PM	6.49 a	8.92 a	3.28 a	0.82 a	2.45 a	10.54 a	22.77 a	3.89 a	6.55 a	0.72 a	3.52 a
P value	*0.8987*	*0.3438*	*0.3082*	*0.3472*	*0.0613*	*0.4823*	*0.0572*	*0.5566*	*0.0074*	*0.0601*	*0.1010*
Storage day (D)											
0 days	6.34 a	8.96 a	3.12 b	0.90 a	0.00 c	0.00 c	0.00 c	0.40 b	6.06 ab	0.77 a	3.87 a
7 days	6.73 a	8.86 a	3.20 b	0.78 b	2.60 b	8.41 b	22.08 b	5.66 a	5.83 b	0.84 a	4.04 a
14 days	6.39 a	8.78 a	3.57 a	0.74 b	4.98 a	21.10 a	38.92 a	5.94 a	6.72 a	0.81 a	3.68 a
P value	*0.0788*	*0.3744*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	0.0144	0.8421	0.7775
Genotype (G)											
A-2428	6.16 cde	9.27 bc	3.45 b	0.81 bcd	2.79 b	8.55 b	27.09 ab	3.81 b	6.03 cd	0.78 a	3.85 a
A-2444	7.09 bcd	10.70 a	3.53 ab	0.76 cde	3.83 a	7.22 b	30.00 a	4.40 b	5.40 cd	0.85 a	4.93 a
A-2453	4.10 f	9.84 b	3.36 b	0.66 de	3.04 b	5.60 b	17.88 ab	2.16 b	8.73 a	0.81 a	4.39 a
A-2526	6.11 de	9.14 bc	3.07 c	0.87 abc	1.76 c	11.11 ab	19.17 ab	3.66 b	4.87 d	0.64 a	3.93 a
APF-268	7.77 ab	7.45 f	2.87 d	0.94 ab	2.00 c	6.44 b	20.26 ab	4.63 b	6.97 bc	0.79 a	2.89 a
Natchez	8.76 a	7.73 ef	3.40 b	0.74 cde	2.21 c	18.91 a	12.64 b	7.36 a	5.53 cd	0.92 a	4.17 a
Osage	5.33 e	8.83 cd	3.64 a	0.61 e	2.95 b	6.33 b	20.74 ab	3.42 b	5.50 cd	0.70 a	3.90 a
Ouachita	5.91 e	8.63 cd	2.95 cd	1.04 a	2.23 c	14.02 ab	12.45 b	2.17 b	4.79 d	1.16 a	3.86 a
Prime-Ark® Traveler	7.14 bc	8.29 de	3.36 b	0.83 bcd	1.92 c	10.32 b	22.80 ab	4.40 b	8.02 ab	0.62 a	2.88
P value	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*0.0475*	*0.0254*	*<0.0001*	*<0.0001*	*0.2855*	*0.3802*
D x G (P value)	*0.3756*	*0.0073*	*<0.0001*	*0.0146*	*<0.0001*	*0.6004*	*0.5346*	*<0.0001*	*0.8197*	*0.6023*	*0.1217*
H x G (P value)	*0.0224*	*0.1113*	*0.1796*	*0.1467*	*0.0021*	*0.1153*	*0.8400*	*0.0582*	*<0.0001*	*0.5707*	*0.4052*
H x D (P value)	*0.0934*	*0.5937*	*0.0726*	*0.0407*	*0.3756*	*0.1061*	*0.3455*	*0.5425*	*0.4007*	*0.0507*	*0.0100*
H x D x G (P value)	*0.2383*	*0.0684*	*0.0777*	*0.3533*	*0.4174*	*0.1607*	*0.8440*	*0.0242*	*0.0582*	*0.5610*	*0.0977*

[z]Genotypes were evaluated in duplicate (n=2). Means with different letter(s) for each attribute within main effects are significantly different.

Table 5. Main and interaction effects of blackberries for harvest time, storage day, and genotypes on physiochemical and marketability attributes of fresh-market blackberry genotypes harvested at 7:00 AM and 12:00 PM, and stored at 10 °C. Clarksville, AR (2017)

Effects	Berry weight (g)	Soluble solids (%)	pH	Titratable acidity (%)	Weight loss (%)	Leakage (%)	Decay (%)	Red drupelet reversion (%)	Firmness (N)	Total organic acids (g/100 g)	Total sugars (g/100 g)
Harvest time (H)											
7:00 AM	5.86 a[z]	8.64 a	3.47 a	0.68 b	6.23 a	20.78 a	33.27 a	4.06 a	4.66 b	0.92 a	4.18 a
12:00 PM	5.73 a	8.48 a	3.38 b	0.77 a	6.48 a	19.22 a	37.00 a	3.45 b	5.48 a	0.80 a	3.59 a
P value	*0.3094*	*0.1984*	*0.0019*	*0.0030*	*0.2329*	*0.6245*	*0.2387*	*0.0310*	*<0.0001*	*0.3133*	*0.3030*
Storage day (D)											
0 days	6.09 a	8.80 a	3.08 c	0.93 a	0.00 c	0.20 c	0.00 c	0.47 b	6.28 a	0.87 a	3.76 a
7 days	5.74 ab	8.61 ab	3.32 b	0.72 b	6.08 b	19.60 b	35.37 b	5.49 a	5.04 b	0.99 a	4.73 a
14 days	5.55 b	8.27 b	3.88 a	0.54 c	12.99 a	40.20 a	70.00 a	5.29 a	3.90 c	0.72 a	3.16 a
P value	*0.0048*	*0.0028*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	0.2120	0.8025
Genotype (G)											
A-2428	5.76 de	9.13 bc	3.80 a	0.62 c	7.16 b	19.57 abc	41.07 a	3.27 bc	4.15 d	0.79 a	4.35 a
A-2444	6.66 bc	10.60 a	3.61 ab	0.72 bc	8.82 a	22.62 abc	41.31 a	4.97 b	4.49 cd	1.26 a	6.61 a
A-2453	3.86 g	9.71 b	3.47 b	0.61 c	6.82 bc	9.61 bc	34.82 a	2.43 c	7.17 a	0.60 a	4.25 a
A-2526	4.72 fg	8.70 cd	3.15 c	0.86 ab	4.94 e	26.72 abc	32.52 a	2.71 c	4.42 cd	0.81 a	3.12 a
APF-268	7.26 ab	7.47 e	3.16 c	0.73 bc	4.97 e	11.90 bc	26.42 a	3.07 c	5.47 bc	0.80 a	3.29 a
Natchez	8.12 a	7.38 e	3.48 b	0.67 bc	6.50 bcd	35.55 a	41.09 a	8.06 a	4.60 cd	0.91 a	4.05 a
Osage	4.24 g	8.19 de	3.59 b	0.69 bc	7.18 b	6.60 c	31.25 a	3.39 bc	4.82 cd	0.85 a	3.37 a
Ouachita	5.26 ef	8.00 de	3.06 c	0.95 a	5.48 cde	30.15 ab	32.57 a	2.78 c	4.22 d	1.08 a	3.32 a
Prime-Ark® Traveler	6.29 cd	7.85 e	3.52 b	0.69 bc	5.31 de	17.28 abc	34.80 a	3.08 c	6.33 ab	0.66 a	2.60 a
P value	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*0.0006*	*0.2167*	*<0.0001*	*<0.0001*	*0.3143*	*0.0816*
D x G (P value)	*0.0027*	*0.0713*	*<0.0001*	*0.0860*	*<0.0001*	*0.0055*	*0.1497*	*<0.0001*	*0.3727*	*0.9468*	*0.7317*
H x G (P value)	*0.0080*	*0.0033*	*0.2750*	*0.6259*	*0.0088*	*0.6042*	*0.4974*	*0.0015*	*<0.0001*	*0.3614*	*0.3167*
H x D (P value)	*0.5160*	*0.5418*	*0.5128*	*0.3762*	*0.4648*	*0.9608*	*0.6313*	*0.0324*	*0.6062*	*0.7977*	*0.6524*
H x D x G (P value)	*0.4148*	*0.0096*	*0.0753*	*0.5000*	*0.2537*	*0.9857*	*0.3999*	*0.0260*	*0.2337*	*0.4598*	*0.2328*

[z]Genotypes were evaluated in duplicate (n=2). Means with different letter(s) for each attribute within main effects are significantly different.

Figures

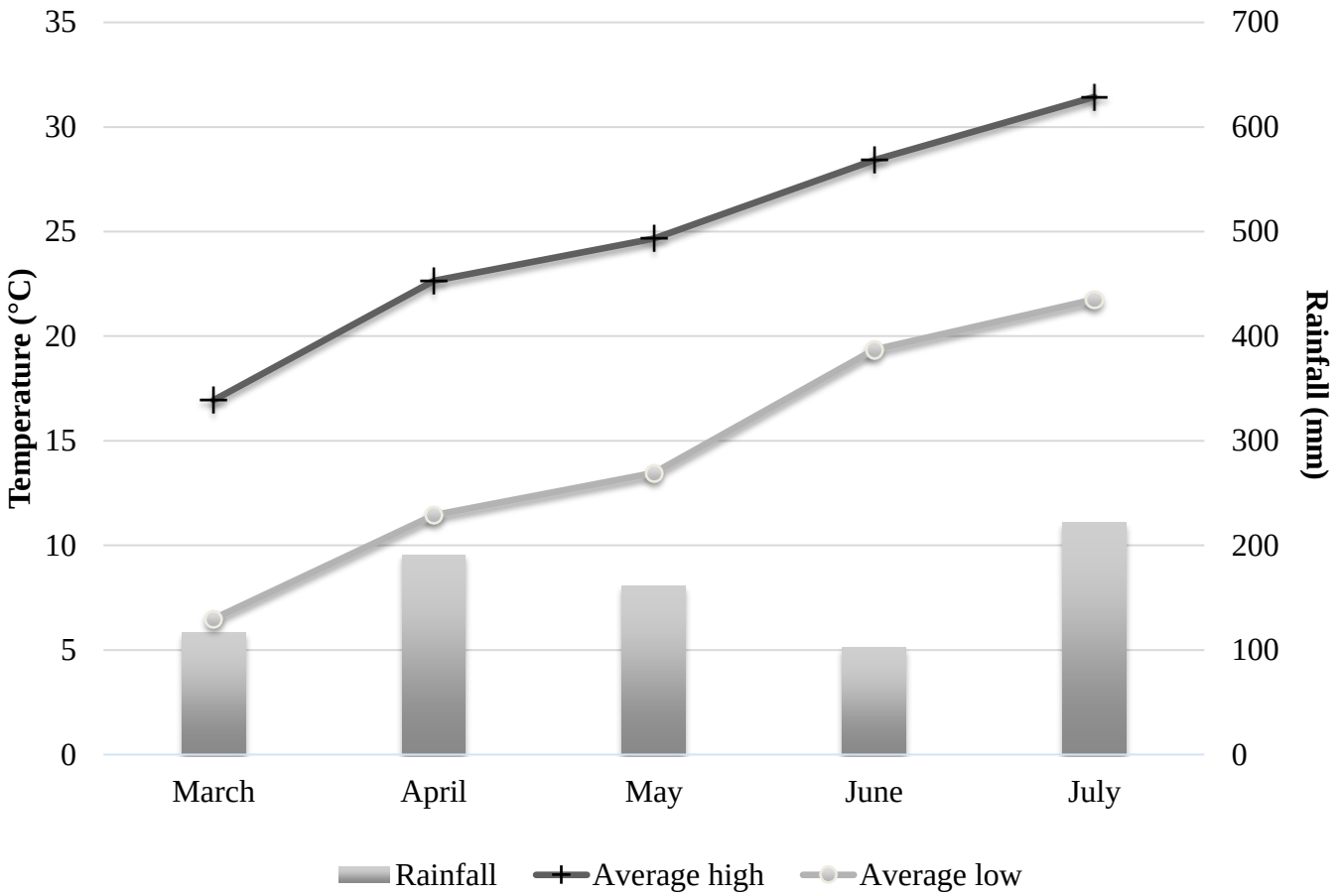

Fig. 1. Temperature and rain conditions at the University of Arkansas Fruit Research Station, Clarksville, AR (2017)

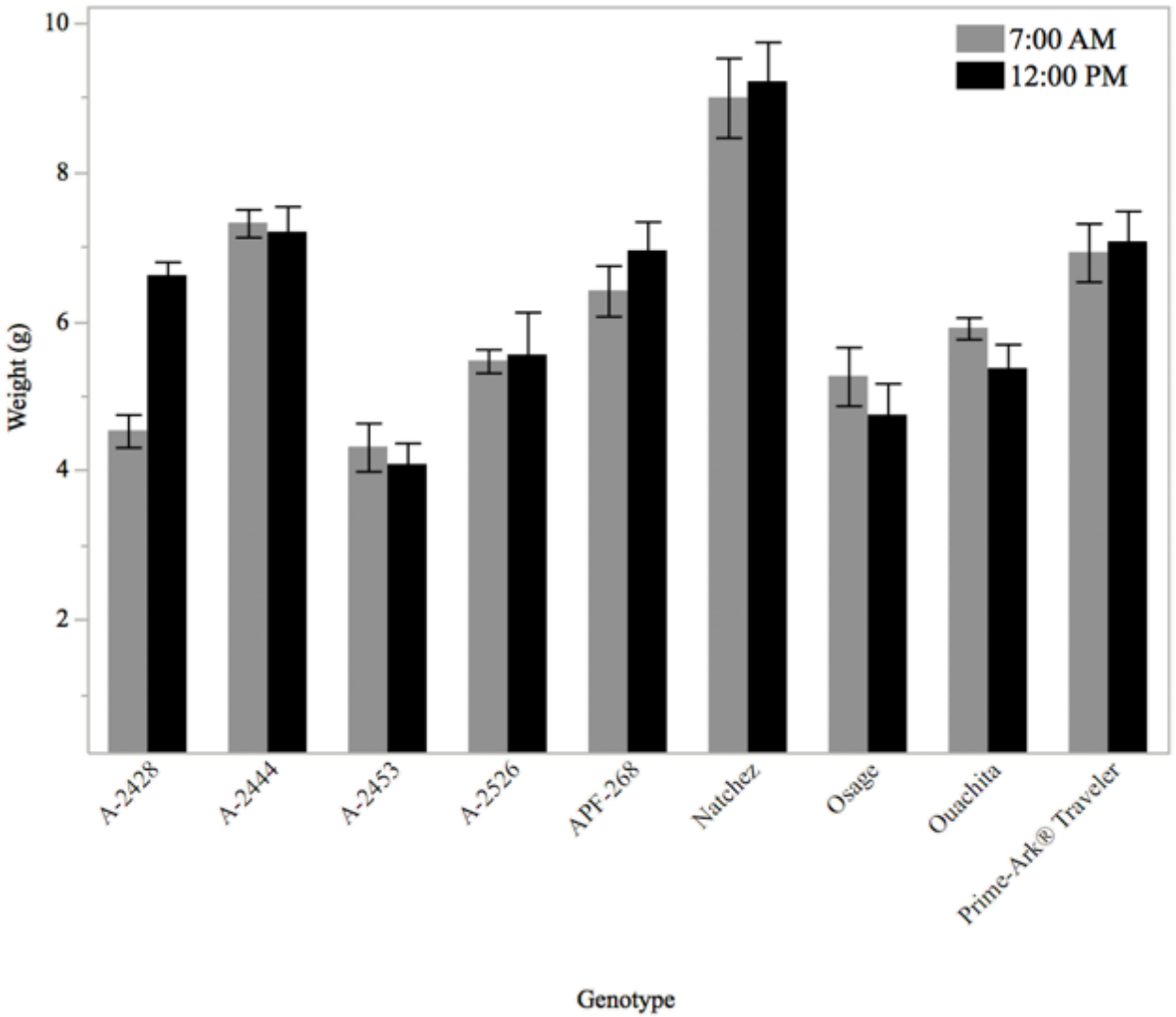

Fig. 2. Effect of harvest time and genotype on initial berry weight for fresh-market blackberry genotypes harvested at 7:00 $_{AM}$ and 12:00 $_{PM}$, Clarksville, AR (2017). Each standard error bar is constructed using 1 standard error from the mean.

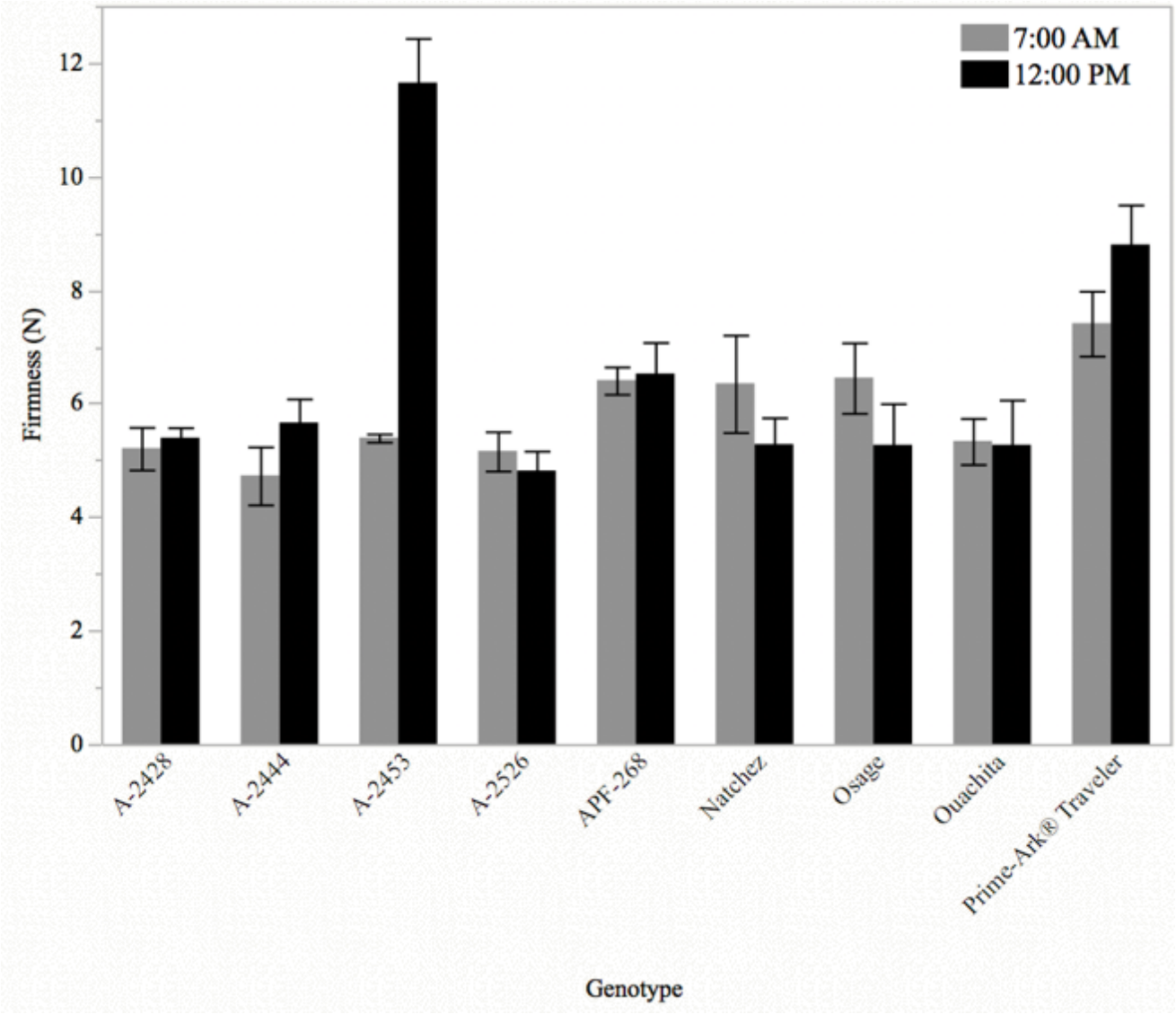

Fig. 3. Effect of harvest time and genotype on initial firmness for fresh-market blackberry genotypes harvested at 7:00 $_{AM}$ and 12:00 $_{PM}$, Clarksville, AR (2017). Each standard error bar is constructed using 1 standard error from the mean.

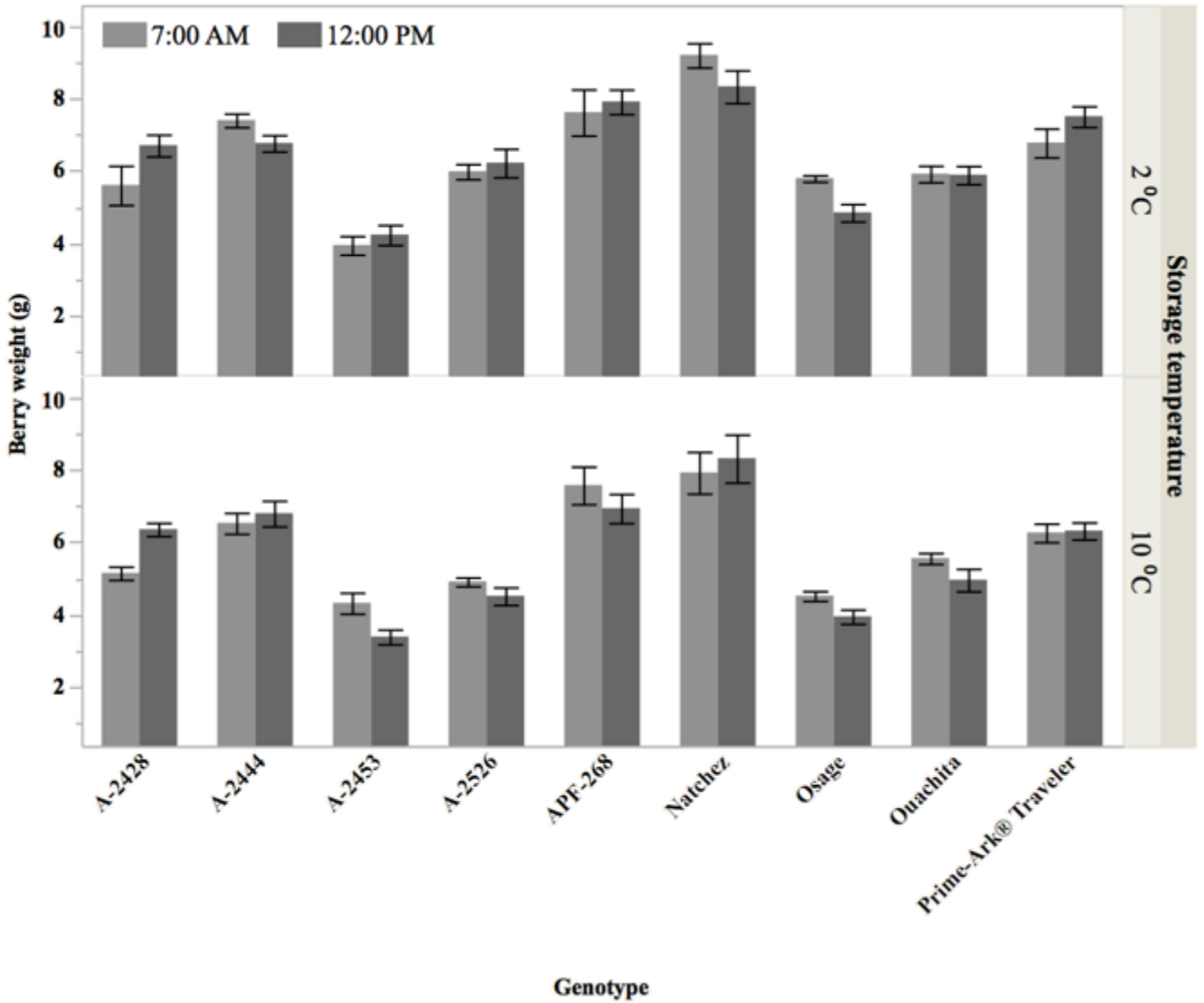

Fig. 4. Effects of harvest time (7:00 AM and 12:00 PM) and genotype on berry weight for fresh-market blackberry genotypes during postharvest storage at 2 °C and 10 °C, Clarksville, AR (2017). Each standard error bar is constructed using 1 standard error from the mean.

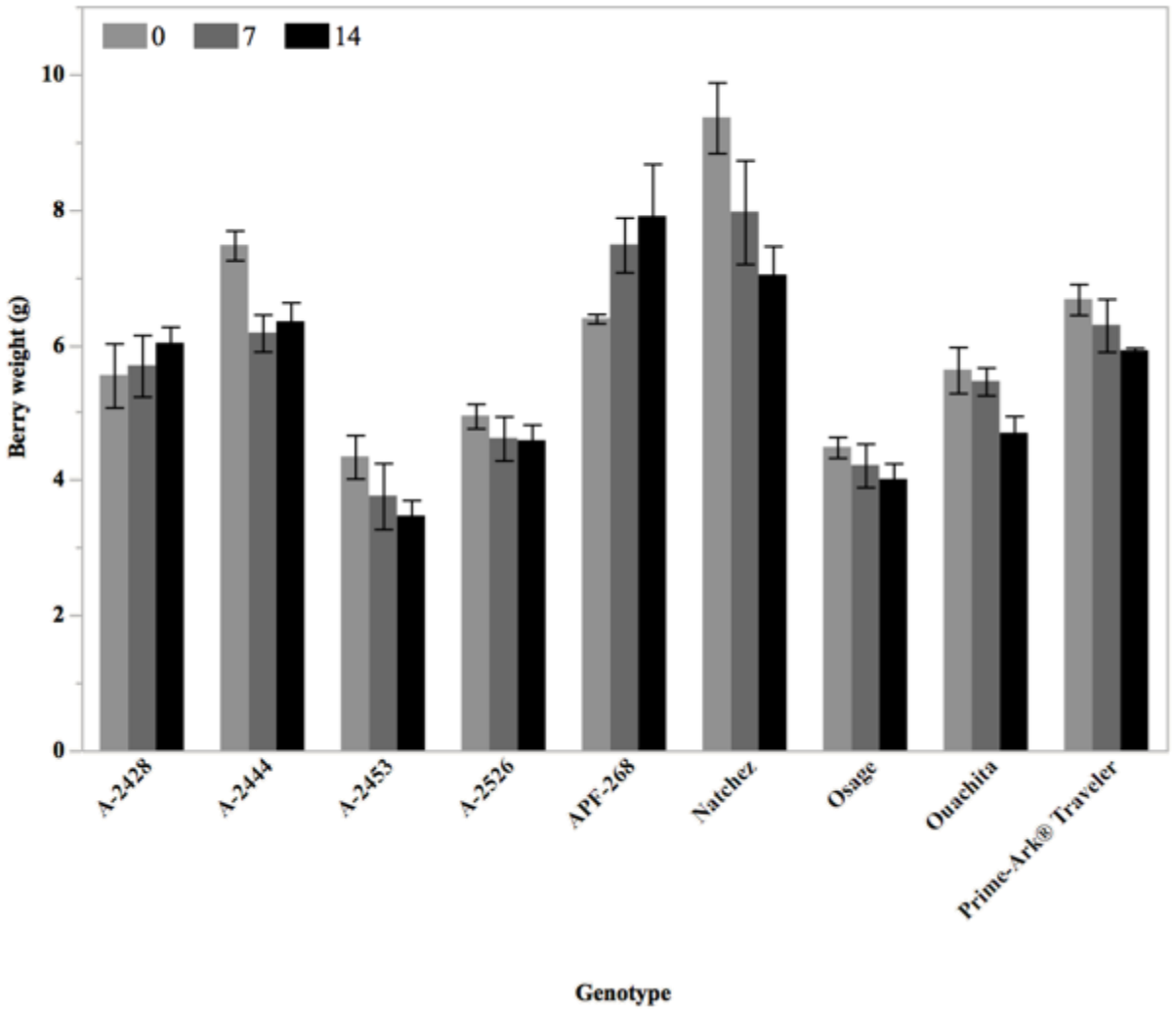

Fig. 5. Effects of storage day (0, 7, and 14 d) and genotype on berry weight for fresh-market blackberry genotypes during postharvest storage at 10 ˚C, Clarksville, AR (2017). Each standard error bar is constructed using 1 standard error from the mean.

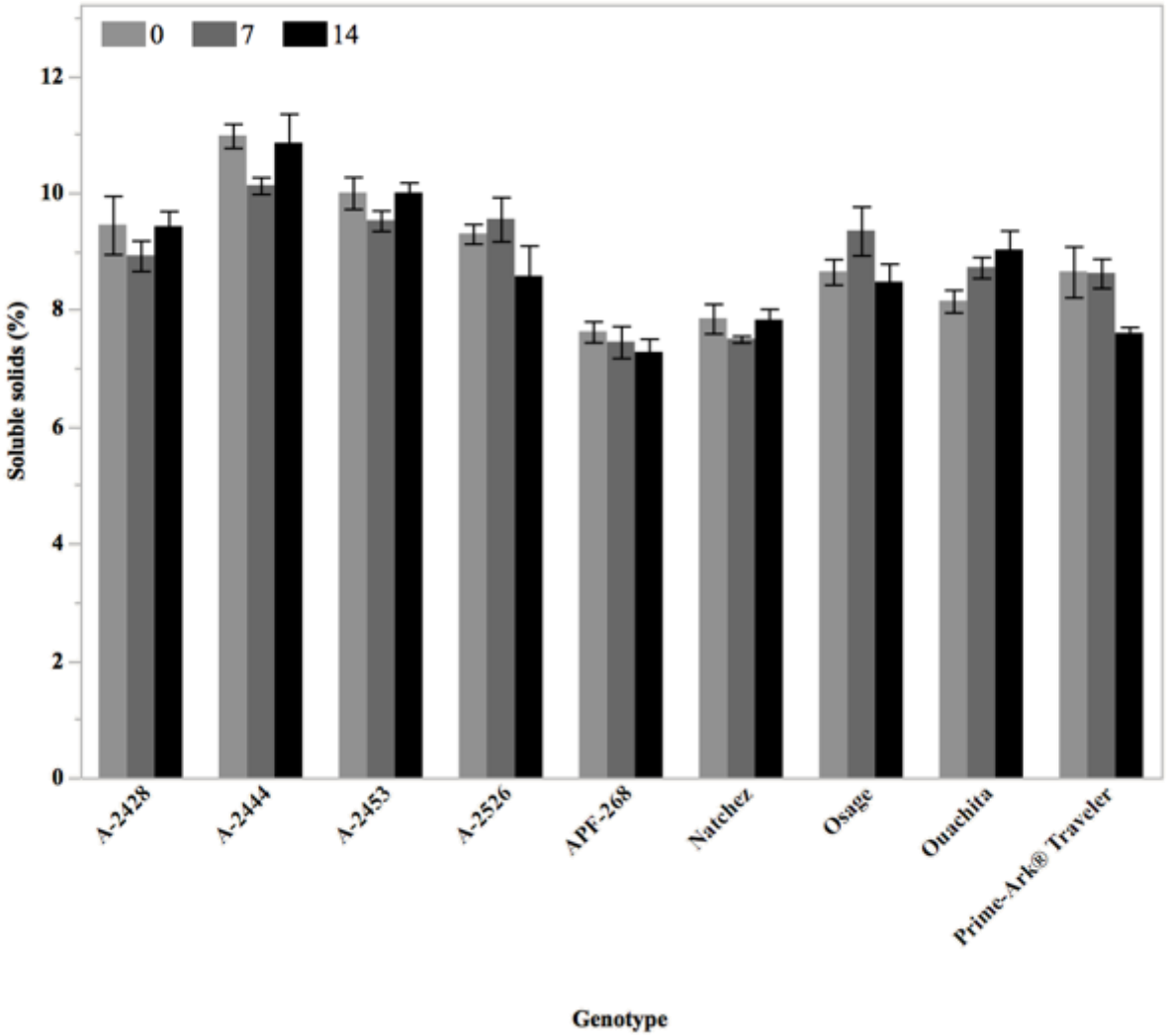

Fig. 6. Effects of storage day (0, 7, and 14 d) and genotype on soluble solids for fresh-market blackberry genotypes during postharvest storage at 2 ˚C, Clarksville, AR (2017). Each standard error bar is constructed using 1 standard error from the mean.

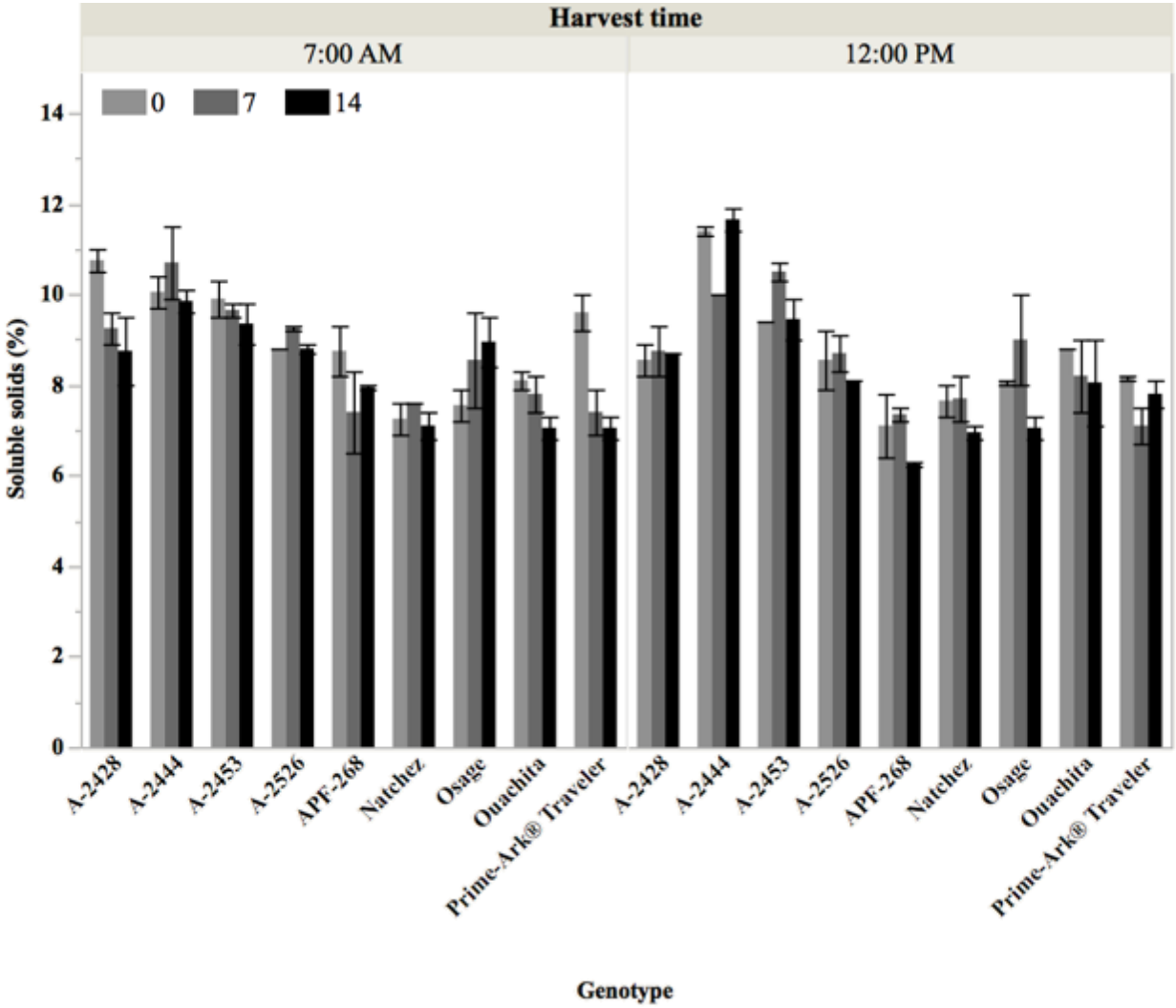

Fig. 7. Effects of harvest time (7:00 AM and 12:00 PM), storage day (0, 7, and 14 d), and genotype on soluble solids for fresh-market blackberry genotypes during postharvest storage at 10 °C, Clarksville, AR (2017). Each standard error bar is constructed using 1 standard error from the mean.

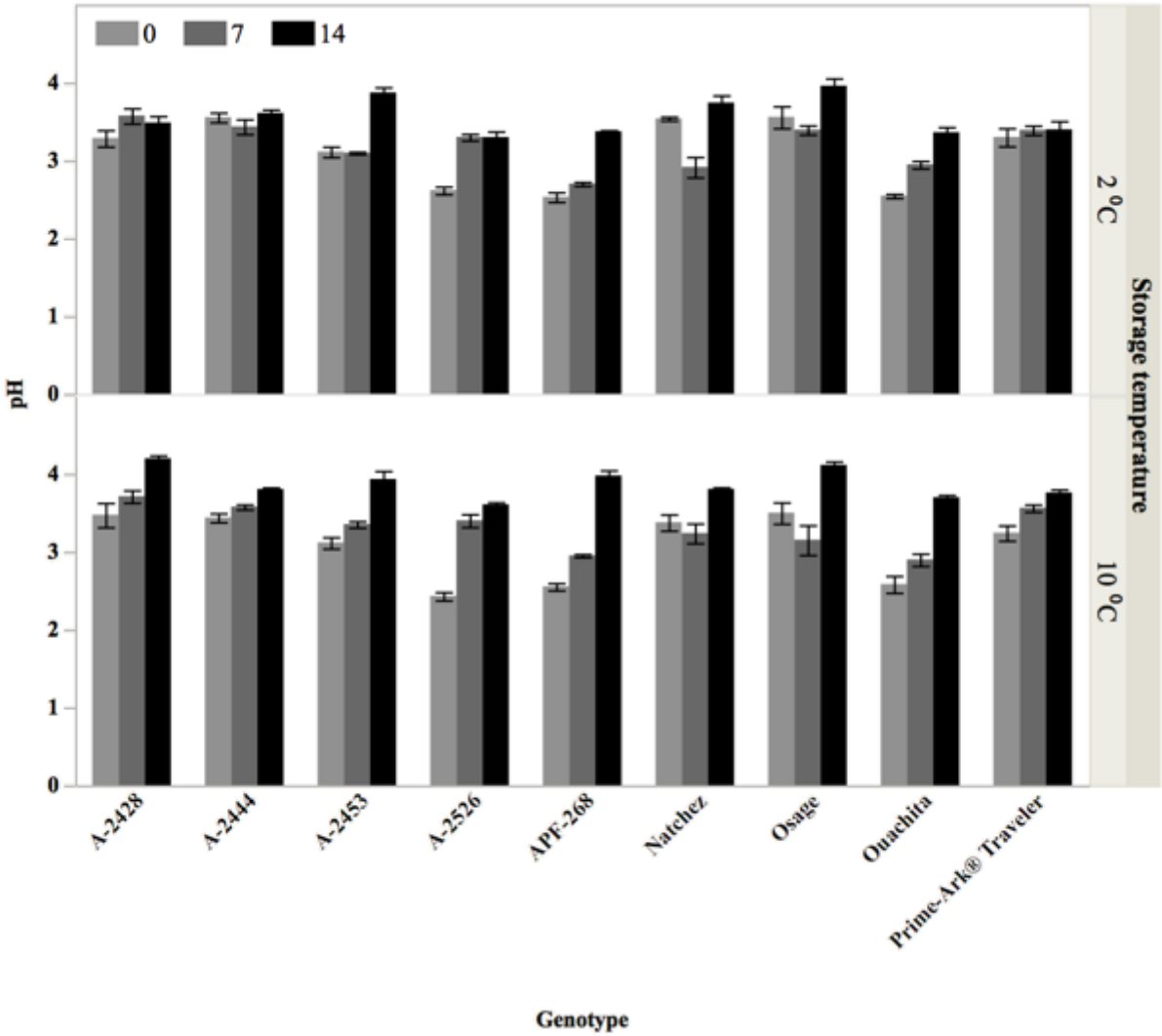

Fig. 8. Effects of storage day (0, 7, and 14 d) and genotype on pH for fresh-market blackberry genotypes during postharvest storage at 2 ˚C and 10 ˚C, Clarksville, AR (2017). Each standard error bar is constructed using 1 standard error from the mean.

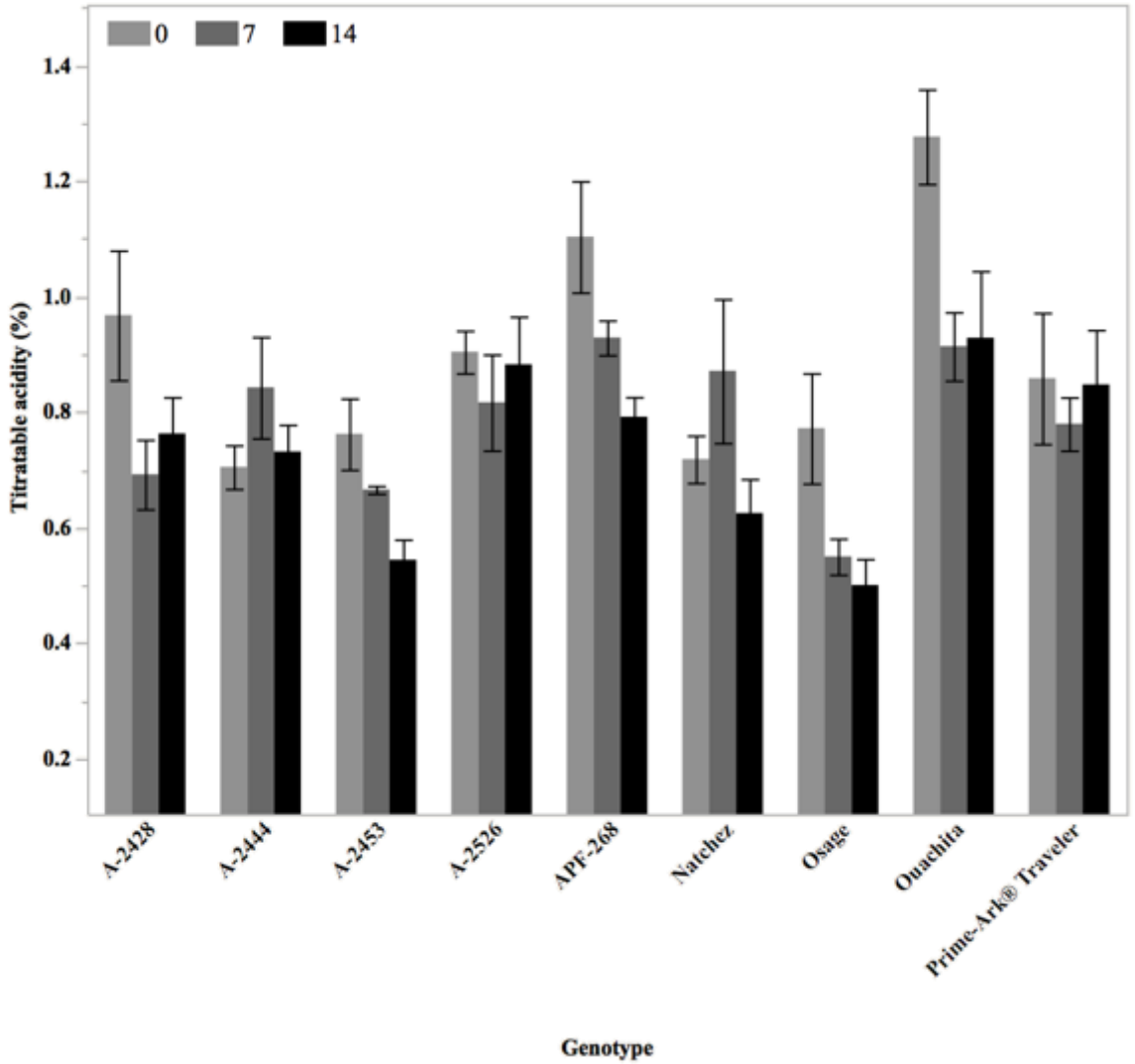

Fig. 9. Effects of storage day (0, 7, and 14 d) and genotype on titratable acidity for fresh-market blackberry genotypes during postharvest storage at 2 ˚C, Clarksville, AR (2017). Each standard error bar is constructed using 1 standard error from the mean.

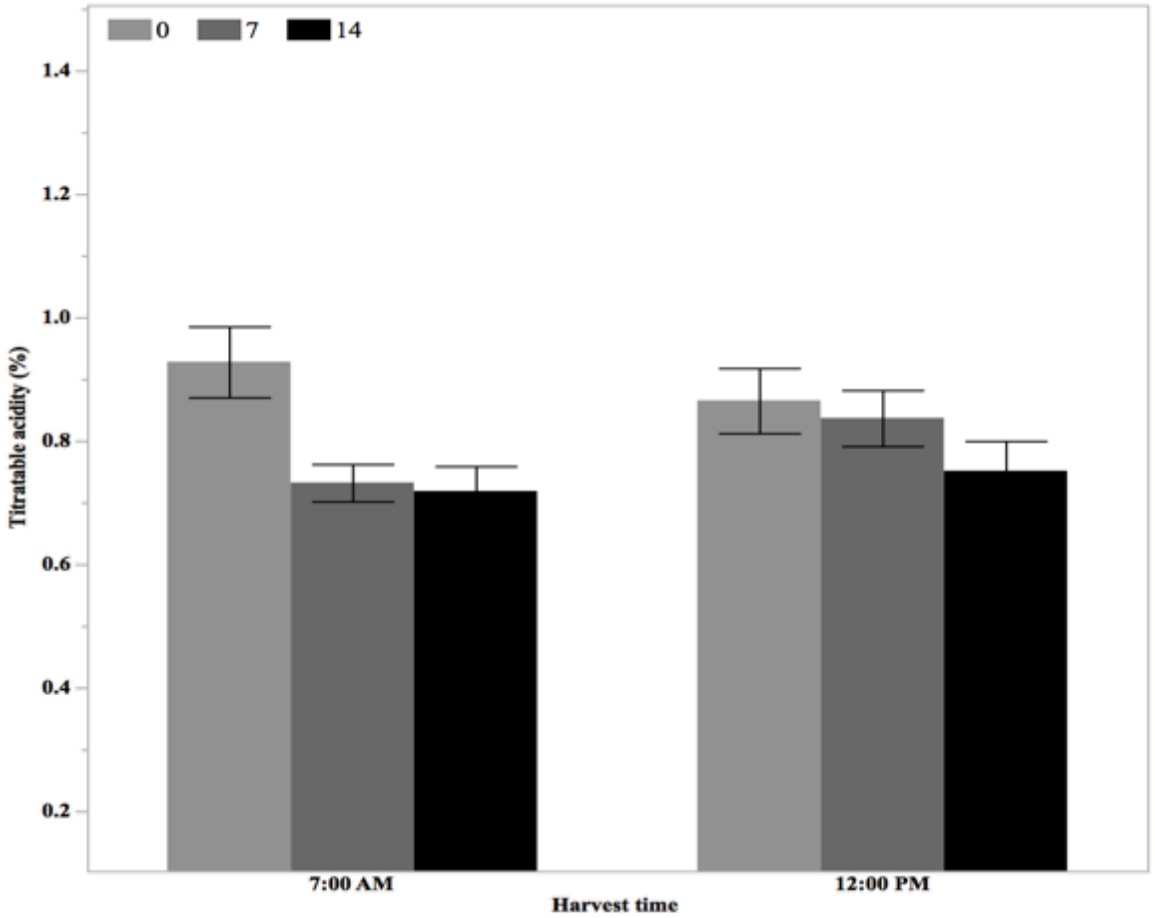

Fig. 10. Effects of harvest time (7:00 $_{AM}$ and 12:00 $_{PM}$) and storage day (0, 7, and 14 d) on titratable acidity for fresh-market blackberry genotypes during postharvest storage at 2 $^{\circ}$C, Clarksville, AR (2017). Each standard error bar is constructed using 1 standard error from the mean.

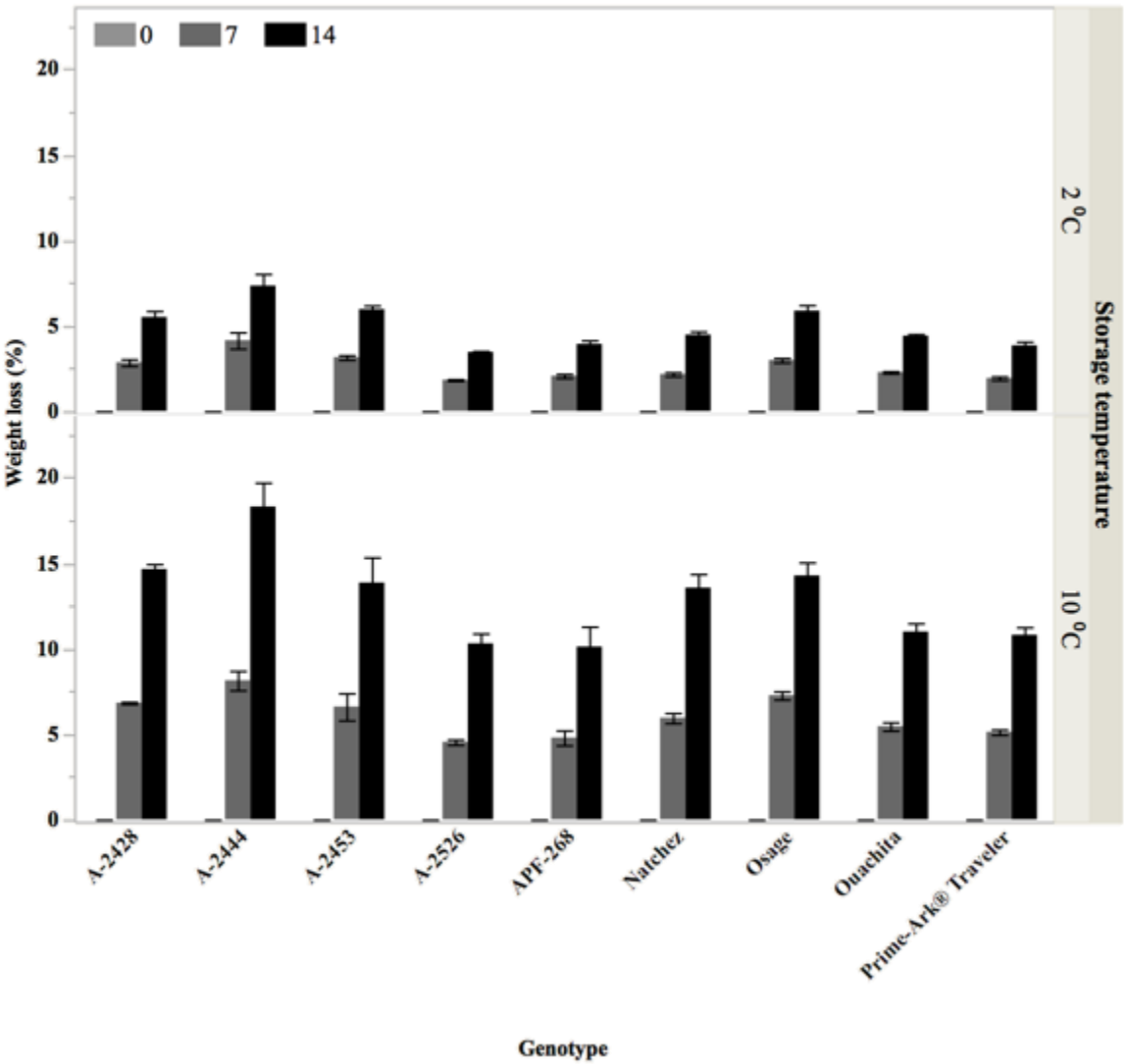

Fig. 11. Effects of storage day (0, 7, and 14 d) and genotype on weight loss for fresh-market blackberry genotypes during postharvest storage at 2 ˚C and 10 ˚C, Clarksville, AR (2017). Each standard error bar is constructed using 1 standard error from the mean.

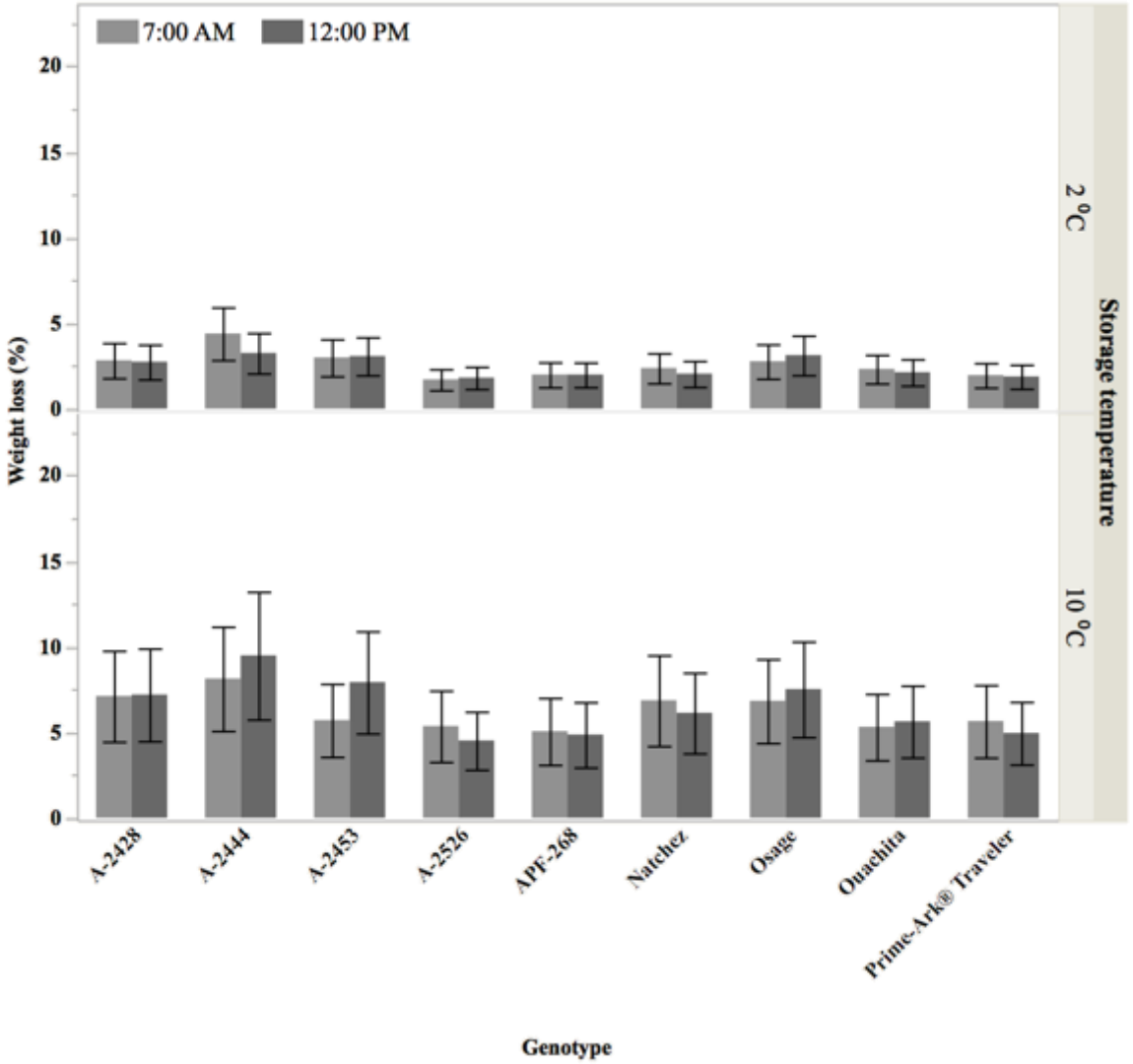

Fig. 12. Effects of harvest time (7:00 $_{AM}$ and 12:00 $_{PM}$) and genotype on weight loss for fresh-market blackberry genotypes during postharvest storage at 2 °C and 10 °C, Clarksville, AR (2017). Each standard error bar is constructed using 1 standard error from the mean.

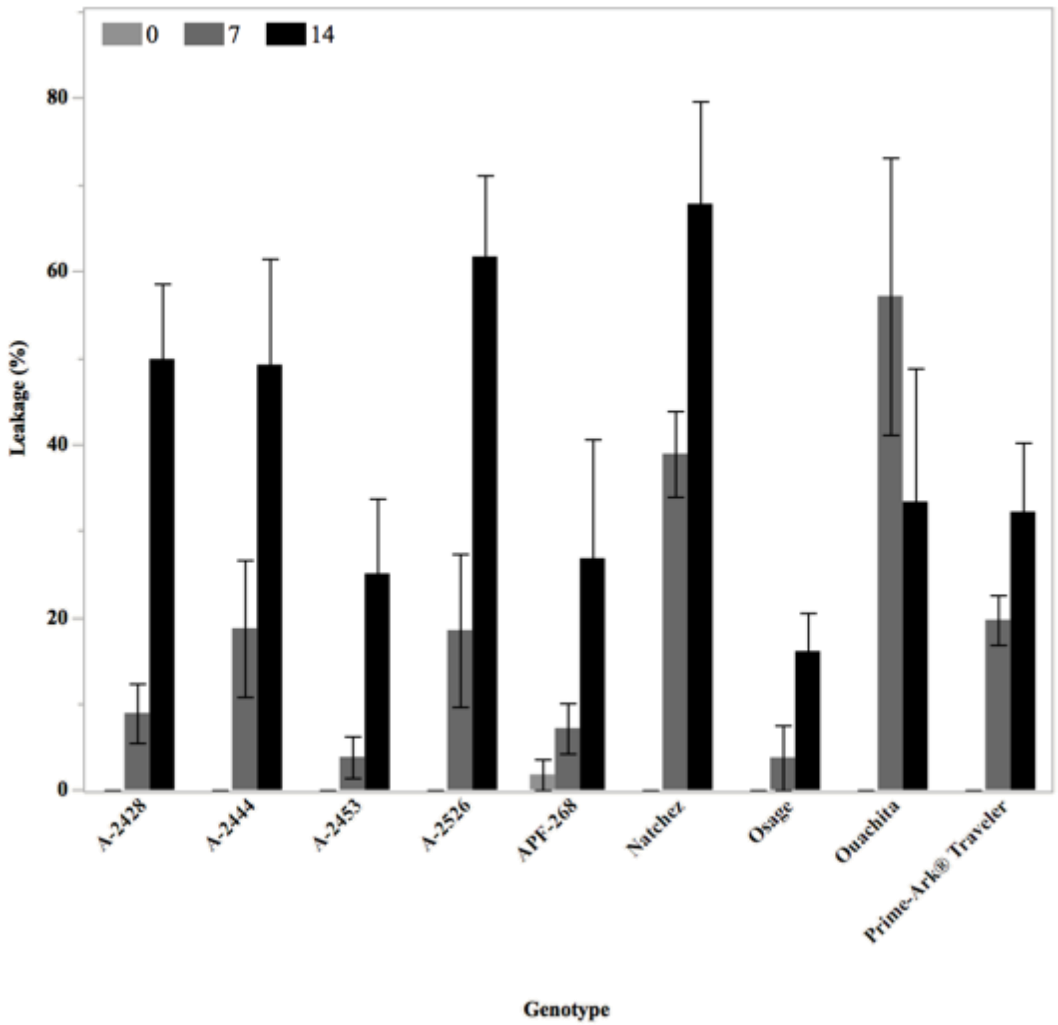

Fig. 13. Effects of storage day (0, 7, and 14 d) and genotype on leakage for fresh-market blackberry genotypes during postharvest storage at 10 ˚C, Clarksville, AR (2017). Each standard error bar is constructed using 1 standard error from the mean.

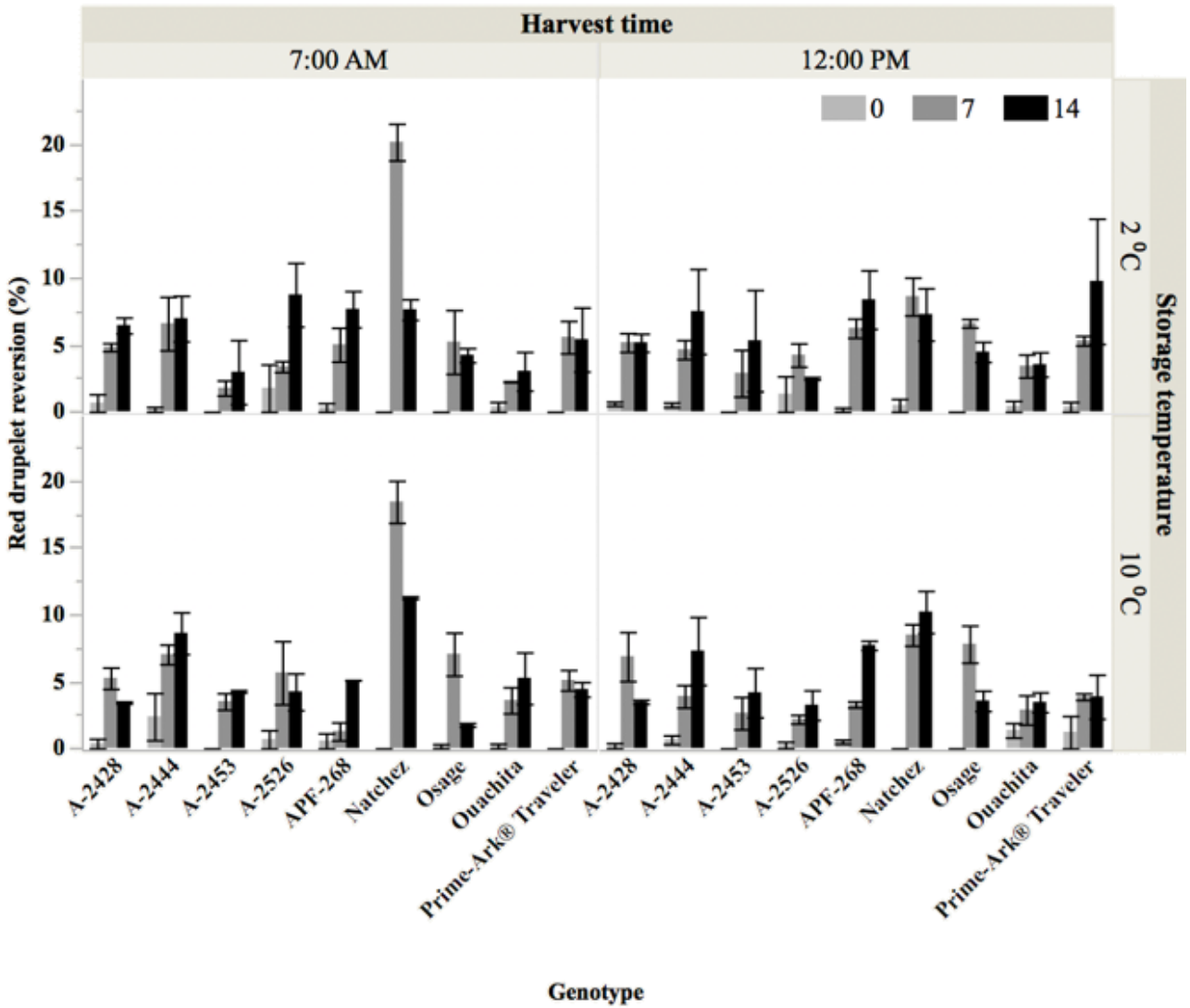

Fig. 14. Effect of postharvest storage (0, 7, and 14 d), harvest time (7:00 AM and 12:00 PM) and blackberry genotype on red drupelet reversion stored at 2 °C and 10 °C, Clarksville, AR (2017). Each standard error bar is constructed using 1 standard error from the mean.

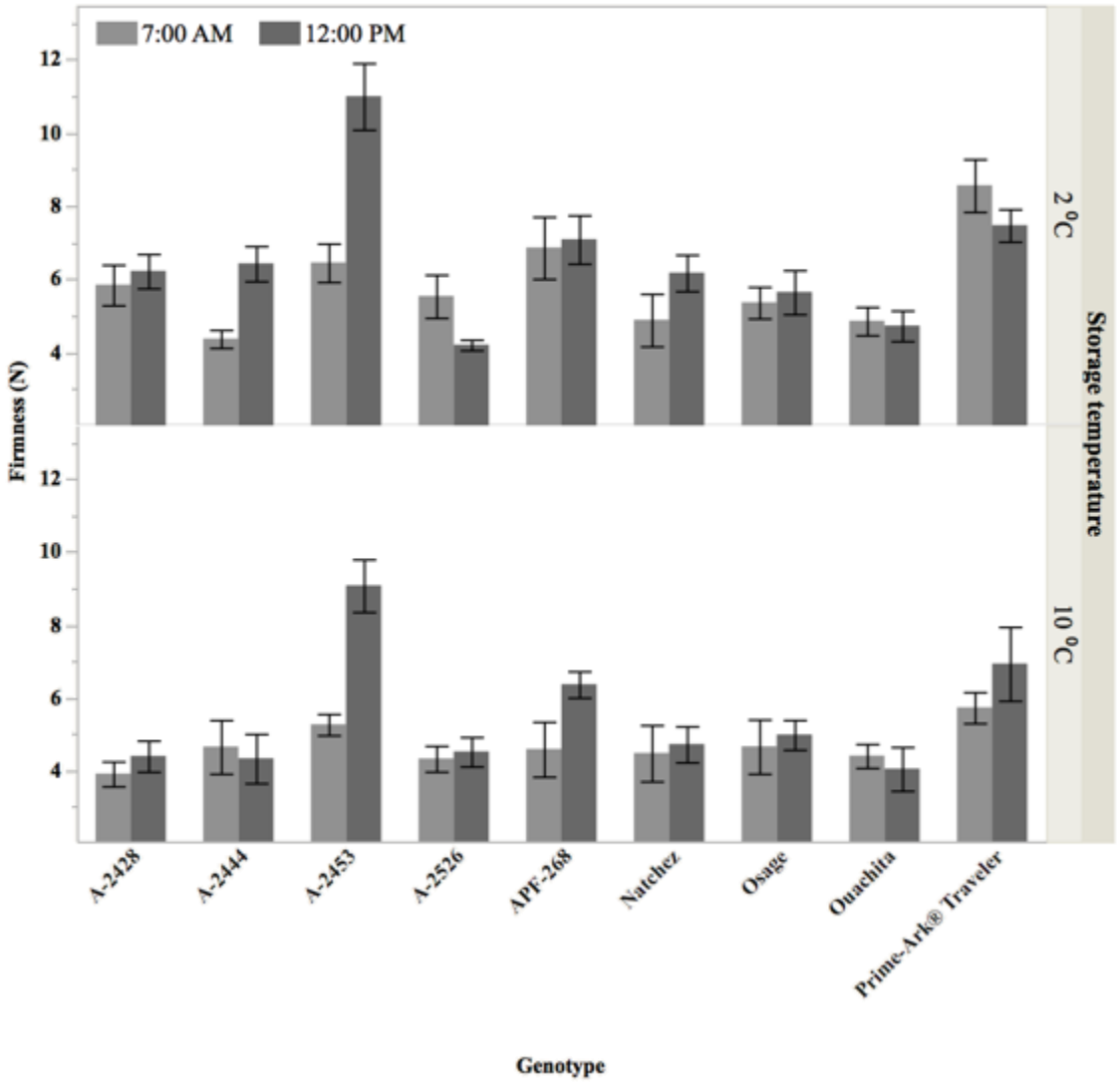

Fig. 15. Effects of harvest time (7:00 $_{AM}$ and 12:00 $_{PM}$) and genotype on firmness for fresh-market blackberry genotypes during postharvest storage at 2 ˚C and 10 ˚C, Clarksville, AR (2017). Each standard error bar is constructed using 1 standard error from the mean.

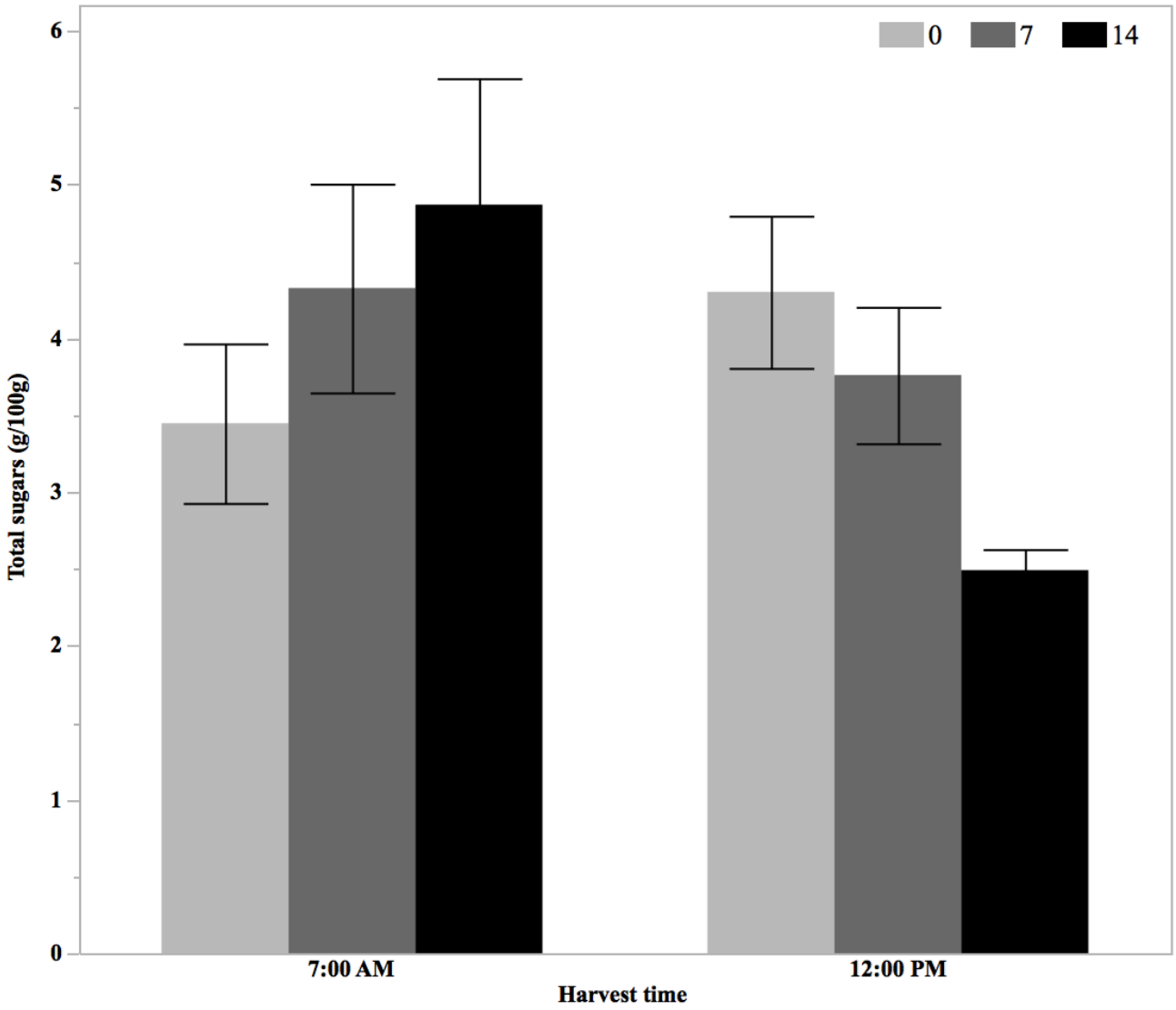

Fig. 16. Effect of storage day (0, 7, and 14) and harvest time (7:00 AM and 12:00 PM) on total sugars during postharvest storage at 2 ˚C, Clarksville, AR (2017). Each standard error bar is constructed using 1 standard error from the mean.

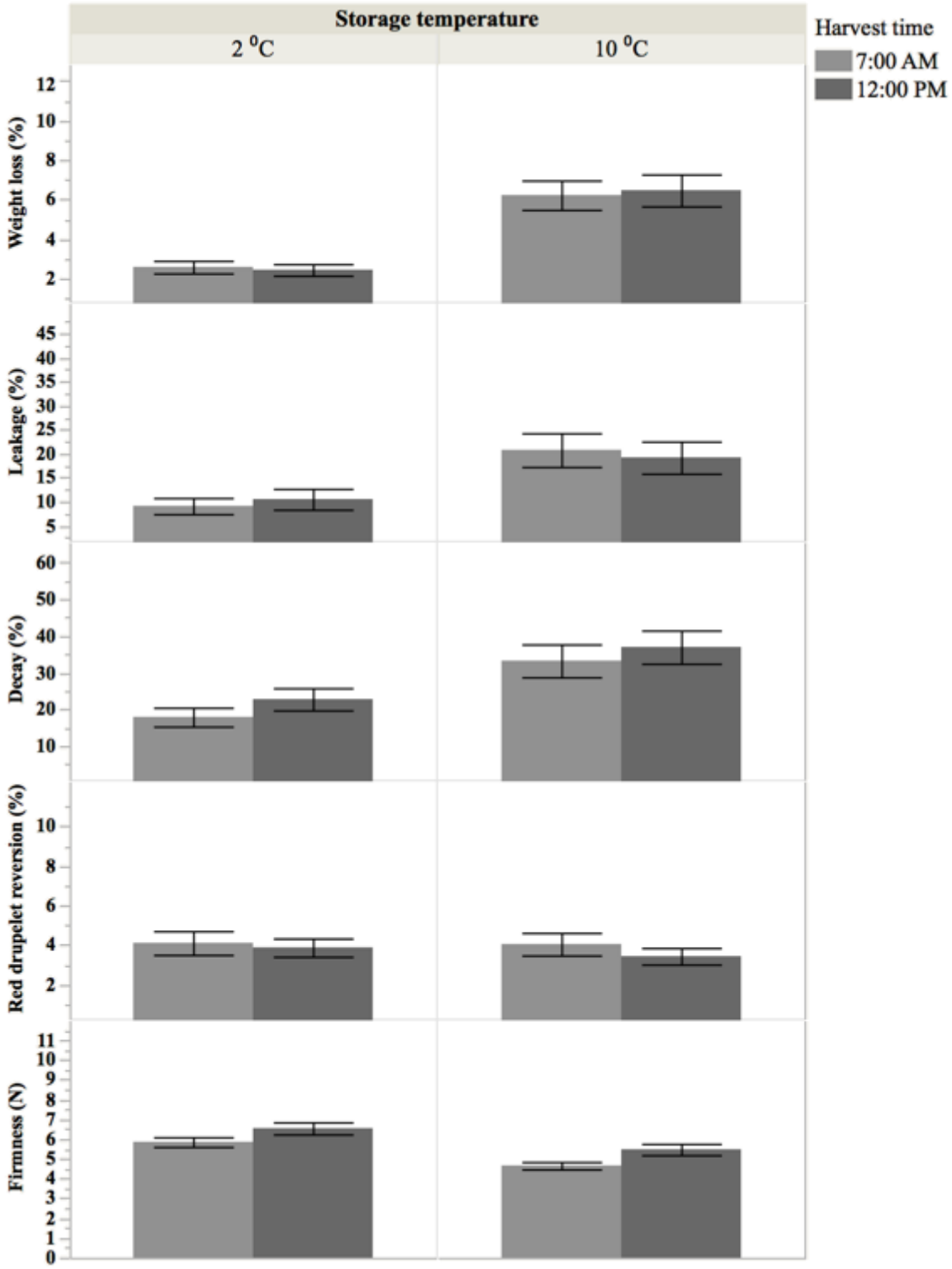

Fig. 17. Marketability attributes of fresh-market blackberries harvested at 7:00 $_{AM}$ and 12:00 $_{PM}$ after 14 d storage at 2 ˚C and 10 ˚C, Clarksville, AR (2017). Each standard error bar is constructed using 1 standard error from the mean.

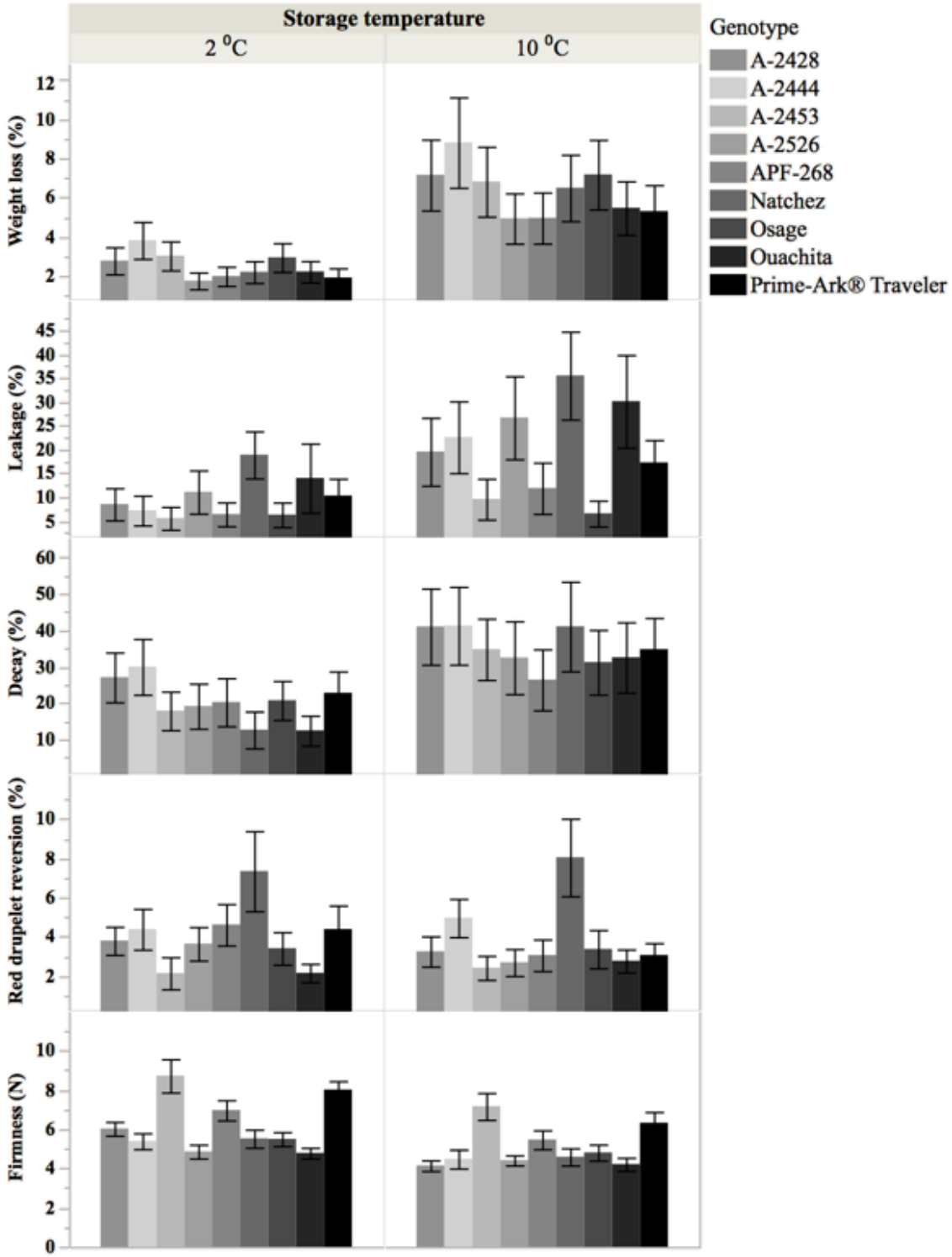

Fig. 18. Marketability attributes of fresh-market blackberry genotypes after 14 d storage at 2 ˚C and 10 ˚C, Clarksville, AR (2017). Each standard error bar is constructed using 1 standard.

Chapter II

Physiochemical, Marketability, and Sensory Analysis of Arkansas-Grown Peaches and Nectarines for Fresh Market

Abstract

Understanding how consumer perception is related to physiochemical attributes and how storage affects fruit quality contribute to identification of harvest, ripeness, and marketability parameters for peaches and nectarines [*Prunus persica* (L.) Batsch]. Six peach and nectarine cultivars ('Amoore Sweet', 'Bowden', 'Effie', 'Loring', 'Souvenirs', and 'White River') and three advanced breeding selections (A-827, A-850, and A-865) were harvested at optimum ripeness from the University of Arkansas System Division of Agriculture Fruit Breeding Program in Clarksville, AR. The physiochemical and sensory attributes of the genotypes were evaluated at harvest (day 0), and physiochemical and marketability attributes were evaluated during postharvest storage (day 0, 7, 14, and 21). The range of physiochemical attributes of the genotypes at harvest were a fruit weight of 134.4-330.2 g, soluble solids of 7.5-14.7%, pH of 3.3-4.8, titratable acidity of 0.2-1.1%, and firmness of 7.8-35.8 N. Overall, A-865 had the lowest pH (3.3) and the highest firmness (35.8 N), soluble solids (14.7%), and titratable acidity (1.1%). A-850 had the lowest titratable acidity (0.2%), while 'Loring' had the lowest soluble solids (7.5%). 'White River' had the largest fruit (330.20 g). A-850 (63.62) had the highest soluble solids/titratable acidity ratio where 'Bowden' (12.07) had the lowest. A trained descriptive sensory panel (n = 10) evaluated the fruit attributes for external appearance (n = 8), aroma (n = 4), internal appearance (n = 6), basic tastes (n = 3), aromatics (n = 5), feeling factors (n = 2), and texture (n = 6). Of all of the physiochemical attributes, texture had the most significant correlations with the descriptive sensory attributes. Additionally, significant correlations between total anthocyanins with amount of blemishes/deformities (r = 0.70), and flesh hardness (r = -

0.84) were found, as well as correlations between total flavonols and astringent feeling factor (r = 0.83). During storage, weight loss was positively correlated to soluble solids at 21 days storage (r = 0.66). Chroma of the fruit flesh was negatively correlated with bruising/pitting (r = -0.59) during storage. Overall, ‘Amoore Sweet’ performed well during storage for 21 days at 2 °C with moderate weight loss, low decay, low bruising/pitting, and high firmness retention. The nine peach and nectarine genotypes had good marketability and retention of compositional attributes at 21 days storage indicating good potential storage for extended fresh-market sales.

Introduction

The peach (*Prunus persica* L. Batsch) is a juicy temperate tree fruit dated back to 8000 BP, with the oldest archaeological peach stones found in China (Zheng et al., 2014). Cultivation of indigenous peach stones were first discovered in the Neolithic village of Hemudu (China) in 1973. The peach was regarded as a symbol for long life and a family's prosperity and throughout time was cultivated in China between 23-50°N Latitude (Layne and Bassi, 2008; Zheng et al., 2014). In the 18th century, peaches were introduced to the United States by Spanish missionaries (Crisosto and Kader, 2000). They are typically grown in hardiness zones 5-8 (USDA, 2018).

Peaches and nectarines are almost identical genetically, however, nectarines lack pubescence, or a fuzzy exterior, common in peaches due to variation at a single genetic locus (Layne and Bassi, 2008). Peaches and nectarines are both climacteric fruit, as they continue to ripen after harvest. Peaches and nectarines can have different flesh types, or mesocarp, such as melting, slow melting, and non-melting. Melting flesh is a dominant trait in peaches and nectarines caused by softening of the fruit during the last stage of ripening. This softening is related to the presence of endopolyglacturonase, an enzyme responsible for cleaving the pectins from the cell wall. Non-melting flesh peaches lack the presence of this enzyme, resulting in firmer, rubbery flesh during ripening (Karakurt et al., 2000; Tanou et al., 2017). Recent findings have also indicated the presence of a third flesh type. Slow-melting fruit resemble a non-melting flesh fruit at ripening with similar firmness and crispness, but during full ripening, the fruit melts at slow speed and shows expression for the presence of endopolyglacturonase, which is present in melting-flesh peaches (Ghiani et al., 2011).

In addition to flesh types, the peach can be defined by how the flesh is attached to the pit or endocarp. Categorized as either freestone or clingstone, the trait is identified by either a

dominant or recessive freestone locus (Gu et al., 2016). With varying degrees of intensity, cultivars can also be defined as semi-clingstone or semi-freestone, a trait particularly found in earlier-ripening cultivars (Layne and Bassi, 2008). Finally, physical attributes of the fruit differ such as the base color of the flesh, or mesocarp, the acidity of the flesh, and the shape. The most common flesh colors are white and yellow, and the exterior of the fruit can have a blush (red hue) which sometimes continues into the flesh close to the pit or skin. The most common peach shape in the United States is round (or oblong shaped) although flat-shaped peaches are also found.

California is the largest U.S. producer of peaches and nectarines, with nearly 508,023 metric tons produced (Arkansas Fruit Production Report, 2015). In 2003, Arkansas was ranked 13th in peach production with most production aimed at the fresh market (Johnson et al., 2003). Most recent statistics indicate that peach production in Arkansas was about 820 metric tons in 2014 (Arkansas Fruit Production Report, 2015). Peach production in Arkansas has historic significance and began after the Civil War as a means to diversify crop production. Commercial plantings of processing peaches began in the late 19th century due to the invention of the refrigerated railway transport (Zeller et al., 2005). When the University of Arkansas Peach Breeding Program (Fruit Research Station, Clarksville, AR) began in the mid-1960s, the initial focus was on the development of canning clingstone peaches to accommodate the needs of the baby food industry (J.R. Clark, Personal Communication). Eventually, the breeding program shifted focus in the 1990s towards fresh-market fruit enhancement due to a decline in the need for processing peaches in Arkansas (Sandefur, 2011). Since the start of the breeding program, 12 new peach and six new nectarine cultivars have been released. Selections criteria includes firm fruit with different flavors, levels of acidity, sweetness, as well as tree characteristics such as

time of ripening, disease resistance, and productivity. The program currently has many advanced peach and nectarine selections with melting and non-melting flesh, as well as white and yellow color, varying levels of blush, ranges of ripening dates, size, and both round and flat shapes.

Postharvest research on peach and nectarine genotypes (cultivars and advanced selections) specific to Arkansas is important in understanding the quality of locally available produce, as well as aiding in further fruit breeding efforts at the University of Arkansas. Factors such as climatic conditions, maturity at harvest, cultural practices, and postharvest handling procedures can influence the overall composition and quality of the fruit. A combination of pre-harvest environmental factors and genetic factors can strengthen postharvest quality (Kader, 2002). Attributes such as appearance, texture, and flavor are extremely important during postharvest storage so that the fruit has good quality when it reaches the consumer.

A wide variety of fruits can provide a balanced diet by aiding in the consumption of various nutrients, antioxidants, phenolics or bioactive compounds, and phytochemicals. Peaches have many health-promoting compounds (Liu, 2013; Andreotti et al., 2008). Phenolic compounds such as chlorogenic acid, cyanidin-3-glucoside, and rutin, commonly found in peaches and nectarines, were negatively correlated with the development of chronic diseases. Therefore, quantification of the phenolic compounds is important for understanding the overall quality of the fruit.

Finally, to gain a comprehensive understanding of fruit quality, utilization of sensory methods, such as descriptive sensory analysis, is important for complete comprehension of how physiochemical attributes, such as texture, are perceived when evaluated by a human subject (Colaric et al., 2005; Contador et al., 2017). Previous studies indicated attributes such as appearance, aroma, flavor, sweetness, sourness, and texture were common indicators of

consumer acceptability of peaches (Belisle et al., 2017). Descriptive sensory analysis provides a means of quantitatively scaling attributes of food; whereas, consumer sensory analysis demonstrates a degree of liking or preference from consumers. Descriptive sensory analysis was effective for identification of texture differences in both melting and non-melting flesh peaches, as well as for soluble solids/titratable acidity ratios (Brovelli et al., 1999; Crisosto and Crisosto, 2005).

Understanding the physiochemical and sensory attributes of Arkansas-grown peach and nectarine genotypes is important to demonstrate fresh-market potential. The purpose of this study was to evaluate how descriptive sensory attributes were related to harvest parameters (size, composition, and firmness) of commercially-ripe fruit and how the physiochemical and marketability attributes of Arkansas-grown peaches and nectarines were affected during postharvest storage.

Materials and Methods

Plants and culture

Nine peach and nectarine genotypes (‘Amoore Sweet’, ‘Bowden’, ‘Loring’, ‘Souvenirs’, ‘White River’, A-805CN, A-827, A-850, and A-865) were evaluated. The fruit was harvested from the University of Arkansas Fruit Research Station, Clarksville AR [west-central Arkansas, lat. 35◦31'58"N and long. 93◦24'12"W; USDA hardiness zone 7a; soil type Linker fine sandy loam (Typic Hapludult)]. The trees were either open-center trained and spaced 5.5 m between trees and rows, or trained to a perpendicular-V system with trees spaced 1.9 m in rows spaced 5.5 m apart. All trees were dormant pruned and fertilized annually with either complete or nitrogen fertilizers and drip irrigated as needed. Pests were managed using a program typical for commercial orchards in this area. Fruit were thinned to a distance of 12 to 15 cm between fruit after shuck split but before pit hardening.

Harvest

The peaches and nectarines were hand harvested in the morning (between 7:00-10:00 $_{AM}$). The fruit was harvested on two harvest dates (27 June and 11 July, 2017) at optimal ripeness and were free of major blemishes, flaws, or damage. ‘Amoore Sweet’, ‘Effie’, Souvenirs’, and A-865 were harvested on 27 June, and ‘Loring’, ‘White River’, A-827, and A-850 were harvested on 11 July. There were no rain events within 24 h of either harvest. About 96 peaches and nectarines were harvested for each genotype and placed onto five boxes that contained corrugated pulp trays with individual wells for each fruit. The boxes of fruit were transported in an air-conditioned vehicle to the University of Arkansas, Department of Food Science, in Fayetteville, AR. The fruit was randomly placed into new pulp trays. The fruit was evaluated for descriptive

sensory attributes after harvest (day 0) and physiochemical and marketability attributes at day 0, 7, 14, and 21 at 2°C with 85-89% relative humidity.

Physiochemical analysis.

Fruit for physiochemical analysis was done in triplicate per genotype. Each replicate was an individual peach or nectarine. The physiochemical analysis included weight, color, firmness, and composition evaluated at 0, 7, 14, and 21 d at 2 °C, and nutraceutical analysis evaluated at day 0. After individual weight, color, and firmness, were evaluated, the fruit were cut in half and frozen at -10 °C for composition and nutraceuticals analysis. Half of each fruit was used for composition, and the other half was used for nutraceutical analysis.

Weight. Fruit and pit weight was measured on a digital scale (PA224 Analytic Balance, Ohaus Corporation, Parsippany, NJ) in triplicate. Fruit weight was the weight of a whole intact peach or nectarine. Pit weight was only evaluated at harvest (day 0) from the pit extracted from the fruit.

Color. The color of the fruit skin and flesh was analyzed using a Konica Minolta CR-400 Chroma Meter (Konica Minolta Inc, Ramsey, NJ). The L*, chroma, and hue angle were evaluated. Color analysis was done to determine Commission Internationale de l'Eclairage (CIE) Lab transmission values of L*=100, a*=0, and b*=0 (C.I.E. 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 were measured. Hue angle, calculated as arctan (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). Chroma, calculated as $((a^*)^2 + (b^*)^2)^{0.5}$, identified color by which

a sample appears to differ from gray of the same lightness and corresponds to intensity of the perceived color. Skin color was evaluated on three locations (90°, 180°, and 270° to the right of the suture). Immediately after cutting the fruit in half, the flesh was analyzed for color similarly in three locations.

Firmness. Firmness was measured using a Stable Micro Systems TA.XT.plus Texture Analyzer (Texture Technologies Corporation, Hamilton, MA). Prior to the firmness measurement, a section of the fruit skin was removed by slicing off a 5 mm section. The fruit was then placed on a flat surface. Using the 2-mm-diameter probe, at a rate of 2 mm/s with a trigger force of 0.02 N, firmness of the fruit flesh was evaluated at three locations per fruit (90˚, 180˚, and 270˚ to the right of the suture). Force to penetrate the fruit was measured in Newtons (N).

Composition. The fruit half for composition was frozen (-10 °C) then thawed for analysis of soluble solids, pH, titratable acidity, organic acids, and sugars. Each fruit half (skin and flesh) was macerated in a blender, then the juice was centrifuged at 5,000 rpm for 8 min and strained through cheese cloth. The pH and titratable acidity were measured using the Titrino plus 862 compact titrosampler (Metrohm AG, Herisan, Switzerland) with the electrode standardized to pH 4.00, 7.00, and 10.00 buffers. Titratable acidity was determined using ~6 g of juice diluted with 50 mL deionized, degassed water with a titration using 0.1 N sodium hydroxide to an endpoint of pH 8.2. Titratable acidity was expressed as percentage of malic acid. Soluble solids (expressed as percent) were measured using an Abbe Mark II refractometer (Bausch and Lomb, Scientific Instrument, Keene, NH). Organic acids and sugars of the fruit were determined using high performance liquid chromatography (HPLC). The remaining juice from compositional analysis was filtered through a 0.45 μm nylon filter (VWR International, Radnor, PA) and analyzed using

HPLC. Glucose, fructose, isocitric acid, and malic acid of the fruit was measured using previously established HPLC procedures (Segantini et al., 2018; 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 (Bio-Rad, Hercules, CA). A Bio-Rad Micro-Guard Cation-H refill cartridge (30 × 4.5 mm) was used for a guard column. 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 0.45 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 35 min. A Waters 410 differential refractometer to measure refractive index connected in series with a Waters 996 photodiode array detector monitored the eluting compounds. Isocitric and malic 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 and acids were expressed as g/100 g, and total sugars (glucose + fructose) and total organic acids (isocitric + malic) were expressed as g/100 g.

Nutraceuticals. Total anthocyanins, total phenolic acids (hydroxycinnamic acids), total carotenoids, and total flavonols were measured by HPLC and ultraviolet-visible (UV-Vis) spectroscopy following methods described by Cho et al. (2004; 2005), and Hager et al. (2008). The fruit was homogenized three times for 1 min in alternating washes of 80 ml of extraction

solution containing methanol/water/formic acid (60:37:3 v/v/v) and acetone/water/acetic (70:29.5:0.5 v/v/v) to the smallest particle size using a Euro Turrax T18 Tissuemizer. Homogenates were centrifuged for 5 min at 10,000 rpm and filtered. The samples were taken to a final volume of 250 mL with extraction solvent and stored at -70 °C until analysis. All samples were passed through 0.45 μm filters prior to HPLC analysis. Equivalents for the peach and nectarine nutraceuticals were determined from previous literature for the most common compounds for each class of phenolics (Brown et al., 2014; Ceccarelli et al., 2016; Gil et al., 2002). Total nutraceuticals were quantified as the sum (mg) of total anthocyanins, total flavonols, total phenolic acids, and total carotenoids per 100 g fresh fruit weight.

Total anthocyanins and total phenolic acids. Sample extracts (7.5 mL) were dried using a Speed Vac concentrator (ThermoSavant, Holbrook, NY) and re-suspended in 1 mL of 5% formic acid. The reconstituted samples were passed through 0.45-mm polytetrafluoroethylene (PTFE) syringe filters (Varian Inc, Palo Alto, CA) before HPLC analysis. The anthocyanin analysis by HPLC was performed based on previous methods (Cho et al., 2004; Hager et al., 2008). The anthocyanin peaks were quantified at 510 nm with results expressed as milligrams cyanidin-3-glucoside equivalents per 100 g fresh fruit weight. The phenolic acid peaks were quantified at 320 nm with results expressed as milligrams of chlorogenic acid equivalents per 100 g of fresh fruit weight.

Total carotenoids. Methods adapted from Biehler et al. (2010) and Gross (1991) were used for saponification and quantification of carotenoids. Sample extracts (50 mL) were saponified to reduce chlorophyll interference in samples. Samples were heated at 60 °C for 1 hr with 1 g of butylated hydroxytoluene (BHT) and 30 mL of 5% sodium hydroxide in methanol. The sample was extracted three times using water, ethanol, and hexane solvent. The hexane

fraction was evaporated using a rotary evaporator (Buchi, New Castle, DE) to dryness and brought up to a known volume with acetone. The reconstituted extract was sonicated for 2 min. Total carotenoids were quantified using a 8452A Diode Array Spectrophotometer (Hewlett Packard, Palo Alto, CA) at 452 nm using an extinction coefficient of 140663 L/mol with results expressed as micrograms beta-carotene equivalents per 100 g fresh fruit weight.

Total flavonols. Sample extracts (3 mL) for flavonols were dried using a Speed Vac concentrator and resuspended in 1.0 mL of 50% methanol. The reconstituted samples were passed through AU2 0.45-mm PTFE syringe filters before HPLC analysis. The flavonols were analyzed according to previous methods (Hager et al., 2008, 2010). The flavonols were quantified at 360 nm with results expressed as milligrams of rutin equivalents per 100 g of fresh fruit weight.

Marketability analysis

Fruit for marketability analysis was done in triplicate per genotype with three peaches and nectarines per replicate evaluated each week (0, 7, 14, and 21 d) at 2 °C. The marketability attributes of the fruit included decay, bruising/pitting, and weight loss.

Decay and bruising/pitting. The decay (visible mold or rot) and bruising/pitting of the fruit were calculated as (number of decayed or bruised/16)×100 and expressed as percent.

Weight loss. The weight loss of the fruit was calculated as the weight decrease of three fruits expressed as percent.

Descriptive sensory evaluation

Descriptive sensory analysis was performed at the Sensory and Consumer Research Center at the University of Arkansas, Fayetteville AR. After harvest, the fruit was stored overnight at 2 °C for sensory. The fruit was removed from cold storage, gently rinsed, placed on

pulp trays, and allowed to air-dry. Each panelist evaluated two fruit for each genotype in duplicate. The fruit was served monadically (one at a time) at room temperature (25 °C) on plates labeled with three-digit codes in a randomized complete block design. Panelists were instructed to cleanse their palates with unsalted crackers and water between samples. Expectorant cups were also provided. The panelists were trained to use a modified Sensory Spectrum method, an objective method for describing the intensity of attributes in products using references for the attributes. The ten descriptive panelists developed a lexicon of sensory terms for the peaches and nectarines through consensus during orientation and practice sessions (Table 1). Serving order was randomized across each replication to prevent presentation order bias. The descriptive panel evaluated the fruit attributes for external appearance (n = 8), aroma (n = 4), internal appearance (n = 6), basic tastes (n = 3), aromatics (n = 5), feeling factors (n = 2), and texture (n = 6). The attributes were evaluated using a 15-point scale where 0 = less of an attribute and 15 = more of an attribute.

Design and statistical analysis

After harvest, the fruit from each of the nine genotypes was completely randomized. The fruit was stored at 2 °C for 0, 7, 14, and 21 d. Statistical analyses were conducted using JMP® (version 13.2.0; SAS Institute, Cary, NC). A univariate analysis of variance (ANOVA) was used to determine the significance of main factors (genotype and storage) and interactions. Tukey's Honestly Significant Difference (HSD) test was used to detect significant differences ($p < 0.05$) among means and verify interactions at 95% significance level. Least significant difference (LSD) test was used to detect significant differences ($p < 0.05$) among means for sensory data. Pairwise correlations using multivariate analysis were used to verify the relationship between/within attributes at a p-value of 0.05 at harvest and at 21 d of storage. Physiochemical

and marketability attributes were evaluated in triplicate and sensory attributes were evaluated in duplicate.

Results and Discussion

At harvest, the peaches and nectarines were within a commercially acceptable range for fruit weight (114.92-409.98 g), soluble solids (7.00%-17.30%), pH (3.23-5.00), titratable acidity (0.14%-1.20%), and firmness (3.03-55.40 N) (data not shown). The genotypes evaluated had various flesh types, flesh colors, and acidity levels (Table 2). The fruit was evaluated for physiochemical and descriptive sensory attributes at harvest and physiochemical and marketability attributes during postharvest storage.

Physiochemical attributes at harvest

The nine peach and nectarine genotypes were evaluated for physiochemical attributes (weight, color, firmness, composition, and nutraceuticals). Initial physiochemical analysis was significant for all attributes except firmness and skin hue for the genotypes evaluated (Tables 3 and 4). Fruit weight and pit weight were also evaluated. 'White River' (330.20 g) was the largest fruit, and A-865 (134.40 g) was the smallest. 'White River' was larger than previously reported, with a 10-14 year fruit weight of 201 g (Clark and Moore, 2003). A study by Rahmati et al. (2015) indicated that when drought stress is high, fruit weight is negatively affected. 2017 was an exceptionally wet year in Arkansas with 455 mm of rain from April-June, which could have contributed to the increased fruit weight. 'White River' (11.06 g) also had the largest pit, and 'Amoore Sweet' (4.62 g) had the smallest.

The composition attributes measured included soluble solids, pH, titratable acidity, organic acids, sugars, and nutraceuticals. A-865 (14.70%) had the highest soluble solids, and 'Loring' (7.50%) had the lowest. A-850 (4.79) had the highest pH, and A-865 (3.30) had the

lowest. Titratable acidity ranged from 0.16%-1.07% at harvest. Titratable acidity had an inverse relationship to pH, where A-850 (0.16%) had the lowest titratable acidity, and A-865 (1.07%) had the highest. Crisosto (1994) established stone fruit maturity indices as a way to define the stage of development of the fruit to give a minimum acceptable quality to the consumer, concluding that of the three composition attributes (soluble solids, pH, and titratable acidity), soluble solids was a good indicator of maturity. Crisosto and Crisosto (2005) found that consumer acceptability increased with an increase in soluble solids and preferred soluble solids of high-acid cultivars ranged from 10-12%, and low-acid cultivars ranged from 15-16%. Above those ranges consumer acceptability plateaued. Another key finding of that study was that consumer acceptance was greatly influenced by the balance of soluble solids/titratable acidity ratio, rather than either attribute alone. However, great differences in consumer acceptance were found for the different acid types indicating no single value will describe the optimum. Of the soluble solids/titratable acidity ratio of nine genotypes in this study, A-850 (63.62) had the highest soluble solids/titratable acidity ratio, while 'Bowden' (12.07) had the lowest (Fig. 1).

The color of the skin and flesh of the fruit were evaluated. For skin L* value, 'White River' (65.52) had the highest value, and 'Souvenirs' (38.38) had the lowest. 'Amoore Sweet' (52.23) had the highest skin chroma value, and A-865 (31.73) had the lowest. McGuire (1992) stated that hue angle can be useful in identification of ripeness as fruit ripen from green to either yellow or shades of red. There was no difference among genotypes for skin hue. Flesh L* value and hue ranged from 55.57-73.02 and 56.52-99.89, respectively at harvest. For both attributes, A-850 had the highest value, and 'Souvenirs' had the lowest. A hue angle from 45-90° is orange to yellow and 90-180° is yellow to green. The flesh hue angle ranged from 57-100°, and the skin hue ranged from 31-58° indicating an orange-yellow color. Commonly, hue angle can be used

for identification of ground color as a determination of ripeness (Shinya et al., 2013). A-850, A-865, 'Bowden', 'Effie', and 'White River' were white-flesh, and A-827, 'Amoore Sweet', 'Loring', and 'Souvenirs' yellow-flesh (Table 2). A-827 (48.63) had the highest flesh chroma value, and 'White River' (19.47) had the lowest. Bible and Singha (1993) indicated fruit from the upper canopy could have higher chroma values and increasing redness, a lower hue angle than fruit found in the lower canopy. As the fruit in this study was randomly taken from all locations on the tree, variations in chroma and hue due to fruit location within a genotype are possible.

The total sugars (glucose and fructose) and total organic acids (isocitric and malic acid) were evaluated. The sugars and organic acids were significantly different for the genotypes in this study. A-865 (10.36 g/100 g) had the highest total sugars, and 'Souvenirs' (1.71 g/100 g) the least. 'Bowden' had the highest total organic acids (0.80 g/100 g) and 'Souvenirs' (0.11 g/100 g) the lowest. The primary sugars and acids varied by genotype. Glucose and fructose ranged from 0.57-5.57 g/100 g and 1.08-4.80 g/100 g, respectively at harvest (Fig. 2). A-865 had the highest glucose and fructose, 'Souvenirs' had the lowest glucose, and 'Amoore Sweet' had the lowest fructose. In a study by Chinnici et al. (2005), the glucose and fructose concentrations in commercial peach juice was 3.65-4.26 g/100 g and 3.43-7.54 g/100 g, respectively. Similarly, they found citric and malic acid concentrations ranging from 0.10-0.19 g/100 g and 0.15-0.56 g/100 g, respectively. At harvest, the isocitric and malic acid contents of the nine genotypes in this study ranged from 0.06-0.59 g/100 g and 0.03-0.66 g/100 g, respectively (Fig. 3). These values were similar to those found by Chinnici et al. (2005). The predominant acid varied by genotype, where A-827, 'Bowden', and 'Souvenirs' had predominantly isocitric acid, A-850, A-865, and 'White River' were predominantly malic acid, and 'Effie' and 'Loring' had roughly equal amounts of both acids. 'Bowden' had the highest isocitric acid content, and 'Amoore

Sweet' had the lowest. A-865 had the highest malic acid content, and 'Souvenirs' had the lowest. In a study by Wang et al., (1993), the malic and citric acid content varied between cultivars which was similar to the results seen in this study.

Total nutraceuticals (sum of total anthocyanin, total phenolic acids, total flavonols, and total carotenoids) ranged from 7.01 mg/100 g ('Loring') to 29.99 mg/100 g (A-865) and were significantly different between genotypes. The individual nutraceuticals of the peaches and nectarines are shown on Fig. 4. Total anthocyanin ranged from 0.31-7.13 mg/100 g. 'Souvenirs' had the highest total anthocyanin content, and A-850 had the lowest. Genotypes with a high degree of blush, or red color, on the exterior of the fruit, had higher total anthocyanins. For example, 'Souvenirs', which had the highest total anthocyanin content, had reported 90% blush, whereas 'Loring' had 71% (Clark and Sandefur, 2013). A-865 (27.38 mg/100 g) had the highest total phenolic acid content, and 'Souvenirs' (1.58 mg/100 g) had the lowest. Total flavonols ranged from 0.64-2.88 mg/100 g at harvest, and total carotenoids ranged from 84.05-555.98 μg/100 g, but the genotypes were not significantly different for either nutraceutical. Total carotenoid content was slightly higher (7-260 μg/100 g) than found by Gil et al. (2002), with significant variation among cultivars, but different genotypes were used in this study.

Sensory attributes at harvest

Descriptive sensory attributes were evaluated on the nine peaches and nectarines at harvest. Sensory analysis has been shown to explain cultivar characteristics, such as texture, better than instrumental measurements alone (Delgado et al., 2013). During orientation and training, the 10 trained panelists created a lexicon using Arkansas-grown peaches and nectarines (Table 1). The panelists then evaluated each of the nine genotypes in duplicate using a 15-point scale where 1 is less of an attribute and 15 is more of an attribute. The panelists evaluated the

fruit for seven categories of attributes (aroma, exterior appearance, interior appearance, aromatics, basic tastes, feeling factors, and texture). Within each category multiple attributes were evaluated.

The panelists evaluated aroma (fruity/peach, earthy/dirty, green/unripe, and mold/mildew) of the whole, intact fruit (Table 5). All of the aroma attributes were less than 5 on the 15-point scale indicating low-mid aroma intensity. Of the attributes, the panelists detected differences between genotypes in fruity/peach, earthy/dirty, and green/unripe, but not mold/mildew which were low (≤ 1). 'Effie' had the highest fruity/peach and green/unripe aromas and the lowest earthy/dirty aroma. A-827 had the lowest fruity/peach aroma, 'White River' had the highest earthy/dirty aroma, and 'Souvenirs' had the lowest green/unripe aroma. In a study by Jordan et al. (1989), a relationship was found between aroma and flavor, however, they concluded that the relationship was not strong enough to influence a consumer to purchase the fruit. Additionally, they found that aroma intensified during later stages of senescence. Therefore, since the fruit in this study were evaluated at harvest, the aroma scores may be lower than the consumer would experience in a commercial setting as the fruit is stored prior to sale.

The panelists then evaluated the appearance (uniformity of color, color-yellowness, color-redness, size, shape, amount of bruises, amount of blemishes/deformities, and fuzziness) of the exterior or skin of the whole, intact fruit (Table 6). Of the eight attributes, the panelists detected differences among the genotypes for all attributes except amount of bruises which was low (≤ 1.6). Uniformity of color was evaluated using ratio of color uniformity where 0% was rated 0 and 100% was scored 15. Uniformity of color ranged from 7.3-9.9 where 'Souvenirs' had the highest uniformity, and A-865 had the lowest. This indicated that A-865 had a fairly equal distribution of yellow and red, whereas 'Souvenirs' had more of one color. Yellowness was

evaluated using a ratio of yellow where 0% yellow was scored 0 and 100% yellow was scored 15. Yellowness of the fruit did not describe intensity of yellow, but rather the ground color (whitish yellow-very yellow depending on genotype). Yellowness ranged from 3.4-6.8 where 'Amoore Sweet' was the most yellow, and 'Souvenirs' was the least yellow. Similar to yellowness, redness was evaluated using a ratio of red where 0% red was scored 0 and 100% red was scored 15. Redness ranged from 6.3-10.0 where 'Souvenirs' was the most red, and 'Amoore Sweet' was the least red. Using 'Souvenirs' as an example, the high degree of uniformity indicated the skin of the fruit was predominantly one color. Results from the degree of yellowness indicated little yellow, or ground color and the degree of redness indicated a high degree of red, or blush. Size was evaluated using spheres of various diameters as references. A 2.5-in (6.4 cm) sphere was scored an 8, whereas a 3-in (7.6 cm) sphere was scored a 13. Size ranged from 8.9-13.5, where 'White River' was the largest, and A-865 was the smallest. Shape was evaluated as the degree of roundness of the fruit using the 2.5-in sphere to indicate a score of 15, and an egg to indicate a score of 5. Shape ranged from 9.4-11.7 where 'White River' was the roundest, and 'Amoore Sweet' was the least round. Shape has been linked to inadequate chilling or prolonged dormancy which could lead to a more oblong shape (Wert et al., 2007). However, elongation or a more oval shape, varied between cultivars (Quilot et al., 2007). Amount of blemishes/deformities were evaluated as the visual ratio of blemishes on the fruit where 0% would be a score of 0 and 100% a score of 15. Blemishes/deformities ranged from 1.8-4.1, where 'Effie' had the most, and 'Loring' had the least. Fuzziness was evaluated as the amount of fuzz or pubescence on the fruit. Fuzziness ranged from 0.0-8.0, with most nectarines scored 0. Fuzziness of the peaches was indistinguishable between A-827, A-850, 'Loring', and 'White River', however, 'Souvenirs' was less fuzzy than the other peaches.

After evaluating the exterior of the fruit, the panelists were instructed to cut the peach/nectarine in half, then slice the half without the pit into four slices (1/8 of the whole). The panelists then evaluated the interior appearance (uniformity of color, color-yellowness, color-redness, amount of bruises, separation of pit, and pit size) of the fruit (Table 7). The panelists used the same scoring for uniformity of color, color-yellowness, color-redness, and amount of bruises as used previously for the exterior appearance. Of the six interior appearance attributes, the panelists detected differences among the genotypes for all attributes. Uniformity of color ranged from 8.5-13.3 where 'Bowden' had the highest uniformity of color, and 'White River' had the least. Yellowness ranged from 7.9-13.5, and redness ranged from 0.9-5.9, where 'Amoore Sweet' had the highest yellowness, 'White River' had the least yellowness and most redness, and 'Bowden' had the least redness. Amount of bruises ranged from 0.4-2.5 where 'Loring' had the most bruises and 'Amoore Sweet' the least, although the amount of bruises were low. Separation from pit was evaluated as the degree of separation of the pit from the flesh where a score of 0 would be easy, and a score of 15 was completely clingy. Separation from pit ranged from 6.9-13.9, where 'Amoore Sweet', a clingstone nectarine, scored highest, and A-850, a freestone peach, scored lowest. Pit size was evaluated using a photo reference of pit size (Fig. 5). Pit size ranged from 7.3-11.0 where 'White River' had the largest pit, and 'Souvenirs' had the smallest.

Three basic tastes (sweet, sour, and bitter) of the fruit were evaluated. The references for sweet, sour, and bitter were solutions of sucrose in spring water, solutions of citric acid in spring water, and solutions of caffeine in spring water, respectively (Table 8). Of the three basic tastes, sourness was the only attribute that differed among the genotypes. Sourness ranged from 1.6-4.6, where 'Bowden' was the most sour, and A-850 was the least sour (with a 0.05% solution of citric

acid = 2 and 0.08% solution = 5). Sweetness ranged from 3.5-4.4 (with a 5% solution of sucrose = 5) and bitterness was less than 1 (with a 0.05% solution of caffeine = 2).

The aromatic category, which were the aromas/flavors evaluated through retronasal olfaction (while eating the fruit), had five attributes (overall aromatic impact, peach/fresh, green/unripe, earthy/dirty, and overripe) (Table 5). Of the five attributes, green/unripe and overripe were significantly different for the nine genotypes. Overall aromatic impact was about 6.0, peach/fresh aromatic was about 4.6, and earthy/dirty was about 1.3. Green/unripe aromatics ranged from 3.0-4.3 with White River' having the least green/unripe. Overripe aromatic attributes were low (0.0-0.8). A-827, 'Amoore Sweet', 'Bowden', 'Effie', and 'Souvenirs' were the least overripe with scores of 0.0.

Two attributes were evaluated for feeling factors, astringent and metallic, and the panelists only detected a significant difference in astringency among the nine genotypes (Table 8). Astringency ranged from 5.9-6.5, where A-827 and 'White River' were the most astringent, and 'Souvenirs' was the least. Metallic feeling factors were $\leq$ 0.8 for these genotypes.

Texture (flesh hardness, moisture release, awareness of skins, flesh crispness, flesh melting, and fibrousness between teeth) of the fruit was evaluated (Table 9). Panelists detected differences among the genotypes for all these attributes. Flesh hardness was evaluated as the force required to compress the sample between molars. References ranged from cream cheese = 1 to an almond = 11. Flesh hardness ranged from 5.2-7.5, where 'Souvenirs' had the hardest flesh, and 'Loring' was the least hard (beef frank = 5 and olive = 7 for the references). Moisture release was evaluated as the amount of wetness in the mouth after one bite or chew. References ranged from a banana = 1 to an orange = 15. Moisture release ranged from 4.9-7.8 where 'Loring' had the most moisture release, and 'Bowden' had the least (mushroom = 4 and snap pea

= 8). Awareness of skins was evaluated as the awareness of the skins during 3-5 bites. References ranged from baked beans = 4 to medium lima beans = 8. Awareness of skins ranged from 6.6-7.5, where 'White River' had the greatest awareness of skins, and 'Amoore Sweet' had the least. Flesh crispness was evaluated as the unique, strong, clean and acute sound produced in the first bite of the food with incisors and open lips. References ranged from a ripe banana = 0 to a carrot = 15. Flesh crispness ranged from 4.8-8.0 where 'Souvenirs' and 'Bowden' were most crisp and 'Loring' the least. Flesh melting was evaluated as the ease with which the flesh disintegrates under a slight pressure exerted between the tongue and the palate. References ranged from a carrot = 0 to a slice of canned mango = 15. Flesh melting ranged from 0.6-6.0, where 'Loring' had the greatest flesh melting, and 'Bowden' had the least. Fibrousness between teeth was evaluated as the amount of grinding of fibers required to chew through the sample in 3-5 bites (references ranged from an apple = 2 to beef jerky = 20). Fibrousness ranged from 4.2-5.5 where 'Bowden' had the greatest fibrousness and 'White River' the least. Overall, 'Loring' was moist and soft, and 'Souvenirs' and 'Bowden' were crisp.

Correlations between physiochemical and sensory at harvest

A multivariate pairwise analysis was carried out to identify significant correlations between the descriptive sensory attributes and physiochemical and nutraceutical attributes (Table 10). Fruit weight was positively correlated to size (r = 0.68), pit size (r = 0.75), overripe aromatics (r = 0.67), and moisture release (r = 0.69). The bigger the fruit, the more aromatic and moist. The pH, titratable acidity, and soluble solids/ titratable acidity ratio were correlated with sour with an r = -0.82, r = 0.89, and r = -0.77, respectively. Titratable acidity was also positively correlated to overall aromatic impact (r = 0.68). The higher the pH and soluble solids/ titratable acidity ratio and lower the titratable acidity, then the least sour.

Of all of the physiochemical attributes, firmness had the most significant correlations with the descriptive sensory attributes. Firmness was correlated with size (r = -0.81), fuzziness (r = -0.70), amount of bruises on the flesh (r = -0.75), pit size (r = -0.72), sourness (r = 0.68), overall aromatic impact (r = 0.75), green/unripe aromatics (r = 0.72), flesh hardness (r = 0.70), moisture release (r = -0.77), flesh crispness (r = 0.69), and fibrousness between the teeth (r = 0.84). The more firm the fruit measured analytically, the smaller the fruit, the bigger the pit, the more aromatic, sour, hard and crisp the flesh, and the less moisture release and bruising/pitting of the flesh.

Analysis of the correlations of descriptive attributes with nutraceutical attributes found no correlations for total carotenoids or total phenolic acids, but a significant correlation of total anthocyanins with amount of blemishes/deformities (r = 0.70) and flesh hardness (r = -0.84). The more anthocyanins, the more blemished the fruit and less hard flesh. Total flavonols was correlated to astringent feeling factor (r = 0.83). A study by Troszynska et al. (2011) indicated flavonols impact the astringency perception in legumes, and the relationship between chlorogenic acid and astringency was observed in coffee (*Coffea arabica* L.*)* and kiwi (*Actinidia deliciosa* Hayward), where positive correlation was found between the two attributes (Kim at al., 2009; Gloess et al., 2013)

Physiochemical and marketability attributes during postharvest storage

During postharvest storage, the nine peach and nectarine genotypes were evaluated at 0, 7, 14, and 21 d at 2 °C. F-test significance from ANOVA indicated significant genotype x storage interactions for many of the attributes (Table 11). The physiochemical attributes measured included fruit weight, color, firmness, and composition (Tables 12 and 13). The genotype x storage interaction was only significant for malic acid, total organic acids, and L*

(flesh). For all the physiochemical attributes without significant interactions, there were significant differences across the genotypes, but storage only impacted soluble solids, pH, and chroma (skin and flesh).

Fruit weight of the genotypes were significantly different with 'White River' (292.27 g) the largest, and A-865 (145.55 g) the smallest, but fruit weight did not change during storage. A-865 (15.52%) had the highest soluble solids and 'Loring' (7.89%) the lowest. On day 21, soluble solids were greater than day 7 but not day 0 or 14. Changes in soluble solids during storage of Arkansas peaches has been shown in previous studies (Sandfur, 2011). A-850 (4.98) had the highest pH and A-865 (3.41) the lowest. Storage affected the pH, where pH of the fruit on day 21 was greater than day 0. Although A-865 (1.00%) had the highest titratable acidity, and A-850 (0.15%) the lowest, storage did not impact titratable acidity.

Total sugars (glucose and fructose) and total organic acids (isocitric and malic) as well as individual sugars and acids were evaluated. 'Bowden' (7.04 g/100 g) had the highest total sugars and A-827 and A-850 (3.05 g/100 g) the lowest. Storage did not impact total sugars and glucose and fructose were in roughly equal amounts. 'Bowden' had the highest glucose, fructose, and total sugars, and A-827 and A-850 the least (Fig. 6). Similarly, storage did not impact individual sugars.

'Bowden' (0.52 g/100 g) had the highest isocitric acid content, and 'Souvenirs' (0.09 g/100 g) had the lowest. Storage did not impact isocitric acid. There was a significant storage x genotype interaction for malic and total organic acids. In general, most genotypes did not have a significant change of malic or total organic acids during storage (Fig. 7). Organic acid content increases during early stages of fruit growth and declines during maturation (Bae et al., 2014). Since peaches are climacteric fruit, ripening can occur during storage, therefore a decrease in

organic acids was expected, however, this was not observed in all genotypes. At 21 d, the average total organic acids was 0.25 g/100 g. Both total organic acids (r = -0.42) and malic acid (r = -0.47) were negatively correlated to pH after 21 d storage. Since total sugars and total organic acids were not be impacted by storage, it can be inferred that most of the genotypes were at full maturity at harvest.

'Amoore Sweet' (29.57 N) had the highest firmness, and 'White River' (6.96 N) the lowest. The non-melting flesh fruit was firmer than the melting flesh fruit during storage and differences were seen between the melting-flesh genotypes, where 'Souvenirs' was firmer than 'White River'. Although the firmness decreased during storage, the decrease was not significant. Fruit with a firmness of 9-14 N is considered ready to eat, however, this does not account for different flesh types (Crisosto, 1999). In a study by Iglesias and Echeverri (2008), they indicated that firmer fruit was positively correlated with consumer acceptance. Unlike Crisosto, the study by Inglesias and Echeverri indicated that peaches with a firmness of 49 N had the highest degree of consumer acceptance. These studies indicate that the range of ripeness may be larger than previously thought as they discuss widely different ranges.

The color attributes (L*, chroma, and hue) were measured on the exterior (skin) and interior (flesh) of the fruit (Table 13). 'Bowden' (57.25), a white-flesh fruit, had the highest L* of the skin, where 'Souvenirs' (42.33), a yellow-flesh fruit, had the lowest. L* (flesh) had a significant storage x genotype interaction (Figure 8). After day 0, the L* value of the flesh of 'Souvenirs' significantly increased. In a study by Cáceres et al. (2015), L* was a quality indicator for internal flesh browning by both descriptive sensory analysis and CIELAB color analysis. Little to no flesh browning was defined as a ΔL* value <4.7 and extreme flesh browning was defined as a ΔL* value >21. At 21 d, A-850 (75.51) had a higher L* of the flesh,

and ‘Loring’ (58.04) a lower. This indicates that all of the genotypes in this study had little to no flesh browning from day 0 to day 21. Chroma and hue were less related to flesh browning than L*. Storage and genotype were significantly different for both the chroma of the skin and chroma of the flesh. For the skin, chroma at 7 d was greater than 0 d, but similar to 14 d and 21 d. For the flesh, chroma at 21 d was greater than 0 d, but similar to 7 d and 14 d. This indicates a higher degree of colorfulness, as increasing chroma value is positively related to colorfulness in the fruit during storage (International Commission on Illumination, 1970). ‘Amoore Sweet’, a yellow-flesh fruit, had the highest skin and flesh chroma, 52.65 and 47.56, respectively. Additionally, A-865 and A-850, both white-flesh fruit, had the lowest chroma for both skin and flesh, respectively. ‘Bowden’ (54.49) had the highest hue for the skin, and A-850 (101.27) had the highest hue for the flesh, both white-flesh fruit. Storage did not impact the hue for the skin or the flesh.

The marketability attributes were evaluated on the fruit during storage. The marketability attributes measured included weight loss, decay, and bruising/pittting (Table 12). Correlations were also performed between physiochemical and marketability data at 21 d. There was a significant storage day x genotype interaction for weight loss and bruising/pittting, but not decay (Fig. 9). At 21 d, weight loss was significantly greater than day 0 for all genotypes with A-865 (11.82%) having the greatest weight loss and ‘Loring’ (5.20%) the least. Overall weight loss was low (<13%) for the genotypes at 21 d storage. Significant correlation was found ($r = 0.66$) with respect to weight loss and soluble solids at 21 d storage. As water is lost from the fruit, the soluble solids concentrated which contributed to the significant change in soluble solids after 21 d storage. After 21 d, A-865 (19.17%) had the greatest bruising and ‘Loring’ (4.17%) the least. Chroma of the flesh was negatively correlated with bruising ($r = -0.59$) at 21 d. Although

unmarketable sections were evaluated on the exterior of the fruit, a clear relationship between flesh color intensity and bruising was seen, where decreased color intensity was related to greater bruising. Storage and genotypes significantly affected decay. A-827 (7.08%) had the most decay, and A-865 (0.83%) the least. In addition, decay of the fruit was greater at 21 d, as compared to 0 d. An inverse relationship was seen with decay and bruising. A-865 which had the least decay, had the most bruising. Improper handling such as skin breaks, bruising, or lesions, lead to increased microbial damage/decay (Kalia and Gupta, 2006). During analysis, bruising was observed to be the precursor to decay as the sections were highly susceptible locations for mold or rot to occur. Therefore, decay was increasing as bruising was decreasing since the bruised locations were becoming decayed locations as mold developed.

At 21 d storage at 2 °C, the marketability attributes (weight loss, decay, bruising/pitting) and firmness of fresh-market peach and nectarine genotypes were apparent (Fig. 10). In a commercial setting, fruit that is resistant to decay, weight loss, and bruising/pitting and retains high firmness during storage is preferable because higher quality fruit would reach the consumer and thus earn a higher price at market. At 21 d of storage, there was a significant difference among the nine genotypes for weight loss and bruising/pitting. 'White River' had the least weight loss, and A-827 and 'Loring' had the least bruising at 21 d storage. Overall, the weight loss, decay, and bruising/pitting of the peaches and nectarines were relatively low and with good firmness at 21 d of postharvest storage at 2 °C.

Conclusion

At harvest, the nine peach and nectarine genotypes had significant correlations between physiochemical and descriptive sensory attributes. Ripeness and harvest parameters, such as texture and appearance, were well described by the analytical measurements for composition and

firmness with firmness having the most correlations. About ≥ 69% of the variation in sensory flesh hardness, moisture release, flesh crispness, and fibrousness between teeth, could be explained by firmness measured analytically. In addition, ≥ 70% of the variation in sensory appearance attributes (amount of bruises, size, fuzziness, and pit size) were explained by firmness. Of the composition attributes, ≥77% of the sour taste could be explained by pH, titratable acidity, or soluble solids/titratable acidity ratio. The relationship between methods used for analysis of fruit ripeness at harvest and the associations between sensory texture, appearance, and sourness attributes further advances understanding of how consumers perceive ripeness of peaches and nectarines. Significant correlation between texture, appearance, and sourness attributes with analytical methods, indicate that analytical methods can describe the ripeness parameters of the fruit. This is important as attributes such as flesh hardness, moisture release, and sourness are quality factors the consumer relies on to determine ripeness of the fruit.

Overall, genotype had the most significant effect on the postharvest quality of fresh-market peaches and nectarines grown in Arkansas. Storage had less of an effect on postharvest quality parameters than previously expected from a climacteric fruit. Soluble solids, pH, weight loss, decay, and chroma of the skin and the flesh were significantly affected by storage. The changes in these attributes during storage indicated a decrease in fruit quality, by increased decay, increased weight loss, and decreased chroma of the flesh, although these changes were relatively small. Correlation between soluble solids and weight loss indicated a concentration of the soluble solids rather than further ripening. This was seen in A-865, which had the highest soluble solids content and weight loss on day 21. Although chroma of the skin increased after 7 d in storage, indicating an increase in colorfulness, the lack of change on 14 or 21 d indicated any potential further ripening was halted after 7 d. Of the nine genotypes evaluated, ‘Amoore Sweet’

performed well at 21 d storage, with moderate weight loss, low decay and low bruising/pitting, and high firmness retention. Overall, at 21 d storage at 2 °C, the nine peach and nectarine genotypes had good marketability and retention of compositional attributes indicating good potential for fresh-market.

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Tables

Table 1. Lexicon developed for fresh-market peach and nectarine attributes by a descriptive sensory panel with ten trained panelists.

Term	Definition	Technique	Reference
Aroma (whole fruit)			
Fruity/peach	Smell associated with fresh, ripe peach	Ripe peach	Intensities based on universal scale[z]
Earthy/dirty	Smell associated with damp soil or wet foliage	Damp potting soil, allspice	Intensities based on universal scale
Green/unripe	Smell associated with freshly cut green vegetation; unripe	Unripe banana	Intensities based on universal scale
Mold/mildew	Smell associated with moldy or mildew aromas	Old mildewed clothes	Intensities based on universal scale
Appearance (exterior of fruit)			
Uniformity of color	Ratio of uniformity of color on the exterior of the peach/nectarine	Observe the sample and rate the degree to which the sample is uniform in color. (un-uniform to uniform)	Ratio of color uniformity 0%=0, 50%=7.5, 100%=15
Color-yellowness	Degree of yellow of the sample	Observe the sample and determine the amount of yellow on the surface of the sample. (none to much)	Ratio of yellow 0%=0, 50%=7.5, 100%=15
Color-redness	Degree of red of the sample	Observe the sample and determine the amount of red on the surface of the sample. (none to much)	Ratio of red 0%=0, 50%=7.5, 100%=15
Size	The visual size of the sample	Observe the sample and determine the overall size of the sample. (small to large)	A=2.5-inch sphere=8.0 B=3-inch sphere=13.0
Shape	Visual shape of the sample	Observe the sample and determine the overall shape of the sample. (oval to round)	Egg/oval=5 A=2.5-inch ball=15.0
Amount of bruises	Visual ratio of bruises on the sample	Observe the sample and determine the amount of bruises on the surface of the sample. (none to much)	Ratio of bruises 0%=0, 50%=7.5, 100%=15
Amount of blemishes/ deformities	Visual ratio of blemishes/deformities on the sample.	Observe the sample and determine the amount of blemishes/deformities on the surface of the sample. (none to much)	Ratio of blemishes and deformities 0%=0, 50%=7.5, 100%=15
Fuzziness	Amount of fuzz on the sample	Feel the sample and determine the amount of fuzz on the sample. (none to much)	Nectarine=0 Artificial peach=10

Table 1. *(Continued)*

Term	Definition	Technique	Reference
Appearance (interior) and pit attributes			
Uniformity of color	Ratio of uniformity of color on the flesh of the peach/nectarine	Observe the sample and rate the degree to which the flesh is uniform in color. (un-uniform to uniform)	Ratio of color uniformity 0%=0, 50%=7.5, 100%=15
Color-yellowness	Degree of yellow of the sample	Observe the sample and determine the amount of yellow on the flesh of the sample. (none- to much)	Ratio of yellow 0%=0, 50%=7.5, 100%=15
Color-redness	Degree of red of the sample	Observe the sample and determine the amount of red on the flesh of the sample. (none to much)	Ratio of red 0%=0, 50%=7.5, 100%=15
Amount of bruises	Visual ratio of bruises on the flesh of the sample	Observe the peach/nectarine and determine the amount of bruises on the flesh of the sample. (none to much)	Ratio of bruises 0%=0, 50%=7.5, 100%=15
Separation of pit	Degree of separation of the pit from the flesh	Using a spoon, separate the pit from the flesh and determine the degree of difficulty the pit separates from the flesh. (easy to hard)	Easy (completely free)=0, Hard (completely clingy)=15.0
Pit size	Visual size of the pit	Observe the pit and determine the overall size of the pit. (small to large)	Photo reference of pits[y] A=7.0, B=9.0, C=13.0
Basic tastes			
Sweet	Basic taste, perceived on the tongue, stimulated by sugars and high potency sweeteners	Solutions of sucrose in spring water	2%=2.0, 5%=5.0, 10%=10.0, 16%=15.0
Sour	Basic taste, perceived on the tongue, stimulated by acids, such as citric acid	Solutions of citric acid in spring water	0.05%=2.0, 0.08%=5.0, 0.15%=10.0, 0.20%=15.0
Bitter	Basic taste, perceived on the tongue, stimulated by substances such as quinine, caffeine, and certain other alkaloids	Solutions of caffeine in spring water	0.05%=2.0, 0.08%=5.0, 0.15%=10.0, 0.20%=15.0

Table 1. *(Continued)*

Term	Definition	Technique	Reference
Aromatics			
Overall aromatic impact	Overall impact of all aromatics in the peach/nectarine		Intensities based on universal scale
Peach/fresh	Aromatic associated with peaches/nectarines	Fresh peach	Intensities based on universal scale
Green/unripe	Aromatic associated with freshly cut green vegetation; unripe	Unripe banana	Intensities based on universal scale
Earthy/dirty	Aromatic associated with damp soil or wet foliage	Damp potting soil, allspice	Intensities based on universal scale
Overripe	Aromatic associated with overripe fruit	Over-ripened fruit	Intensities based on universal scale
Feeling factors			
Astringent	Feeling factor on the tongue or other skin surfaces of the mouth described as puckering or drying	Chew sample to point of swallow, expectorate and feel surfaces of the mouth. Swish references in mouth, swallow or expectorate and wait 5 seconds.	0.053 g/500 mL water = 6.0 Swish, expectorate, wait 5 seconds
Metallic	Aromatic associated with metals, tinny or iron or a flat chemical feeling factor stimulated on the tongue by metal coins	Tin foil to bite on	Intensities based on universal scale
Texture (cut each of the slices in half)			
Flesh hardness	Force required to compress the sample	Place the sample in the mouth with the skin facing toward the cheek. Compress or bite through sample one time with molars or incisors. (soft to hard)	Cream cheese=1.0, Egg white=2.5, Am cheese=4.5, Beef frank=5.5, Olive=7.0, Peanut=9.5, Almond=11.0
Moisture release	Amount of wetness or moistness felt in the mouth after one bite or chew	Compress sample with molars one time only. (dry to wet)	Banana=1.0, Carrot=2.0, Mushroom=4.0, Snap beans=7.0, Cucumber=8.0, Apple=10.0, Honeydew=12.0, Orange=15.0 (chew reference 5 times)
Awareness of skins	How aware are you of the skins during mastication of the sample	Place sample in mouth and chew 3-5 times. Can also be evaluated in first bite stage. (none to much)	Baked beans=4.0, Medium lima beans=8.0

Table 1. *(Continued)*

Term	Definition	Technique	Reference
Flesh crispness	Unique, strong, clean and acute sound produced in the first bite of the food with incisors and open lips	Place the sample between the incisors (front teeth) and penetrate it. Evaluate the sound intensity produced at the first bite. (none to much)	Ripe banana=0.0, Granny smith apple=7.5, Carrot=15.0
Flesh melting	Ease with which the flesh disintegrates under a slight pressure exerted between the tongue and the palate	Place the sample on the tongue with the skin side on the tongue and press it against the palate. Evaluate how the sample flows. (none to much)	Carrot=0.0, Canned sliced mango=15.0
Fibrousness between teeth	Amount of grinding of fibers required to chew through the sample. (not including the skins)	Place sample between molars and chew 3-5 times. Evaluate during chewing but ignore the skin. (none to much)	Apple=2.0, Apricot=5.0, Salami=7.0, Celery=9.0, Toasted oats (4-5)=10.0, Bacon=12.0, Beef jerky=20.0

[z]Intensities based on universal scale (saltine = 3.0; applesauce = 7.0; orange juice = 10.0; grape juice = 14.0; Big Red Gum® = 15.0).
[y]See Figure 5 for photo reference.

Table 2. Genotypic traits of peach and nectarines, Clarksville, AR (2017)

Genotype	Fruit type	Stone type	Flesh type	Flesh color	Acidity
A-827	Peach	Freestone	Slow melting	Yellow	Low
A-850	Peach	Freestone	Melting	White	Low
A-865	Nectarine	Freestone	Melting	White	High
Amoore Sweet	Nectarine	Clingstone	Non-melting	Yellow	Low
Bowden	Nectarine	Clingstone	Non-melting	White	High
Effie	Nectarine	Clingstone	Non-melting	White	Low
Loring	Peach	Freestone	Melting	Yellow	High
Souvenirs	Peach	Freestone	Slow melting	Yellow	Low
White River	Peach	Freestone	Melting	White	Low

Table 3. Initial fruit and pit weight, composition, and firmness attributes for fresh-market peach and nectarine genotypes, Clarksville, AR (2017).

Genotype	Fruit weight (g)	Pit weight (g)	Soluble solids (%)	pH	Titratable acidity (%)[z]	Total sugars (g/100 g)	Total organic acids (g/100 g)	Total nutraceuticals (mg/100 g)[y]	Firmness (N)
A-827	224.97 abc[x]	6.27 bc	7.93 b	4.48 ab	0.24 de	2.45 b	0.23 b	19.38 ab	7.77 a
A-850	252.33 abc	6.58 bc	9.87 ab	4.79 a	0.16 e	2.09 b	0.30 b	7.21 b	13.25 a
A-865	134.40 c	5.49 bc	14.70 a	3.30 e	1.07 a	10.36 a	0.84 a	29.99 a	35.81 a
Amoore Sweet	137.46 c	4.62 c	8.93 b	4.21 bc	0.36 cde	1.99 b	0.14 b	10.04 b	25.31 a
Bowden	170.62 bc	9.16 ab	8.67 b	3.68 de	0.75 ab	5.95 ab	0.86 a	6.33 b	35.14 a
Effie	201.54 bc	9.15 ab	11.93 ab	4.03 cd	0.45 b-e	2.93 b	0.16 b	16.43 ab	24.70 a
Loring	286.67 ab	6.27 bc	7.50 b	3.66 de	0.51 bcd	2.72 b	0.48 ab	7.01 b	17.74 a
Souvenirs	168.15 bc	4.70 c	10.67 ab	4.67 a	0.23 de	1.71 b	0.11 b	9.91 b	35.18 a
White River	330.20 a	11.06 a	10.17 ab	3.62 de	0.65 bc	6.29 ab	0.26 b	12.33 b	9.55 a
P value	0.0003	0.0408	0.0032	<0.0001	<0.0001	0.0025	<0.0001	0.0011	0.0860

[z] Titratable acidity expressed as % malic acid.

[y] Total nutraceuticals is expressed as the summation of total anthocyanins + total phenolic acids + total flavonols + total carotenoids.

[x] Genotypes were evaluated in triplicate (n=3). Means with different letter(s) for each attribute within effects are significantly different ($p<0.05$) using Tukey's Honestly Significant Difference test.

Table 4. Initial skin and flesh color attributes for fresh-market peach and nectarine genotypes, Clarksville, AR (2017).

	Skin			Flesh		
Genotype	**L***	**Chroma**	**Hue**	**L***	**Chroma**	**Hue**
A-827	51.72 ab[z]	44.52 abc	49.76 a	70.56 a	48.63 a	87.20 ab
A-850	56.39 ab	37.71 bcd	41.03 a	73.02 a	16.27 b	99.89 a
A-865	59.51 ab	31.73 d	57.51 a	70.01 a	20.28 b	81.49 ab
Amoore Sweet	49.65 ab	52.23 a	46.68 a	65.70 a	49.68 a	80.45 ab
Bowden	57.73 ab	37.37 bcd	57.45 a	72.42 a	26.14 b	98.22 a
Effie	47.73 ab	36.13 cd	40.64 a	71.15 a	23.09 b	99.08 a
Loring	59.56 a	47.52 ab	57.44 a	66.34 ab	47.50 a	83.85 ab
Souvenirs	38.38 b	37.94 bcd	30.74 a	55.57 b	38.79 a	56.52 b
White River	62.52 a	33.53 d	54.22 a	67.09 ab	19.47 b	60.72 b
P value	0.0205	<0.0001	0.0934	0.0095	<0.0001	0.0039

[z] Genotypes were evaluated in triplicate (n=3). Means with different letter(s) for each attribute within effects are significantly different ($p<0.05$) using Tukey's Honestly Significant Difference test.

Table 5. Descriptive sensory aroma and aromatic attributes for peach and nectarine genotypes evaluated on a 15-point scale (0 = less of the attribute; 15 = more of the attribute in terms of intensity), Clarksville, AR (2017).

	Aroma				Aromatics				
Genotype	**Fruity/ peach**	**Earthy/ dirty**	**Green/ unripe**	**Moldy/ mildew**	**Overall aromatic impact**	**Peach/ fresh**	**Green/ unripe**	**Earthy/ dirty**	**Overripe**
A-827	2.5 d[z]	1.3 a	1.4 cd	0.7 a	5.4 a	4.3 a	3.8 a	1.7 a	0.0 c
A-850	2.7 d	1.2 abc	1.4 cd	0.3 a	5.8 a	4.8 a	3.0 b	1.5 a	0.2 bc
A-865	3.2 cd	1.1 abcd	2.1 ab	1.1 a	6.2 a	4.6 a	4.3 a	1.5 a	0.2 bc
Amoore Sweet	4.0 ab	0.8 bcd	1.8 abc	0.8 a	5.8 a	4.7 a	3.9 a	0.9 a	0.0 c
Bowden	3.7 abc	0.7 cd	1.9 abc	0.9 a	6.2 a	4.8 a	4.0 a	1.1 a	0.0 c
Effie	4.3 a	0.7 d	2.3 a	1.0 a	6.1 a	4.6 a	4.2 a	1.0 a	0.0 c
Loring	4.1 a	1.1 abcd	1.5 bcd	0.6 a	6.0 a	4.8 a	3.0 b	1.3 a	0.6 ab
Souvenirs	3.2 bcd	1.3 ab	1.1 d	0.9 a	5.9 a	4.2 a	4.0 a	1.2 a	0.0 c
White River	3.6 abc	1.5 a	1.2 d	0.8 a	5.8 a	4.6 a	3.0 b	1.6 a	0.8 a
P value	<0.0001	0.0240	0.0001	0.3040	0.1240	0.5760	<0.0001	0.0720	0.0090

[z]Genotypes were evaluated in duplicate by ten trained panelists. Means with different letter(s) for each attribute are significantly different ($P < 0.05$) using least significant difference.

Table 6. Descriptive sensory exterior appearance attributes of peach and nectarine genotypes evaluated on a 15-point scale (0 = less of the attribute; 15 = more of the attribute in terms of intensity), Clarksville, AR (2017).

Genotype	Uniformity of color	Color-yellowness	Color-redness	Size	Shape	Amount of bruises	Amount of blemishes/ deformities	Fuzziness
A-827	9.6 a[z]	4.7 de	9.3 ab	12.2 b	11.3 a	0.6 a	4.0 ab	7.5 a
A-850	8.2 b	4.9 cde	8.7 bc	12.7 ab	11.3 a	1.6 a	3.2 bcd	8.0 a
A-865	7.3 b	5.6 bcd	8.0 cd	8.9 e	9.9 bc	0.9 a	3.6 abc	0.0 c
Amoore Sweet	7.4 b	6.8 a	6.3 e	9.7 de	9.4 c	0.8 a	3.8 ab	0.0 c
Bowden	7.5 b	6.3 ab	7.1 de	10.8 c	11.1 ab	1.0 a	3.8 ab	0.5 c
Effie	7.5 b	4.4 ef	8.1 cd	10.4 cd	9.9 bc	1.1 a	4.1 a	0.0 c
Loring	8.3 b	6.5 ab	7.8 cd	13.1 ab	11.3 a	1.0 a	1.8 e	7.8 a
Souvenirs	9.9 a	3.4 f	10.0 a	10.7 cd	10.8 ab	1.4 a	2.7 d	6.3 b
White River	8.1 b	5.8 abc	7.8 cd	13.5 a	11.7 a	1.1 a	3.0 cd	7.9 a
P value	<0.0001	<0.0001	<0.0001	<0.0001	0.0030	0.4800	<0.0001	<0.0001

[z]Genotypes were evaluated in duplicate by ten trained panelists. Means with different letter(s) for each attribute are significantly different ($P < 0.05$) using least significant difference.

Table 7. Descriptive sensory interior appearance and pit attributes of the flesh of peach and nectarine genotypes evaluated on a 15-point scale (0 = less of the attribute; 15 = more of the attribute in terms of intensity), Clarksville, AR (2017).

Genotype	Uniformity of color	Color-yellowness	Color-redness	Amount of bruises	Separation of pit	Pit size
A-827	10.1 b[z]	9.8 c	4.4 b	2.1 a	10.8 cd	8.7 bc
A-850	13.1 a	13.0 ab	1.6 c	1.9 a	6.9 f	9.5 b
A-865	10.8 b	9.6 c	3.4 b	1.1 b	11.9 bc	7.9 cd
Amoore Sweet	13.2 a	13.5 a	1.0 c	0.4 b	13.9 a	8.3 cd
Bowden	13.3 a	13.2 ab	0.9 c	0.8 b	13.1 ab	8.1 cd
Effie	12.7 a	12.2 b	1.9 c	0.6 b	13.6 ab	9.4 b
Loring	10.0 b	10.1 c	4.2 b	2.5 a	8.6 ef	10.9 a
Souvenirs	9.9 b	9.8 c	4.4 b	1.0 b	11.8 bc	7.3 d
White River	8.5 c	7.9 d	5.9 a	2.3 a	9.5 de	11.0 a
P value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

[z]Genotypes were evaluated in duplicate by ten trained panelists. Means with different letter(s) for each attribute are significantly different ($P < 0.05$) using least significant difference.

Table 8. Descriptive sensory basic tastes and feeling factors for peach and nectarine genotypes evaluated on a 15-point scale (0 = less of the attribute; 15 = more of the attribute in terms of intensity), Clarksville, AR (2017).

	Basic tastes			Feeling factors	
Genotype	**Sweet**	**Sour**	**Bitter**	**Astringent**	**Metallic**
A-827	3.5 a[z]	2.1 cd	0.8 a	6.5 az	0.2 a
A-850	4.4 a	1.6 d	0.6 a	6.1 bcd	0.4 a
A-865	4.1 a	4.5 a	0.9 a	6.4 abc	0.5 a
Amoore Sweet	4.3 a	2.9 bc	0.6 a	6.1 cd	0.4 a
Bowden	4.0 a	4.6 a	0.8 a	6.2 abcd	0.4 a
Effie	4.2 a	3.4 b	0.8 a	6.2 abcd	0.4 a
Loring	4.2 a	2.8 bc	0.9 a	6.4 abc	0.8 a
Souvenirs	3.8 a	2.8 bc	0.8 a	5.9 d	0.4 a
White River	3.9 a	3.4 b	0.8 a	6.5 ab	0.6 a
P value	0.2160	<0.0001	0.6870	0.0170	0.3380

[z]Genotypes were evaluated in duplicate by ten trained panelists. Means with different letter(s) for each attribute are significantly different ($P < 0.05$) using least significant difference.

Table 9. Descriptive sensory texture attributes for peach and nectarine genotypes evaluated on a 15-point scale (0 = less of the attribute; 15 = more of the attribute in terms of intensity), Clarksville, AR (2017).

Genotype	Flesh hardness	Moisture release	Awareness of skins	Flesh crispness	Flesh melting	Fibrousness between teeth
A-827	6.8 a[z]	6.5 b	6.9 abc	7.1 a	2.7 bcd	4.8 bc
A-850	5.9 b	6.6 b	7.2 ab	6.0 b	3.1 bc	4.3 c
A-865	7.1 a	5.6 c	7.0 abc	7.4 a	2.0 cde	5.3 ab
Amoore Sweet	7.2 a	5.1 c	6.6 c	7.8 a	0.8 e	5.4 a
Bowden	7.3 a	4.9 c	6.8 bc	8.0 a	0.6 e	5.5 a
Effie	7.3 a	5.4 c	6.7 bc	7.7 a	1.1 de	5.2 ab
Loring	5.2 b	7.8 a	7.4 a	4.8 c	6.0 a	4.5 c
Souvenirs	7.5 a	5.2 c	7.0 abc	8.0 a	1.3 cde	5.3 ab
White River	5.4 b	7.7 a	7.5 a	5.1 bc	4.6 ab	4.2 c
P value	<0.0001	<0.0001	0.0490	<0.0001	<0.0001	<0.0001

[z]Genotypes were evaluated in duplicate by ten trained panelists. Means with different letter(s) for each attribute are significantly different ($P < 0.05$) using least significant difference.

Table 10. Multivariate pairwise analysis of physiochemical and descriptive sensory attributes of peach and nectarine genotypes Clarksville, AR (2017).

Descriptive attributes	Fruit weight (g)	pH	Titratable acidity (%)	Soluble solids/ titratable acidity ratio	Firmness (N)	Total anthocyanins (mg/100 g)	Total flavonols (mg/100 g)
Appearance (exterior)							
Size	***0.68***[z]	0.17	-0.38	0.17	***-0.81***	0.26	-0.27
Fuzziness	0.43	0.39	-0.51	0.43	***-0.70***	-0.65	0.18
Amount of blemishes/deformities	-0.31	-0.07	0.08	-0.02	0.11	**0.70**	-0.52
Appearance (interior)							
Amount of bruises	0.60	-0.03	-0.13	0.05	***-0.75***	0.16	0.33
Pit size	***0.75***	-0.25	-0.03	-0.20	***-0.72***	0.11	-0.22
Basic tastes							
Sour	-0.01	***-0.82***	***0.89***	***-0.77***	***0.68***	*-0.24*	*0.58*
Aromatics							
Overall aromatic impact	-0.26	-0.61	***0.68***	-0.43	***0.75***	*-0.28*	*-0.30*
Green/unripe aromatics	-0.48	-0.11	0.30	-0.19	***0.72***	*-0.59*	*0.14*
Overripe aromatics	***0.67***	-0.46	0.27	-0.33	-0.48	-0.13	-0.19
Feeling factors							
Astringency	*0.65*	-0.59	0.45	-0.58	-0.53	0.04	**-0.83**
Texture							
Flesh hardness	-0.59	0.17	0.04	0.06	***0.70***	***-0.84***	*0.47*
Moisture release	***0.69***	-0.15	-0.07	-0.07	***-0.77***	*0.37*	*-0.17*
Flesh crispness	-0.61	0.20	0.02	0.08	***0.69***	*-0.38*	*-0.07*
Fibrousness between teeth	-0.52	-0.11	0.26	-0.24	***0.84***	*-0.32*	*-0.20*

[z]Bold values are significant correlations (P<0.05) using a multivariate pairwise analysis.

Table 11. F-test significance from ANOVA for physiochemical and marketability of fresh-market peach and nectarine genotypes stored at 2 °C for 0, 7, 14, and 21 d, Clarksville, AR (2017).

Attributes	Genotype	Storage day	Genotype x storage day
Physiochemical			
Fruit weight (g)	<0.0001	0.9357	0.4861
Soluble solids (%)	<0.0001	0.0269	0.2482
pH	<0.0001	0.0269	0.6989
Titratable acidity (%)	<0.0001	0.1434	0.7142
Glucose (g/100g)	0.0018	0.0851	0.0736
Fructose (g/100g)	0.0296	0.1852	0.1884
Total sugars (g/100g)	0.0082	0.1452	0.1289
Citric acid (g/100g)	<0.0001	0.5602	0.7483
Malic acid (g/100g)	0.0018	0.0029	0.0036
Total organic acids (g/100g)	<0.0001	0.0054	0.0030
L* (skin)	<0.0001	0.6841	0.6270
Chroma (skin)	<0.0001	0.0330	0.4856
Hue (skin)	<0.0001	0.1525	0.2783
L* (flesh)	<0.0001	0.0995	<0.0001
Chroma (flesh)	<0.0001	<0.0001	0.1995
Hue (flesh)	<0.0001	0.3716	0.1274
Firmness (N)	<0.0001	0.2934	0.4201
Marketability			
Weight loss (%)	<0.0001	<0.0001	<0.0001
Decay (%)	0.0001	<0.0001	0.5378
Bruised/pitting (%)	<0.0001	0.3738	0.0095

Table 12. Main and interaction effects for physiochemical attributes and decay of fresh-market peach and nectarine genotypes stored at 2 °C for 0, 7, 14, and 21 d. Clarksville, AR (2017).

	Fruit weight (g)	**Soluble solids (%)**	**pH**	**Titratable acidity (%)**	**Total sugars (g/100 g)**	**Firmness (N)**	**Decay (%)**
Storage (days)							
0	211.81 a[z]	10.04 ab	4.05 b	0.49 a	4.06 a	22.72 a	0.00 c
7	204.27 a	9.70 b	4.13 ab	0.46 a	5.52 a	21.70 a	1.85 bc
14	206.52 a	10.45 ab	4.13 ab	0.44 a	4.31 a	17.17 a	2.87 b
21	208.54 a	11.01 a	4.21 a	0.42 a	3.68 a	18.47 a	8.29 a
P value	*0.9357*	*0.0269*	*0.0269*	*0.1434*	*0.1452*	0.2934	*<0.0001*
Genotype							
A-827	209.26 b	8.58 cd	4.42 bc	0.24 ef	3.05 d	14.64 abc	7.08 a
A-850	268.43 a	9.54 bcd	4.98 a	0.15 f	3.05 d	13.33 abc	4.27 ab
A-865	145.55 c	15.52 a	3.41 f	1.00 a	6.46 ab	21.99 abc	0.83 b
Amoore Sweet	159.72 bc	10.30 bc	4.40 c	0.34 de	3.40 cd	29.57 a	2.19 b
Bowden	161.12 bc	9.25 cd	3.84 de	0.66 b	7.04 a	27.96 a	3.23 ab
Effie	186.20 bc	11.66 b	4.00 d	0.45 cd	5.58 abc	28.84 a	1.35 b
Loring	280.16 a	7.89 d	3.77 de	0.44 cd	3.29 cd	10.43 bc	4.17 ab
Souvenirs	167.40 bc	10.57 bc	4.65 b	0.24 ef	3.44 cd	25.42 ab	1.88 b
White River	292.27 a	9.41 cd	3.72 e	0.53 bc	4.44 bcd	6.96 c	4.27 ab
P value	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*0.0082*	<0.0001	<0.0001
Storage x Genotype (P value)	*0.4861*	*0.2482*	*0.6989*	*0.7142*	*0.1289*	0.4201	*0.5378*

[z]Genotypes were evaluated in triplicate (n=3). Means with different letter(s) for each attribute within effects are significantly different ($p<0.05$) using Tukey's Honestly Significant Difference test.

Table 13. Main and interaction effects for color attributes of fresh-market peach and nectarine genotypes stored at 2 °C for 0, 7, 14, and 21 d. Clarksville, AR (2017)

	L* (skin)	**Chroma (skin)**	**Hue (skin)**	**Chroma (Flesh)**	**Hue (Flesh)**
Storage (days)					
0	53.69 a[z]	39.85 b	48.39 a	32.21 a	83.05 a
7	52.59 a	43.10 a	45.78 a	29.79 ab	87.16 a
14	52.17 a	42.53 ab	45.74 a	28.78 b	85.14 a
21	51.30 a	41.73 ab	41.95 a	26.19 c	87.14 a
P value	*0.6841*	*0.0330*	*0.1525*	*<0.0001*	*0.3716*
Genotype					
A-827	49.16 ab	46.16 b	46.34 abc	44.94 ab	86.00 bc
A-850	57.13 a	36.78 c	39.91 bc	12.94 f	101.27 a
A-865	55.54 a	35.67 c	47.52 abc	17.06 ef	86.56 bc
Amoore Sweet	52.52 a	52.65 a	52.35 ab	47.56 a	80.01 c
Bowden	57.25 a	38.21 c	54.49 a	24.24 d	96.39 ab
Effie	48.64 ab	39.84 c	39.71 bc	21.20 de	97.76 ab
Loring	55.48 a	48.58 ab	52.82 ab	41.51 b	76.31 cd
Souvenirs	42.33 b	40.13 c	37.32 c	36.27 c	79.41 cd
White River	53.88 a	38.20 c	38.72 c	17.46 e	66.87 d
P value	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*
Storage x Genotype (P value)	*0.6270*	*0.4856*	*0.2783*	*0.1995*	*0.1274*

[z]Genotypes were evaluated in triplicate (n=3). Means with different letter(s) for each attribute within effects are significantly different ($p<0.05$) using Tukey's Honestly Significant Difference test.

Figures

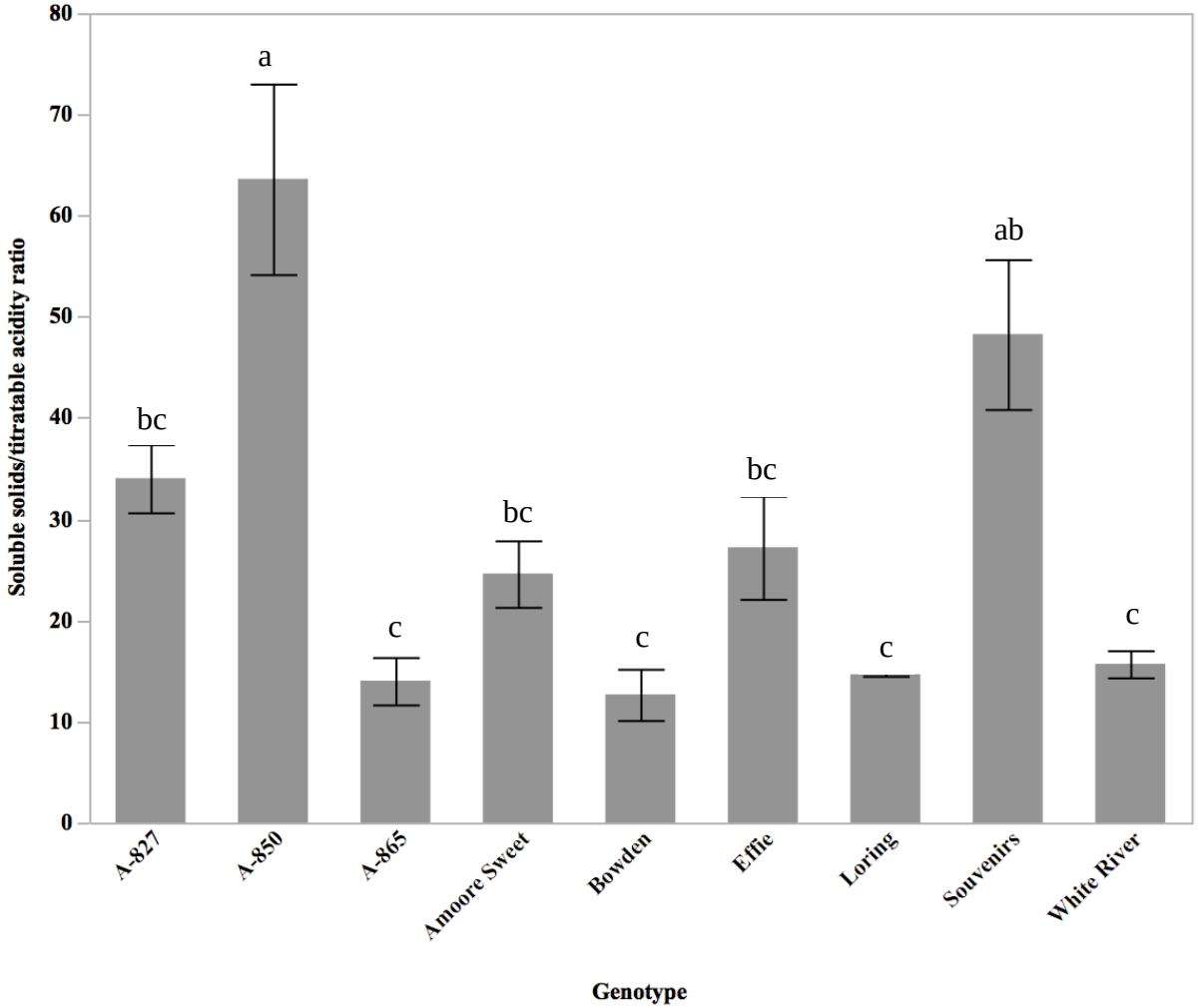

Fig. 1. Soluble solids/titratable acidity ratio for fresh-market peach and nectarine genotypes, Clarksville, AR (2017). Each standard error bar is constructed using 1 standard error from the mean. Means with different letter(s) for each attribute are significantly different ($P < 0.05$) using Tukey's Honestly Significant Difference test.

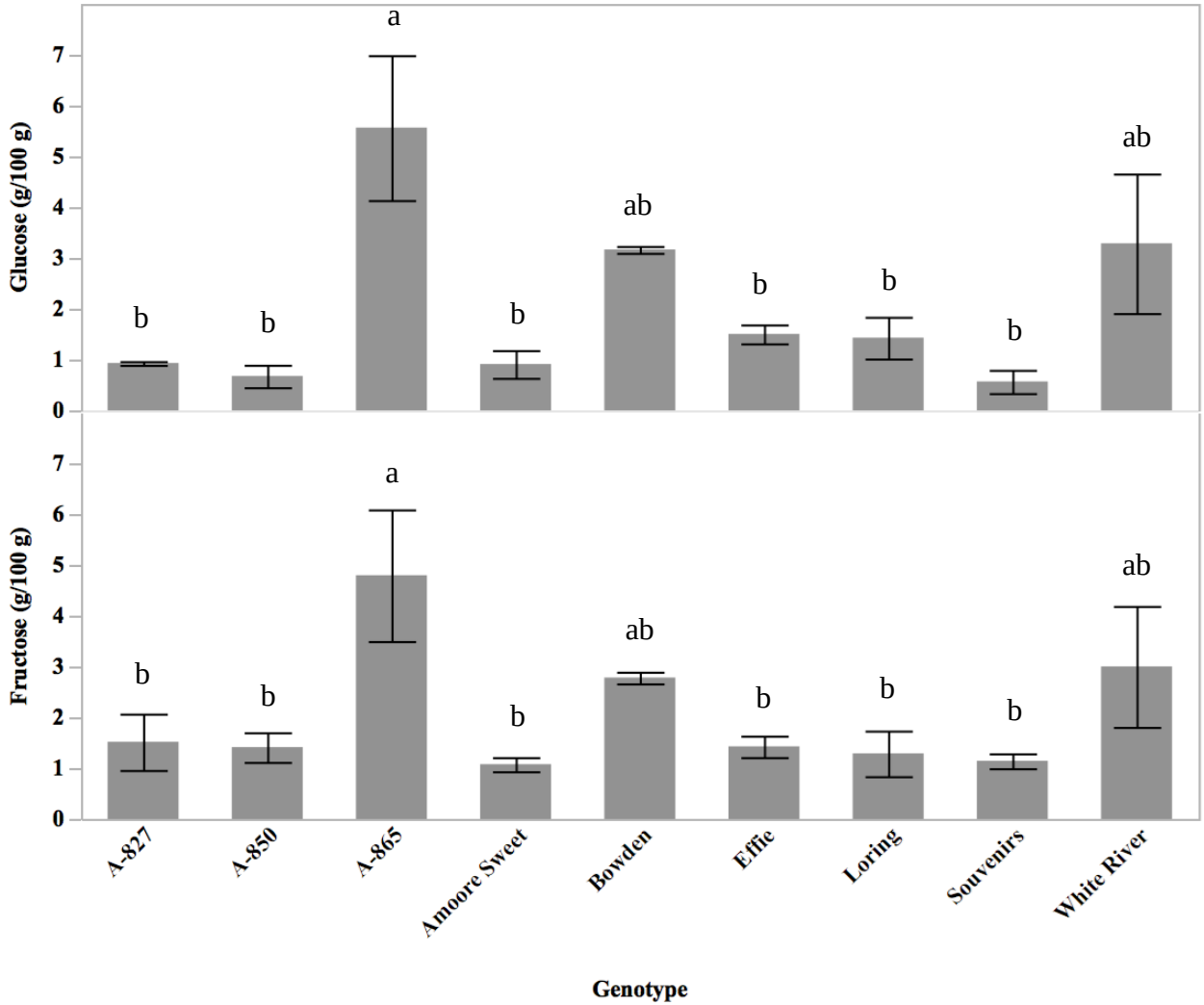

Fig. 2. Effect of genotype on initial sugars (glucose and fructose) for fresh-market peach and nectarine genotypes, Clarksville, AR (2017). Each standard error bar is constructed using 1 standard error from the mean. Means with different letter(s) for each attribute are significantly different ($P < 0.05$) using Tukey's Honestly Significant Difference test.

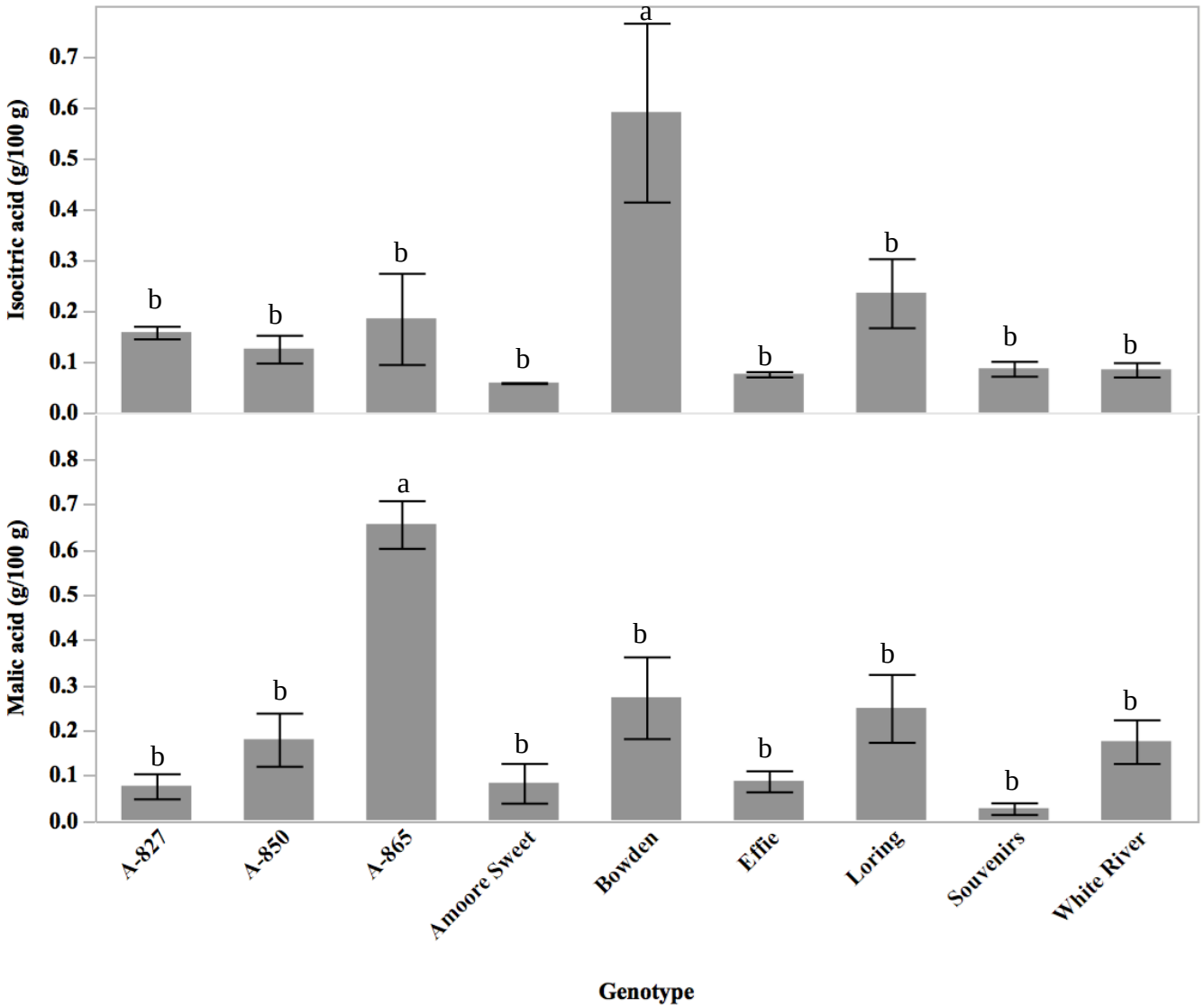

Fig. 3. Effect of genotype on initial organic acids (isocitric and malic acid) for fresh-market peach and nectarine genotypes, Clarksville, AR (2017). Each standard error bar is constructed using 1 standard error from the mean. Means with different letter(s) for each attribute are significantly different ($P < 0.05$) using Tukey's Honestly Significant Difference test.

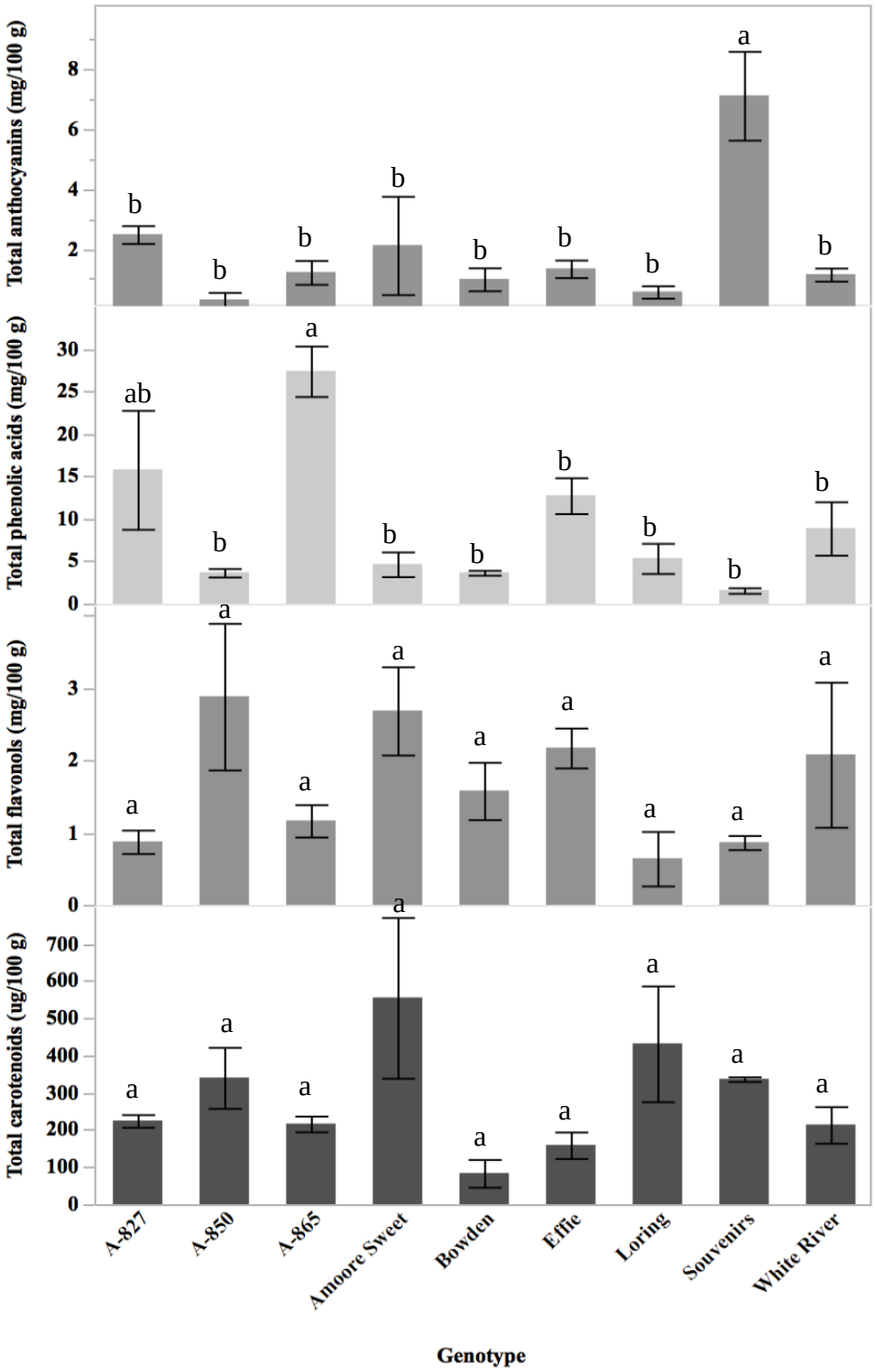

Fig. 4. Effect of genotype on initial nutraceuticals (total anthocyanins, total phenolic acids, total flavonols, and total carotenoids) for fresh-market peach and nectarine genotypes, Clarksville, AR (2017). Each standard error bar is constructed using 1 standard error from the mean. Means with different letter(s) for each attribute are significantly different ($P < 0.05$) using Tukey's Honestly Significant Difference Test.

Fig. 5. Pit reference for descriptive sensory analysis of fresh-market peach and nectarine genotypes, Clarksville, AR (2017). A=7.0, B=9.0, and C=13.0 (0 = less of the attribute; 15 = more of the attribute).

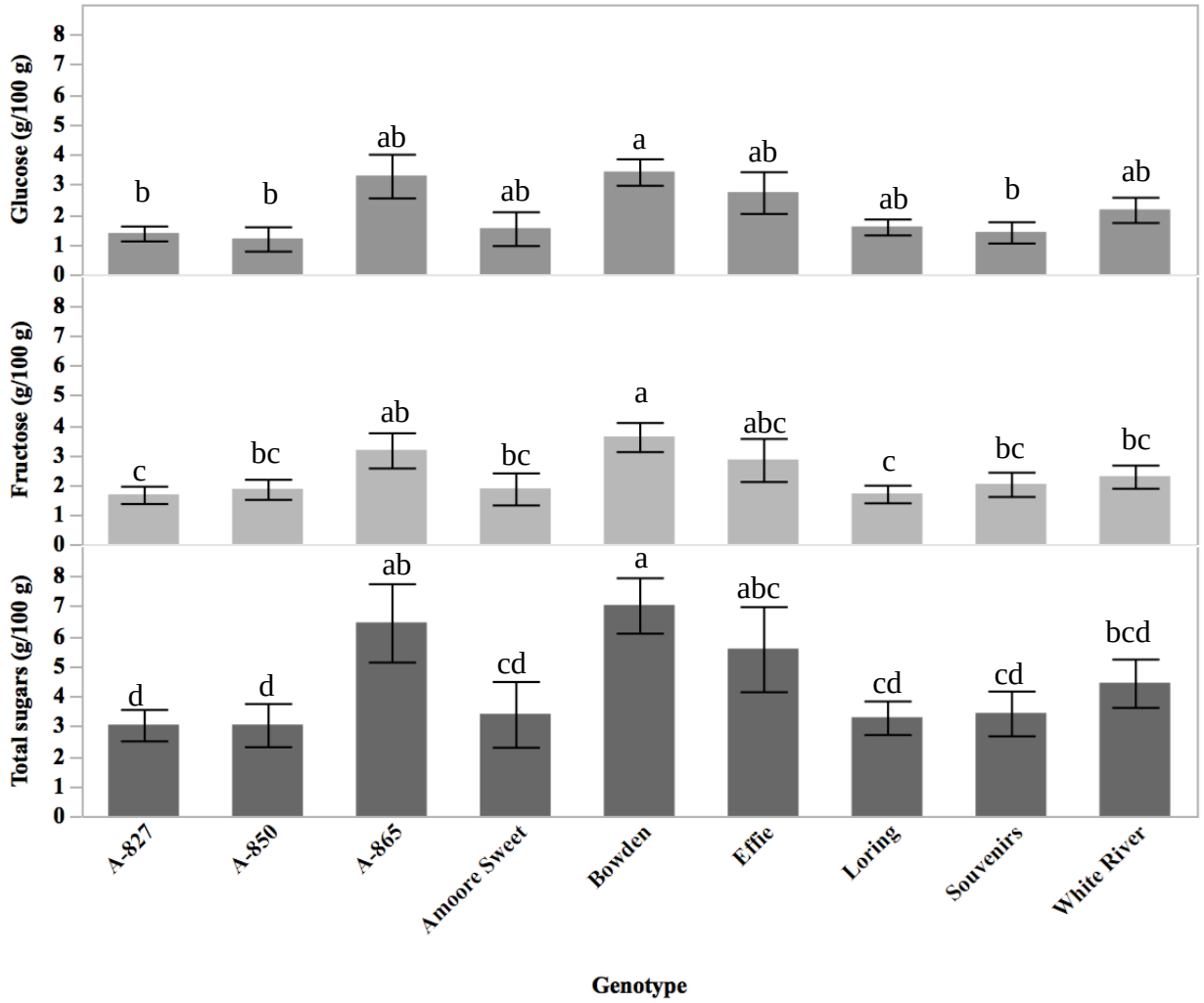

Fig. 6. Glucose, fructose, and total sugars for fresh-market peach and nectarine genotypes during postharvest storage at 2 °C for 0, 7, 14, and 21 d, Clarksville, AR (2017). Each standard error bar is constructed using 1 standard error from the mean.

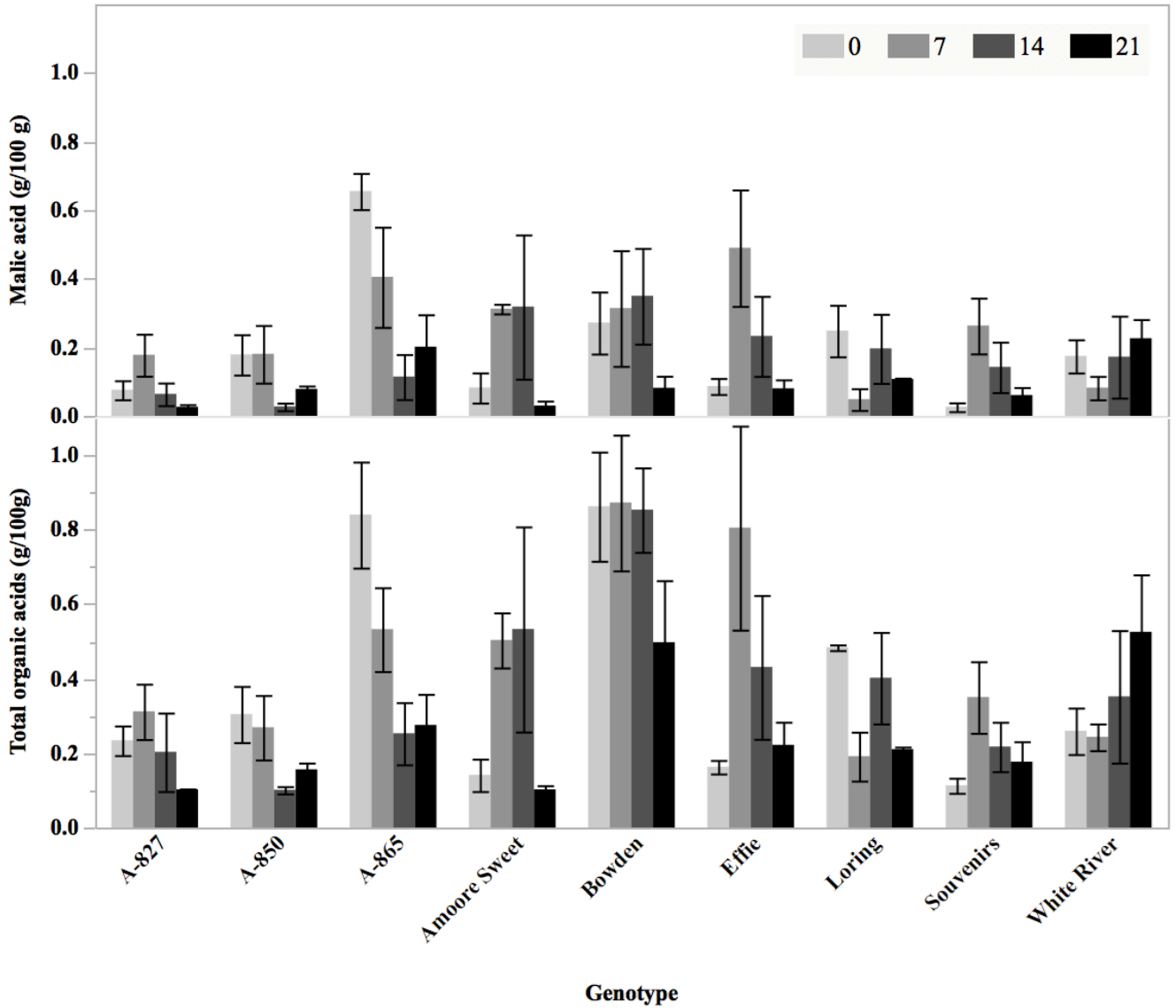

Fig. 7. Malic acid and total organic acids for fresh-market peach and nectarine genotypes during postharvest storage at 2 °C for 0, 7, 14, and 21 d, Clarksville, AR (2017). Each standard error bar is constructed using 1 standard error from the mean.

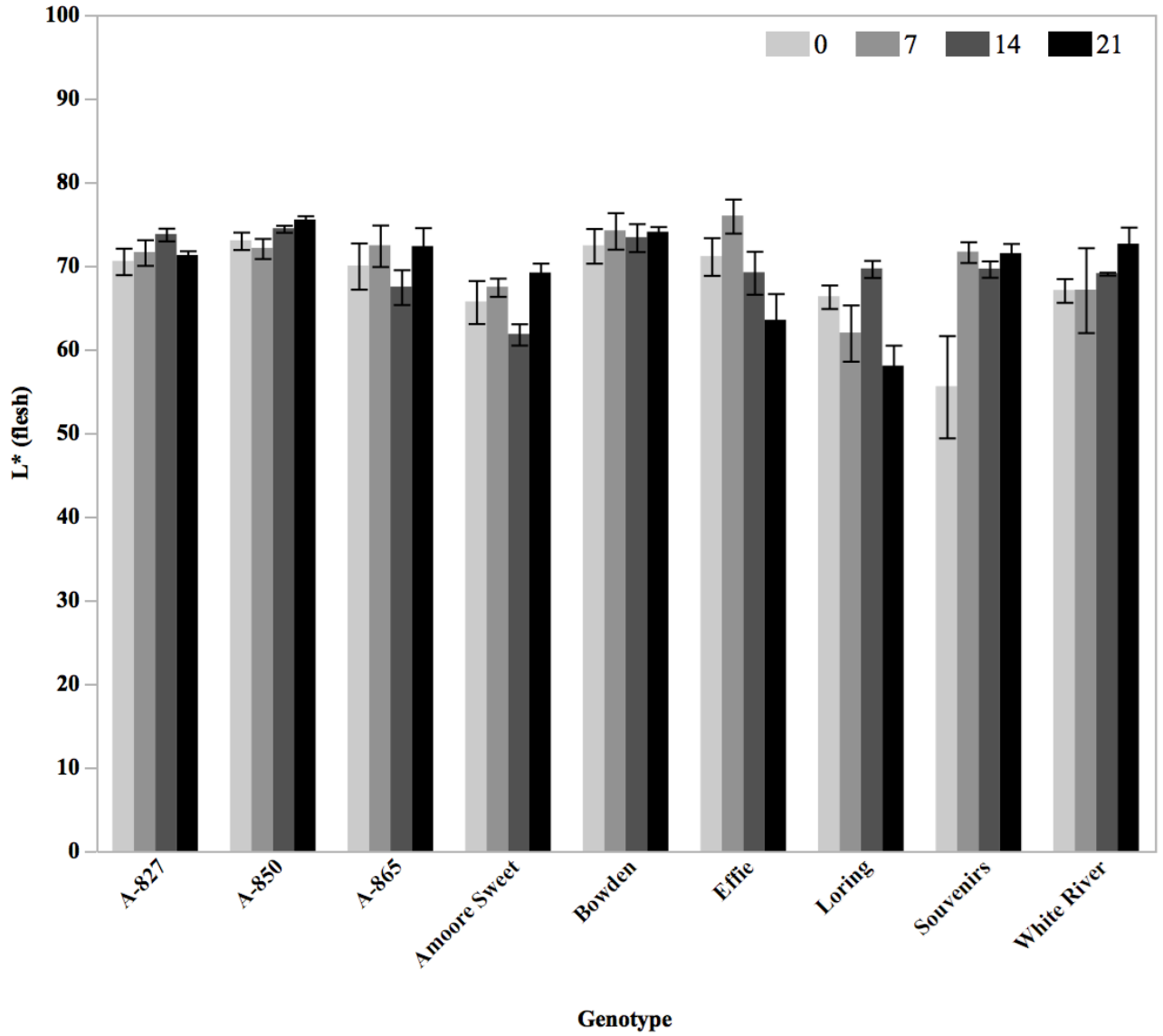

Fig. 8. L* values of the flesh of fresh-market peach and nectarine genotypes during postharvest storage at 2 °C for 0, 7, 14, and 21 d, Clarksville, AR (2017). Each standard error bar is constructed using 1 standard error from the mean.

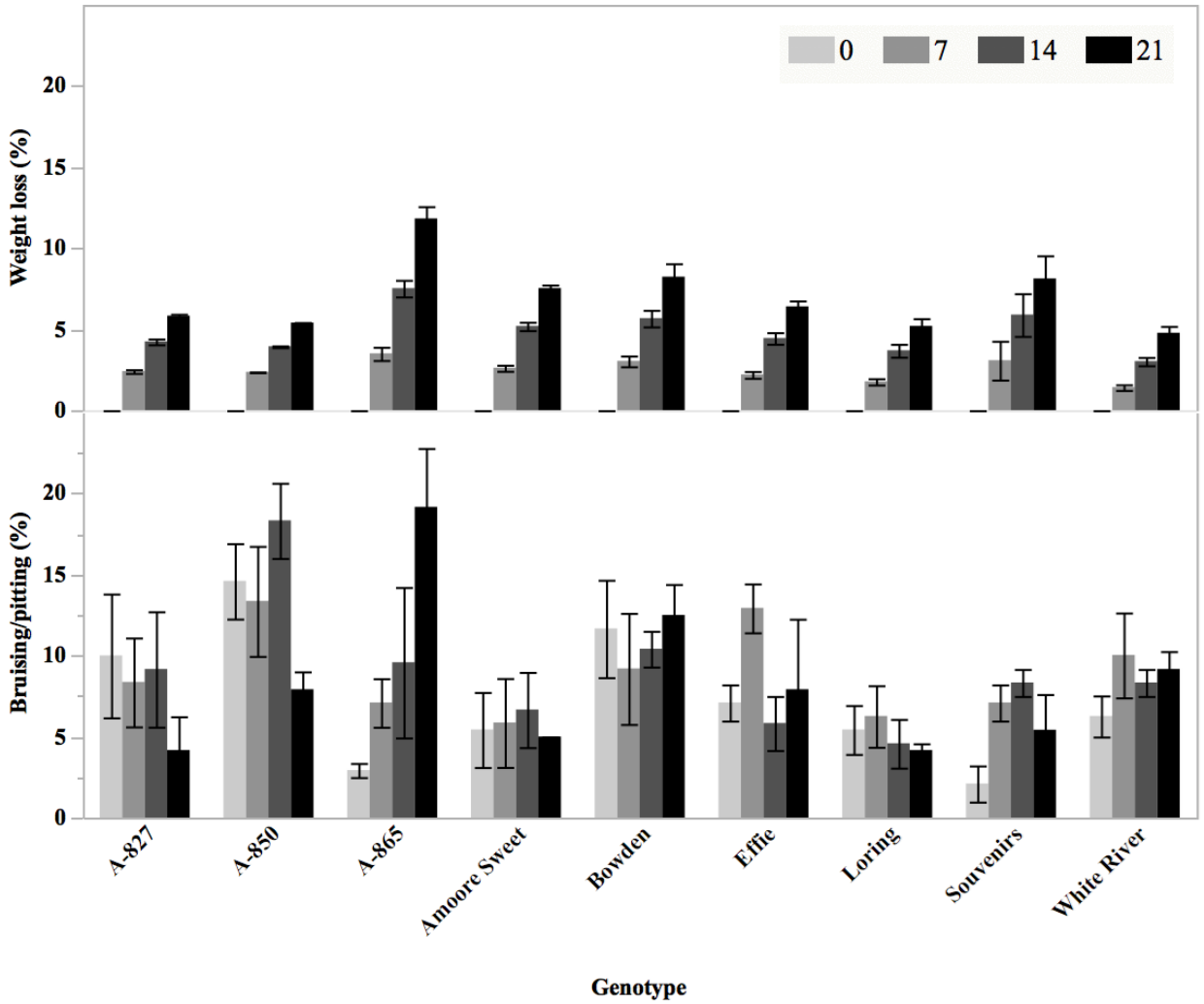

Fig. 9. Weight loss and bruising/pitting of fresh-market peach and nectarine genotypes during postharvest storage at 2 °C for 0, 7, 14, and 21 d, Clarksville, AR (2017). Each standard error bar is constructed using 1 standard error from the mean.

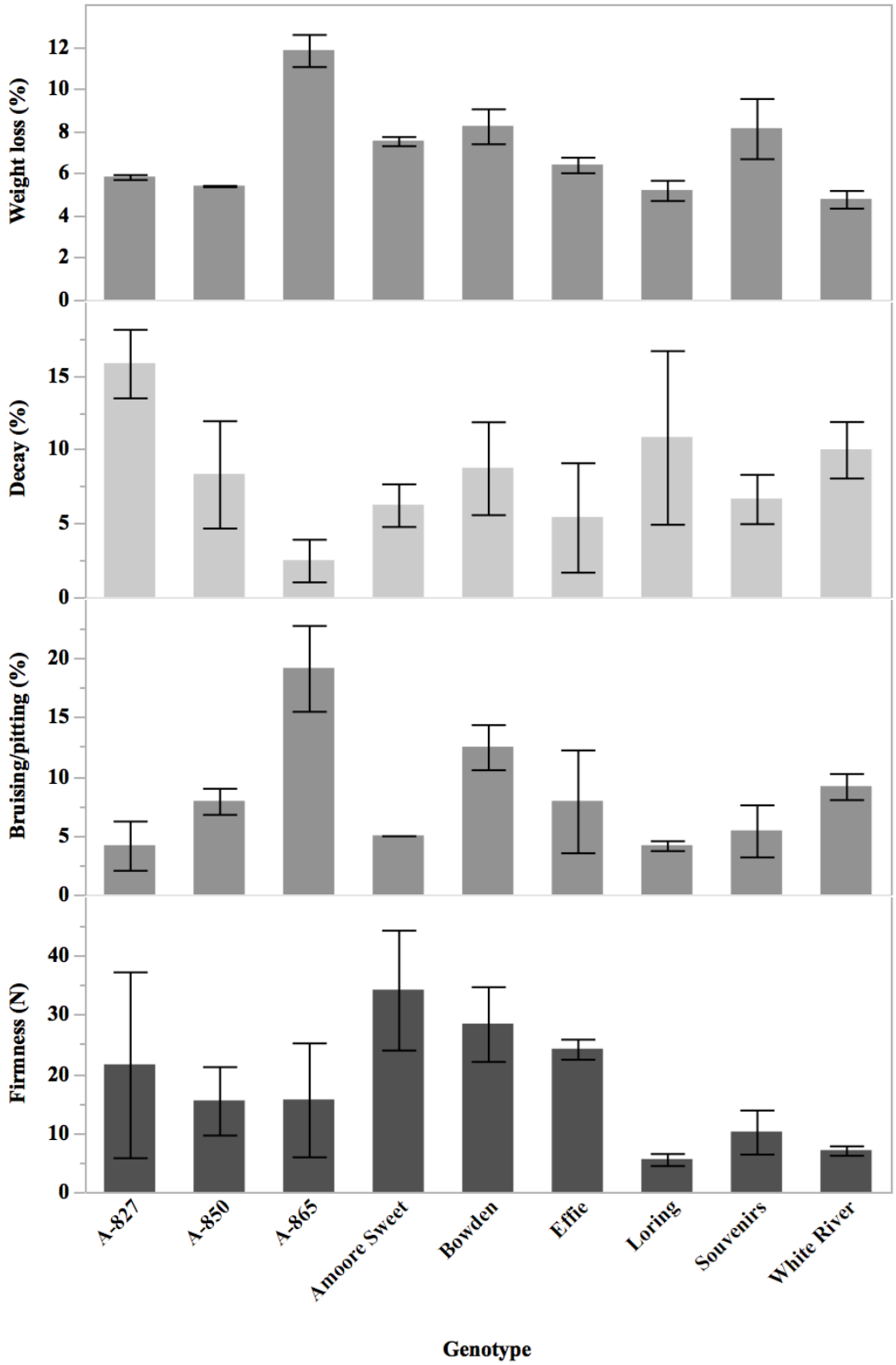

Fig. 10. Marketability attributes of fresh-market peach and nectarine genotypes after 21 d storage at 2 °C, Clarksville, AR (2017). Each standard error bar is constructed using 1 standard error from the mean.

Chapter III

Physiochemical and Marketability Analysis of Traditional and High-Tunnel Grown Arkansas Table Grapes for Fresh Market

Abstract

The marketability of table grapes (*Vitis sp.)* is dependent on the capacity of the fruit to maintain quality before reaching the consumer. Table grapes grown in the southern region of the United States are an extremely high input crop because of pest pressures in a humid climate requiring high fungicide and insecticide inputs. The economic and environmental sustainability of grape production could be improved in the southern region by producing grapes in protected agriculture systems such as high tunnels (passively heated structures that physically protect crops). Postharvest marketability of Arkansas table grapes from two production systems (high tunnel and traditional) was evaluated. Six traditionally-grown table grape genotypes ('Gratitude', 'Hope', 'Jupiter', 'Mars', A-2497, and A-2755) were harvested from the Fruit Research Station, Clarksville, AR, and four high-tunnel-grown table grape cultivars (Faith, Gratitude, Jupiter, and Mars) were harvested from the Arkansas Agricultural Research and Extension Center, Fayetteville. The fruit was hand-harvested into 0.9 kg vented clamshells in July-August, 2017. Two to three clusters per clamshell were evaluated in triplicate for physiochemical and marketability attributes. Nutraceuticals were evaluated at harvest (day 0). Physiochemical attributes (berry and cluster weight, firmness, organic acids, sugars, and composition) and marketability attributes in a clamshell (weight loss, decay, and berry drop) were evaluated during storage (0, 7, 14, and 21 days) at 2 °C. At harvest, the ranges from both production systems were, cluster weight (142.37-396.51 g), berry weight (2.18-5.65 g), soluble solids (12.00%-17.30%), pH (3.13-3.71), titratable acidity (0.34%-0.65%), firmness (2.53-4.35 N), and skin elasticity (3.18-9.03 mm). Total nutraceuticals evaluated at harvest were similar for both

production methods. During storage, glucose and fructose were present in a 1:1 ratio and tartaric acid was the predominant acid for all genotypes and production methods. At 21 days of storage, weight loss, berry drop, and decay were lowest and firmness and skin elasticity were highest in fruit grown in a high tunnel as compared to traditionally-grown. ‘Jupiter’ and ‘Mars’ from the high tunnel, and ‘Jupiter’ and A-2497 from the traditional vineyard had the best quality after 21 days storage. Additional growing protection, such as a high tunnel, may improve quality of the fruit grown in Arkansas, especially with well-adapted genotypes such as ‘Jupiter’ and A-2497.

Introduction

Table Grapes (*Vitis vinifera.*) were first domesticated around 8000 BP in what is currently known as Georgia and Turkey (This et al., 2006). Grapes were widely cultivated in the Middle East and played a role in religion and culture, thus utilization of grapes spread rapidly across the world (Fuller, 1996). In the Mediterranean, native people believed "the wine sprang from the blood of humans who had fought the gods", and many aspects of life revolved around wine (Blanco, 1997; McGovern, 2003). The introduction of *V. vinifera* grapes to the United States began with the arrival of European settlers in the 16th century where the grapes were introduced as seeds then cuttings (Barber et al., 2007; Royer, 1988).

Throughout history, grapes have been eaten fresh and used for wine, juice, and raisins. Grapes are one of the world's most important fruit crops, and by total value of production were the number one crop in the world with 67 million metric tons produced for a $70 billion value in 2014 (FAO, 2016). One of the most utilized table grape cultivars is 'Thompson Seedless' or 'Sultana' which originated in Asia as a raisin grape and was introduced to the United States in 1872 (Bioletti, 1919). With respect to table grapes, 24 million metric tons were produced worldwide in 2014. The United States was the fifth largest producer behind China, India, Turkey, and Egypt. In 2016, the United States produced 907,000 metric tons of fresh-market grapes (table and raisin) of which 99.97% were used for table grapes (USDA, 2017). U.S. production of table grapes was valued at $1.56 billion dollars in 2016, of which California is the largest U.S. producer of over 99% of fresh-market grapes grown.

Known as one of the oldest grape-producing states in the southern United States, Arkansas has a diverse industry for grapes and was ranked 12th in grape production with 9% of the crops used for fresh-market consumption (Johnson et al., 2003). In 2015, grape production in

Arkansas was around 1,400 metric tons (USDA, 2015). In a state-wide survey by Alman (2016), 22% of Arkansas grape production was table grapes with the remainder used for wine or juice.

Traditional grape varieties (*V. vinifera*), new world species (*V. rotundifolia* Michx, *V. labruscana*, and *V. aestivalis*), and hybrids are grown all over the United States. The table grape breeding program at the University of Arkansas began in 1964 by Dr. James Moore and was focused on fruit quality, seedlessness, large berry size, skin cracking resistance, adaptation to the upper South and Midwest United States, non-slip fruit textures, an array of fruit flavors, and a range of fruit shapes (Clark, 2002). Since the start of the program, 12 cultivars have been released including: 'Faith', 'Hope', 'Gratitude', 'Joy', 'Jupiter', 'Mars', 'Neptune', 'Saturn', 'Venus', 'Sunbelt', 'Reliance', and 'Compassion'. Prior to the program, limited table grape cultivars for the Midwest, southern, and eastern states existed. Moore began the program with this in mind as a means to expand production, and Dr. John Clark continued the program after Moore retired. Clark (2010) defined the objective of table grape breeding as, a grape with improved physical and eating quality, size, seedless, crispness, and having an edible skin. Many unique shapes, aromas, and flavors have come from the crosses made in the program. As an example, the maternal parent of the 'Cotton Candy' grape, a popular United States table grape, released by International Fruit Genetics in 2011, came from an advanced selection from the University of Arkansas (Vann, 2017).

Although traditional breeding has drastically improved table grape production in the South, weather, disease, and pest pressures are still higher than more arid production regions such as the San Joaquin Valley of California. High tunnels, or passively heated structures, have been used as a way to extend the growing season and protect crops from weather and pests. Previous research has shown that high tunnels can extend the growing season, increase yields,

and increase the marketability of fruit grown in tunnels (Bergefurd et al., 1999; Cavins et al., 2000; Demchak, 2003; Kadir et al., 2006; Wittwer and Castilla, 1995). In an article published in Wines and Vines, it was noted that high tunnel grape production had the potential to double profits and provide an added barrier for frost/weather protection which minimized damage to the vines (Carey, 2013).

Understanding the physiochemical and marketability attributes of Arkansas table grape genotypes (cultivars and advanced selections) is important to demonstrate fresh-market potential. The purpose of this study was to evaluate how the physiochemical and marketability attributes of Arkansas table grapes, high tunnel and traditionally grown, were affected at harvest and during postharvest storage.

Materials and Methods

Plants and culture

Two production systems for table grapes were evaluated at two vineyards in Arkansas, Clarksville (traditional) and Fayetteville (high tunnel). The vines in each production system were grown in research vineyards with an integrated pest management approach and a minimal spray program. Vines received trickle irrigation as needed, and no cluster, shoot, or leaf removal practices were implemented.

In the traditional vineyard, the table grape genotypes ('Gratitude', 'Hope', 'Jupiter', 'Mars', A-2497, and A-2755) evaluated were grown at the University of Arkansas Fruit Research Station, Clarksville AR [west-central Arkansas, lat. 35◦31'58"N and long. 93◦24'12"W; U.S. Dept of Agriculture (USDA) hardiness zone 7a; soil type Linker fine sandy loam (Typic Hapludult)]. The vines were planted in various years, trained to a bi-lateral, high-cordon/curtain training system, and pruned to three- to four-bud spurs annually. Vines were spaced 2.4 m and rows 3.1 m. 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 black rot (*Guignardia bidwellii* Viala & Ravaz), powdery mildew (*Erysiphe necator* Schw. (syns. *Uncinula necator* (Schw.) Burr., *E. tuckeri* Berk., *U. americana* Howe, and *U. spiralis* Berk. & Curt; anamorph *Oidium tuckeri* Berk.), downy mildew (*Plasmopara viticola* Berl. & de Toni), and anthracnose (*Elsinoë ampelina* Shear). Insecticides were applied as needed to control climbing cutworm (several species common including *Agrotis ipsilon* Hufnagel, *Feltia jaculifera* Guenée, and *Peridroma saucia* Hübner) and grape berry moth (*Paralobesia viteana* Clemens).

The last application of fungicides was usually done near the end of June to early July. On average, 16 sprays (including fungicide and insecticide) were applied to the grapes.

In the high tunnel vineyard, the four table grape cultivars (Faith, Gratitude, Jupiter, and Mars) evaluated were grown at the Arkansas Agricultural Research and Extension Center, Fayetteville AR [north-west Arkansas, lat. 36°6'7.8516" N and long. 94°10'3.8316" W; U.S. Dept of Agriculture (USDA) hardiness zone 6b; soil type Captina silt loam. The vines were planted in 2014 under a 8 m x 61 m Quonset-style Haygrove Supper Solo Tunnel with 80 gram (1.0 x 0.6 mm) Tek-Knit exclusion netting (Tek-Knit Industries, Quebec, Canada). The vineyard in the tunnel had three trellis systems, but grapes for this study were harvested from the Geneva Double Curtain trellis in the center of the tunnel. The vines were trained to a bilateral cordon and pruned using a balanced 30 + 10 pruning method annually. Vines were spaced 2.6 m. and 3.0 m between rows. Fertilizer applications were based on soil and tissue analyses. On average, six sprays (four fungicide and two insecticide) were applied to the grapes.

Harvest

The table grapes for both production methods were hand harvested in the early morning prior to $11{:}00_{AM}$. The fruit was harvested from July to August at optimal ripeness and was free of major blemishes, flaws, or damage (Table 1). The target soluble solids for the grapes at harvest was ~16%, but fruit was harvested if soluble solids did not increase or fruit quality was declining. About 10 kg of table grapes of each genotype at each location were harvested into paper sacks and placed in ice chests chilled with ice packs. ‘Gratitude’, ‘Hope’, ‘Jupiter’, ‘Mars’, A-2497, and A-2755 were harvested from the traditional vineyard in Clarksville, AR. ‘Faith’, ‘Gratitude’, ‘Jupiter’, and ‘Mars’ were harvested from the high-tunnel vineyard in in Fayetteville, AR. After harvest the fruit was transported in an air-conditioned vehicle to the

University of Arkansas Department of Food Science, Fayetteville, AR. Samples were randomized, and 2-4 clusters were placed in new 0.9 kg clamshells for each genotype and replication. The grapes were evaluated for physiochemical and marketability attributes at day 0, 7, 14, and 21 at 2 $^{\circ}$C (85% to 89% relative humidity).

Physiochemical analysis

Fruit for physiochemical analysis was done in triplicate per genotype. Each replicate was a clamshell that contained 2-4 clusters. The physiochemical analysis included berry and cluster weight, exterior berry color, composition, and berry firmness evaluated at 0, 7, 14, and 21 d at 2 °C, and nutraceutical analysis was evaluated at day 0. A five-berry sample was used for berry weight and firmness, 50 berries were used for composition, and 10 berries were used for nutraceutical analysis.

Weight. Berry and cluster weight was measured on a digital scale (PA224 Analytic Balance, Ohaus Corporation, Parsippany, NJ). Cluster weights were only evaluated at harvest.

Color. The exterior color of the berries was analyzed using a Konica Minolta CR-400 Chroma Meter (Konica Minolta Inc, Ramsey, NJ) on the end opposite from the stem scar. The L*, chroma, and hue angle were evaluated. Color analysis was done to determine Commission Internationale de l'Eclairage (CIE) Lab transmission values of L*=100, a*=0, and b*=0 (C.I.E. 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 were measured. Hue angle, calculated as arctan (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. Chroma, calculated as $((a^*)^2 + (b^*)^2)^{0.5}$, identified

color by which a sample appears to differ from gray of the same lightness and corresponds to intensity of the perceived color.

Composition. The berries were frozen (-10 °C) then thawed for compositional analysis (soluble solids, pH, titratable acidity, organic acids, and sugars). The 50 berry samples were thawed and squeezed through cheese cloth to extract juice. The pH and titratable acidity were measured using the Titrino plus 862 compact titrosampler (Metrohm AG, Herisan, Switzerland) with the electrode standardized to pH 4.00, 7.00, and 10.00 buffers. Titratable acidity was determined using ~6 g of juice diluted with 50 mL deionized, degassed water with a titration using 0.1 N sodium hydroxide to an endpoint of pH 8.2. Titratable acidity was expressed as percentage of tartaric acid. Soluble solids (expressed as percent) were measured using an Abbe Mark II refractometer (Bausch and Lomb, Scientific Instrument, Keene, NH). Organic acids and sugars of the fruit were determined using high performance liquid chromatography (HPLC). The remaining juice from compositional analysis was filtered through a 0.45 μm nylon filter (VWR International, Radnor, PA) and analyzed using HPLC. Glucose, fructose, isocitric acid, malic acid, and tartaric acid of the fruit was measured using previously established HPLC procedures (Walker et al., 2003; Segantini et. al., 2018). 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 (Bio-Rad, Hercules, CA). A Bio-Rad Micro-Guard Cation-H refill cartridge (30 × 4.5 mm) was used for a guard column. 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 a 0.45 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 35 min. A Waters 410 differential refractometer to measure refractive index was connected in series with a Waters 996 photodiode array detector monitored the eluting compounds. Tartaric, isocitric and malic acid 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 and acids were expressed as g/100 g, and total sugars (glucose + fructose) and total organic acids (isocitric + malic + tartaric) were expressed as g/100 g.

Nutraceuticals. Total anthocyanins, total phenolic acids (hydroxycinnamic acids), total ellagitannins, and total flavonols were measured by HPLC and ultraviolet-visible (UV-Vis) spectroscopy, following methods described by Cho et al. (2004; 2005), and Hager et al. (2008). The fruit was homogenized three times for 1 min in alternating washes of 80 ml of extraction solution containing methanol/water/formic acid (60:37:3 v/v/v) and acetone/water/acetic (70:29.5:0.5 v/v/v) to the smallest particle size using a Euro Turrax T18 Tissuemizer. Homogenates were centrifuged for 5 min at 10,000 rpm and filtered. The samples were taken to a final volume of 250 mL with extraction solvent and stored at -70 °C until analysis. All samples were passed through 0.45 μm nylon filters prior to HPLC analysis. Equivalents for the table grape nutraceuticals were determined from previous literature for the most common compounds for each class of phenolics (Gil et al., 2002; Mattivi et al., 2006; Ceccarelli et al., 2016; Benmeziane et al., 2016). Total nutraceuticals were quantified as the sum (mg) of total anthocyanins, total flavonols, total ellagitannins, and total phenolic acids per 100 g fresh fruit weight.

Total anthocyanins and total phenolic acids. Sample extracts (7.5 mL) were dried using a Speed Vac concentrator (ThermoSavant, Holbrook, NY) and resuspended in 1 mL of 5% formic acid. The reconstituted samples were passed through 0.45-mm polytetrafluoroethylene (PTFE) syringe filters (Varian Inc, Palo Alto, CA) before HPLC analysis. The anthocyanin analysis by HPLC was performed based on previous methods (Cho et al., 2004; Hager et al., 2008). Samples (50 μL) were analyzed using a Waters HPLC system equipped with a model 600 pump, a model 717 Plus autosampler and a model 996 photodiode array detector. Separation was carried out using a 4.6 mm × 250 mm Symmetry® C18 column (Waters Corp, Milford, MA) preceded by a 3.9 mm × 20 mm Symmetry® C18 guard column. The mobile phase was a linear gradient of 5% formic acid and methanol from 2% to 60% for 60 min at 1 ml/min. The system was equilibrated for 20 min at the initial gradient prior to each injection. The anthocyanins peaks were quantified at 510 nm with results expressed as milligrams malvidin-3-glucoside equivalents per 100 g fresh fruit weight. The phenolic acid peaks were quantified at 320 nm with results expressed as milligrams of chlorogenic acid equivalents per 100 g of fresh fruit weight.

Total ellagitannins and total flavonols. Sample extracts (3 mL) were dried using a Speed Vac concentrator (ThermoSavant, Holbrook, NY) and resuspended in 1.0 mL of 50% methanol. The reconstituted samples were passed through 0.45-mm PTFE syringe filters before HPLC analysis. The ellagitannins and flavonols were analyzed according to previous methods (Hager et al., 2008; 2010). The samples (50 μL) were then analyzed using a Waters HPLC system (Waters Corp, Milford, MA) equipped with a model 600 pump, model 717 plus autosampler and model 996 photodiode array detector. Separation was carried out using a 4.6 mm × 250 mm Aqua® C18 column (Phenomenex, Torrance, CA) preceded by a 3.9 mm × 20 mm Symmetry® C18 guard column. The mobile phase was a gradient of 20 g/L acetic acid (A) and 5 g/L acetic acid in

water and acetonitrile (50:50 v/v, B) from 10% B to 55% B in 50 min and from 55% B to 100% B in 10 min. The system was equilibrated for 20 min at the initial gradient prior to each injection. The ellagitannins were quantified at 255 nm with results expressed as milligrams of ellagic acid equivalents per 100 g of fresh fruit weight. The flavonols were quantified at 360 nm with results expressed as milligrams of quercetin-3-O-glucoside equivalents per 100 g of fresh fruit weight.

Firmness. Firmness was measured using a Stable Micro Systems TA.XT.plus Texture Analyzer (Texture Technologies Corporation, Hamilton, MA). The berries were placed horizontally on the plate and using the 2-mm-diameter probe, at a rate of 2 mm/s with a trigger force of 0.02 N, the firmness and skin elasticity of the berries was measured. Firmness, the force required to penetrate the fruit (skin and pulp), was measured in Newtons (N). Skin elasticity, the distance traveled before the fruit was penetrated, was measured in millimeters (mm).

Marketability analysis

Marketability analysis was performed on fruit in triplicate clamshells for each genotype. The marketability analysis included total decay, total berry drop, and weight loss evaluated at 0, 7, 14, and 21 d at 2 °C.

Decay and berry drop. The decay (visible mold or rot) and berry drop (dislodged berries from the cluster) of the berries were calculated as (number of decayed or dropped berries/total berries) × 100 and expressed as percent.

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

Design and statistical analysis

After harvest, the fruit from each of the ten genotypes were completely randomized. The fruit was stored at 2 °C for 0, 7, 14, and 21 d. Statistical analyses were conducted using JMP®

(version 13.2.0; SAS Institute, Cary, NC). A univariate analysis of variance (ANOVA) was used to determine the significance of main factors (genotype and storage) and interactions. Tukey's Honestly Significant Difference (HSD) test was used to detect significant differences ($p < 0.05$) among means and verify interactions at 95% significance level. Physiochemical and marketability attributes were evaluated in triplicate.

Results and Discussion

At harvest, the table grapes from both production systems were within a commercially acceptable range for cluster weight (142.37-396.51 g), berry weight (2.18-5.65 g), soluble solids (12.00%-17.30%), pH (3.13-3.71), titratable acidity (0.34-0.65%), firmness (2.53-4.35 N), and skin elasticity (3.18-9.03 mm) (data not shown). The genotypes were evaluated by production method for physiochemical and nutraceutical attributes at harvest and physiochemical and marketability attributes during postharvest storage.

High-tunnel grown table grapes

Four cultivars (Faith, Gratitude, Jupiter, and Mars) were evaluated at 0, 7, 14, and 21 d at 2 °C from the high tunnel (Tables 2 and 3). Cluster weight and nutraceuticals were evaluated only at harvest. During storage, berry weight and weight loss had significant storage x cultivar interactions, but soluble solids, pH, titratable acidity, L*, chroma, hue, firmness, skin elasticity, total sugars, individual sugars, total organic acids, individual acids, berry drop, and decay did not have significant interactions (Figs. 1-4 and Table 3).

At harvest, cluster weight (201.64-359.28 g) was not impacted by cultivar, but berry weight (2.38-4.56 g) was. 'Jupiter' (4.56 g) had the highest berry weight, and 'Gratitude' (2.38 g) had the lowest (Table 2). At 21 d, 'Jupiter' (5.00 g) had the highest berry weight, and 'Gratitude' (2.93 g) and 'Mars' (2.61 g) had the lowest (Fig. 1). As the fruit was protected by the

high tunnel, size differences could be attributed to genotypic traits or plant age. In the release of 'Jupiter' and 'Gratitude' average berry weights observed were 5.50 g and 3.50 g, respectively (Clark and Moore, 1999). 'Gratitude' and 'Jupiter' were noted to have average berry weights larger than observed in this study. This could be attributed to vine crop load (Keller et al., 2005). All of the berries grown in the high tunnel had lower berry weights than reported in their release manuscript (Clark and Moore, 1999; 2013; Moore, 1985).

The table grapes at harvest had a composition of soluble solids (12.00%-17.30%), pH (3.13-3.71), and titratable acidity (0.42%-0.65%). 'Jupiter' had the highest soluble solids and pH, and lowest titratable acidity, whereas, 'Gratitude' had the lowest soluble solids and pH, and highest titratable acidity (Table 2). Composition evaluated during storage (Table 3), showed that 'Jupiter' had the highest soluble solids (17.90%), pH (3.64), and lowest titratable acidity (0.48%). 'Gratitude' had the lowest soluble solids (13.10%), pH (3.10), and highest titratable acidity (0.60%). Storage did not impact soluble solids or titratable acidity, but did impact pH. At day 21 the pH of the fruit was lower than day 0. Studies have shown that the ideal soluble solids/titratable acidity ratio was 35-40 for 'Crimson Seedless' (Jayasena and Cameron, 2008). 'Jupiter' and 'Gratitude' in this study had soluble solids/titratable acidity ratios of 40 and 22, respectively. 'Gratitude' was not in the ideal range for ratio.

The table grapes at harvest had total organic acids (tartaric, isocitric, and malic acid) of 0.27-0.51 g/100 g and total sugars (glucose and fructose) of 3.95-9.56 g/100 g. Individual organic acids and sugars were evaluated at harvest; however, cultivar did not have an impact (data not shown). During storage, individual sugars and organic acids, total sugars, and total organic acids were evaluated. Total sugars and individual sugars were not impacted by cultivar or storage. The average total sugars, glucose, and fructose were 8.38 g/100 g, 3.99 g/100 g, and

4.39 g/100 g, respectively. Glucose and fructose were present in a 1:1 ratio in all cultivars. At harvest, the relationship between glucose and fructose has been observed to equilibrate, whereas, in the early stages of ripening glucose is predominant (Muñoz-Robredo et al., 2011). Malic acid was impacted by cultivar (Table 3), however total organic acids, isocitric acid, and tartaric acid were not impacted by cultivar or storage. 'Jupiter' (0.11 g/100 g) had the most malic acid, and 'Mars' (0.03 g/100 g) had the least. The average total organic acids, tartaric acid, and isocitric acid, were 0.52 g/100 g, 0.37 g/100 g, and 0.08 g/100 g, respectively. Tartaric was the predominant acid in all genotypes. In a study by Muñoz-Robredo et al. (2011), tartaric acid was the predominant acid at harvest followed by malic then isocitric acid. Isocitric acid was present in the early stages of ripening and gradually depleted during maturation of the berries. The organic acids and sugars found in this study were similar to values found by Liu et al. (2006), Muñoz-Robredo et al. (2011), and Soyer et al. (2003).

Nutraceuticals (total anthocyanins, total phenolic acids, total ellagitannins, and total flavonols) were evaluated only at harvest (day 0) with total nutraceuticals of 3.01-65.01 mg/100 g (Table 2). At harvest, total anthocyanins, total phenolic acids, and total flavonols were different among the cultivars (Fig. 2), but there were no ellagitannins in these grapes. 'Gratitude', a green-skinned cultivar, had the lowest level ($\leq$3 mg/100 g) of total anthocyanins, total phenolics, total flavonols, and total nutraceuticals as would be anticipated for a grape of this skin color. 'Jupiter', a blue-skinned cultivar, (24.44 mg/100 g) had the most anthocyanins. There was no difference in total anthocyanins when comparing the three blue-skinned cultivars (Faith, Jupiter, and Mars). 'Mars' had the most phenolic acids (39.37 mg/100 g), total flavonols (7.44 mg/100 g), and total nutraceuticals (65.01 mg/100 g). These grapes are rich in flavonoids and have high nutraceutical values. Consumption of fruit with high nutraceutical values has been linked to improved brain

function, decreased obesity and diabetes, prevent liver damage, reduce cardiovascular disease, and act as an anti-cancer agent (Georgiev et al., 2014).

At harvest, L* chroma, and hue values were impacted by cultivar (Fig. 3). ‘Gratitude’ had the highest L* (42.80) and chroma value (17.46), and lowest hue (116.82). ‘Jupiter’ had the lowest L*(28.58), and chroma (3.10), and the highest hue (299.55) at harvest. ‘Jupiter’ was in the blue to red range, and ‘Gratitude’ was in the yellow to green range. During storage, ‘Gratitude’ had the highest L* value (42.73), chroma (16.57), and lowest hue (116.76), while ‘Jupiter’ had the lowest L* value (27.84), chroma (2.88), and highest hue (281.05) (Table 3). Storage did not impact L* or hue, but did impact chroma. Grapes at day 14 and 21 had lower chroma values as compared to day 0. This indicates a decreasing degree of colorfulness, as increasing chroma value is positively related to colorfulness in the fruit during storage (International Commission on Illumination, 1970). The decrease in chroma during the 21 d storage indicated the color intensity of the berries decreased as the fruit began to senesce. However, L* and hue did not change during storage, indicating significant browning did not occur.

The firmness attributes of the table grapes at harvest included firmness (3.03-4.35 N) and skin elasticity (4.12-9.03 mm) (Table 2). ‘Mars’ had the highest firmness (4.35 N) and skin elasticity (9.03 mm). ‘Jupiter’ had the lowest firmness (3.03 N), and ‘Gratitude’ had the lowest skin elasticity (4.12 mm) at harvest. During storage, firmness was impacted by cultivars (Table 3). ‘Mars’ had the highest firmness (4.39 N) and skin elasticity (9.14 mm), and ‘Gratitude’ had the lowest firmness (3.25 N) and skin elasticity (4.48 mm). Storage did not impact either texture attribute. Increased crop densities have been positively correlated with increased berry firmness as the berries are smaller and less mature (Leão and Lima, 2017).

Marketability attributes (weight loss, berry drop, and decay) were evaluated during storage (Table 3). There was a significant storage x cultivar interaction for weight loss (Fig. 4). Weight loss increased in each cultivar during storage, but was low (< 4%). At 21 d, 'Faith' had the most weight loss, and 'Mars' and 'Jupiter' had the least. During storage 'Faith' had the most berry drop (2.65%) and decay (3.36%), and 'Mars' had the least berry drop (0.00%) and decay (0.05%) (Table 3). Storage did not impact berry drop or decay. Overall, decay was low (<3.5%). Previous studies indicated high tunnels decreased the presence of gray mold in small fruits such as strawberries by reducing the moisture from rain on the plant (Burlakoti et al., 2013). This form of protection by the high tunnel could have contributed to the low overall decay of the grapes.

Traditionally grown table grapes

Four University of Arkansas cultivars (Gratitude, Hope, Jupiter, and Mars) and two advanced selections (A-2497 and A-2755) were harvested and evaluated at 0, 7, 14, and 21 d at 2 °C (Tables 2 and 3). Cluster weight and nutraceuticals were evaluated only at harvest. During storage, berry weight, soluble solids, pH, titratable acidity, L*, chroma, hue, firmness, and weight loss had significant storage x genotype interactions. However, skin elasticity, total sugars, individual sugars, total organic acids, individual organic acids, berry drop, and decay did not have significant interactions (Table 4).

At harvest, the grapes had cluster weights of 142.37-433.74 g and berry weights of 3.29-4.91 g (Table 2). 'Mars' (4.91 g) had the highest berry weight, and 'Gratitude' (3.29 g) the lowest. At harvest, there was no difference among the genotypes for cluster weight. During storage, there was a significant storage x genotype interaction for berry weight (Fig. 5). At 21 d, A-2755 (6.69 g) had the highest berry weight, and 'Gratitude' (3.38 g) had the lowest. During

storage A-2755 had a significantly higher berry weight on day 21 as compared to 0 d. Commercial berry weight of table grapes can be controlled with growth regulators, such as gibberellic acid. In an experiment on 'Thompson Seedless' table grapes, the berry weight of control fruit (untreated) was 3.55 g, and the berry weight of vines sprayed with gibberellic acid was 4.01 g (Abu-Zahra, 2010).

The soluble solids (12.50%-16.10%), pH (3.26-3.82), and titratable acidity (0.34%-0.53%) of these table grapes were evaluated at harvest. At harvest, 'Gratitude' had the lowest soluble solids and pH, 'Hope' had the highest soluble solids, A-2497 had the lowest titratable acidity, and 'Gratitude' and 'Jupiter' had the highest titratable acidity (Table 2). Composition (soluble solids, pH, and titratable acidity) during storage had significant storage x genotype interactions (Fig. 6). At 21 d, there was no significant change in soluble solids or titratable acidity within a genotype, compared to 0 d. A-2497 had a significantly lower pH at 21 d compared to 0 d, however, all other genotypes had no significant change during storage.

Total sugars, individual sugars, total organic acids and individual organic acids were not impacted by genotype at harvest. At harvest, the average total sugars and total organic acids were 7.62 g/100g and 0.51 g/100 g, respectively (Table 2). Total sugars, glucose, and fructose were evaluated during storage and neither storage nor genotype had a significant impact. As previously mentioned, glucose and fructose were present in a 1:1 ratio in these six genotypes. The average total sugars, glucose, and fructose were 7.73 g/100 g, 3.77 g/100 g, and 3.99 g/100 g, respectively. Total organic acids and tartaric acid were not impacted by genotype or storage, however, isocitric acid and malic acid were impacted by genotype. The average total organic acids and tartaric acid were 0.50 g/100 g, and 0.31 g/100 g, respectively. Tartaric acid was the predominant acid in all genotypes. 'Mars' (0.10 g/100 g) had the highest isocitric acid, and A-

2497 and ‘Hope’ (0.07 g/100 g) the least. ‘Jupiter’ (0.20 g/100 g) had the most malic acid, and A-2497 (0.06 g/100 g) had the least. Storage did not impact isocitric acid or malic acid. The organic acids and sugars found in this study were similar to studies done by Liu et al. (2006), Muñoz-Robredo et al. (2011), and Soyer et al. (2003).

Nutraceuticals (total anthocyanins, total phenolic acids, total ellagitannins, and total flavonols) were evaluated only at harvest (day 0). There were no ellagitannins in the fruit, similar to the fruit grown in the high tunnel (Fig. 7). At harvest, the table grapes had total nutraceuticals of 3.96-64.61 mg/100 g (Table 2). ‘Mars’ had the highest total nutraceuticals (64.61 mg/100 g), and ‘Gratitude’ had the least (3.96 mg/100 g). Total anthocyanins, total phenolic acids, total flavonols, and total nutraceuticals were different among the genotypes. A-2755 (34.13 mg/100 g) had the most anthocyanins and A-2497, ‘Gratitude’, and ‘Hope’ (0.00 mg/100 g) the least. When comparing the three blue-skinned genotypes (A-2755, Jupiter, and Mars), A-2755 and ‘Mars’ had higher total anthocyanins than ‘Jupiter’. ‘Mars’ had the most phenolic acids (26.90 mg/100 g) and A-2755 (1.38 mg/100 g) the least. A-2755 had the most flavonols (8.58 mg/100 g) and ‘Gratitude’ (0.48 mg/100 g) the least. As seen in this study, blue grapes have anthocyanins, which greatly increase the total nutraceuticals of the berries.

At harvest, L*, chroma, and hue were impacted by genotype (Fig. 8). ‘Hope’ and ‘Mars’ had the highest L* values, 40.55 and 39.27, respectively and the highest chroma values, 15.27 and 13.75, respectively. A-2755 and ‘Gratitude’ had the highest hue, 311.83 and 257.39, respectively at harvest. During storage L*, chroma, and hue had significant storage x genotype interactions (Fig. 9). ‘Hope’ and ‘Mars’ had the highest L* value during all storage days. ‘Rolle et al. (2013) found similar L* values for colored table grapes ranging from 25.68-28.57. A-2755 and ‘Gratitude’ had the highest mean hue values across all storage days. At 21 d, there was no

significant change in L*, chroma, or hue, within a genotype, as compared to 0 d. Careño et al. (1995) found that the relationship between these color values is appropriate for defining optimum color of red grapes known as the color index for red grape (CIRG). A CIRG value of >5 was identified as optimum for red table grape, but was not observed at harvest in any of the genotypes in this study.

At harvest, the table grapes had firmness of 2.53-4.21 N and skin elasticity of 3.18-7.03 mm (Table 2). 'Gratitude' had the lowest firmness and skin elasticity, and 'Mars' had the highest firmness, and A-2497 at the highest skin elasticity at harvest. Texture attributes were evaluated during storage, and there was a significant storage x genotype interaction for firmness, but not skin elasticity (Fig. 10). 'Mars' had the highest firmness at harvest (4.21 N) and after 21 d (3.72 N), and 'Gratitude' had the lowest at harvest (2.53 N) and after 21 d (2.46 N). Storage did not impact skin elasticity, but genotype had an impact. A relationship between the firmness and skin elasticity has been used to describe berry firmness, but limited work on the relationship between instrumental and sensory texture attributes have been performed to correlate ideal texture analysis methods and properties (Rolle et al., 2011). However, it has been shown that consumers tend to prefer firmer grape berries. Flesh hardness of grapes has been defined as soft to very firm where 0.074-0.391 N/mm, firmness divided by skin elasticity, is the established descriptor (Giacosa et al., 2014). 'Gratitude' and 'Mars' from this study at harvest would be classified as extremely firm with values of 0.79 N/mm and 0.80 N/mm, respectively.

Marketability attributes (weight loss, berry drop, and decay) were evaluated during storage (Table 4 and Fig. 11). There was a significant storage x genotype interaction for weight loss, but not for berry drop or decay (Fig. 11). Weight loss was low (< 4.5%) but did increase during storage. At 21 d, A-2755 had the most weight loss, and 'Jupiter' had the least. Clamshells

or covered packages with lids have been shown to control weight loss in Arkansas cultivars which likely attributed to the low weight loss in this study (Perkins-Veazie et al., 1992). A-2755 had the most berry drop (8.89%), and 'Gratitude' (2.29%) the least. Genotype did not impact decay. Berry drop and decay were higher on 21 d as compared to 0 d. Decay in vineyards, which is predominantly caused by *Botrytis cinerea*, or gray mold, is regularly controlled by fungicides, sulfur dioxide, biocontrol agents, or antimicrobials such as essential oils (Romanazzi et al., 2012). However, no control was used on the grapes in this study to quantify the resistance of the plant. Overall, decay was low (<3.5%) for the genotypes in this study.

Marketability and texture of table grapes at 21 d storage

At 21 d storage at 2 °C, the marketability attributes (weight loss, berry drop, and decay), and texture attributes (firmness and skin elasticity) of the table grape genotypes were apparent in both production methods (Figs. 12 and 13). There was no difference in either production method for decay or berry drop for the table grapes evaluated, but there were differences in weight loss, firmness and skin elasticity. In a commercial setting, fruit that is resistant to weight loss, berry drop, and decay and retains good texture during storage is preferable because higher quality fruit would reach the consumer and earn a higher price at market. In the high-tunnel grown vineyard, 'Jupiter' and 'Mars' had the lowest weight loss, 'Mars' had the highest firmness and skin elasticity (Fig. 12). In the traditionally-grown vineyard, A-2755 had the greatest weight loss, 'Gratitude' had the lowest, firmness and skin elasticity, 'Jupiter' had the lowest weight loss, 'Mars' had the highest firmness, and A-2497 had the highest skin elasticity (Table 13).

Comparisons of the two production methods showed that the fruit grown in a high tunnel performed better than the fruit traditionally-grown (Fig. 14). Weight loss, berry drop, and decay were lowest and firmness and skin elasticity were highest in fruit grown in a high tunnel. High

tunnels with blackberries have been shown to improve marketability by increasing yield, reducing disease, and improving quality (Demchak, 2009), which is evident in the lower decay of the grape clusters grown in the high tunnel. Although these grapes were grown in different locations, this research demonstrates a general comparison of the two production methods. Fruit grown in a high tunnel was of higher quality than traditionally-grown fruit.

Conclusion

Analysis of the physiochemical and marketability attributes at harvest and during postharvest storage at 2 °C, indicated that genotype had the most impact on the quality of Arkansas table grapes regardless of production method. Many of the attributes varied by genotype, but berry color (blue versus green) also played a key role in analytically measured berry color and nutraceutical content. At harvest, the fruit from both production methods had similar size, composition, nutraceutical content, and texture.

Production method did not have a significant impact on physiochemical attributes, but had a greater impact on marketability attributes of these Arkansas table grapes for fresh market. While grapes from both production methods performed well during storage with respect to physiochemical attributes, the high tunnel table grape cultivars had better marketability attributes than the traditionally-grown table grapes. The high tunnel cultivars had a low degree of decay and berry drop in the clamshell. The marketability attributes of the traditionally-grown table grapes were more negatively impacted during storage as demonstrated by greater decay and berry drop.

‘Jupiter’, regardless of production method, had the low weight loss and decay, and high firmness during storage. Additionally, ‘Mars’ grown in the high tunnel and A-2497 grown in the traditional vineyard had good marketability and texture during storage. This study demonstrated

that high tunnel production could lead to better marketability and quality in fresh-market table grapes. If genotypes, such as ‘Jupiter’ and A-2497, have good performance in the traditional vineyard in Arkansas, then growing these genotypes in a high tunnel may provide additional improvement on the quality of the fruit. This study demonstrates the potential for a table grape industry in Arkansas.

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Tables

Table 1. Table grape genotypes harvested, Fayetteville and Clarksville, AR (2017).

Production method	Location	Harvest date	Genotype	Skin color
Traditional	Fayetteville	20 July	Jupiter	Blue
		26 July	Faith	Blue
		3 August	Mars	Blue
		24 August	Gratitude	Green
High tunnel	Clarksville	19 July	Jupiter	Red
		26 July	A-2755	Green
		8 August	A-2497	Red
		8 August	Hope	Green
		8 August	Mars	Red
		16 August	Gratitude	Green

Table 2. Initial physiochemical attributes of traditional and high-tunnel grown table grape genotypes. Fayetteville and Clarksville, AR (2017).

Production method	Genotype	Cluster weight (g)	Berry weight (g)	Soluble solids (%)	pH	Titratable acidity (%)	Firmness (N)	Skin elasticity (mm)	Total organic acids (g/100 g)	Total sugars (g/100 g)	Total nutraceuticals (mg/100 g)
Traditional											
	A-2497	142.37 a[z]	3.66 b	15.90 a	3.82 a	0.34 c	3.44 ab	7.03 a	0.27 a	4.49 a	10.86 c
	A-2755	254.80 a	3.35 b	15.60 ab	3.59 ab	0.40 bc	3.30 ab	3.58 cd	0.34 a	7.11 a	44.09 b
	Gratitude	433.74 a	3.29 b	12.50 c	3.26 c	0.53 a	2.53 b	3.18 d	0.77 a	7.41 a	3.96 c
	Hope	215.05 a	3.93 ab	16.10 a	3.46 bc	0.48 ab	2.60 b	5.05 bc	0.58 a	9.72 a	6.60 c
	Jupiter	172.60 a	3.34 b	15.60 ab	3.69 ab	0.53 a	3.19 b	3.80 bcd	0.57 a	9.21 a	27.80 b
	Mars	282.57 a	4.91 a	13.50 bc	3.67 ab	0.43 abc	4.21 a	5.33 b	0.50 a	7.79 a	64.61 a
	P value	*0.2256*	*0.0012*	*0.0014*	*0.0003*	*0.0009*	*0.0008*	*<0.0001*	*0.7358*	0.5167	<0.0001
High tunnel											
	Faith	246.95 a	3.21 bc	15.90 a	3.44 ab	0.47 ab	3.13 ab	4.43 b	0.27 a	4.45 a	33.36 b
	Gratitude	359.28 a	2.38 c	12.00 b	3.13 b	0.65 a	3.46 ab	4.12 b	0.33 a	3.95 a	3.01 c
	Jupiter	256.83 a	4.56 a	17.30 a	3.71 a	0.42 b	3.03 b	4.50 b	0.51 a	9.56 a	34.25 b
	Mars	201.64 a	3.65 ab	16.90 a	3.33 b	0.52 ab	4.35 a	9.03 a	0.51 a	7.77 a	65.01 a
	P value	*0.0563*	*0.0011*	*0.0002*	*0.0074*	*0.0123*	*0.0030*	*0.0007*	*0.2304*	*0.2507*	*0.0001*

[z]Genotypes were evaluated in triplicate (n=3). Means with different letter(s) for each attribute within effects and production methods are significantly different ($p<0.05$) using Tukey's Honestly Significant Difference test.

Table 3. Main and interaction effects for composition, color, and marketability attributes of high-tunnel table grape cultivars stored at 2 °C for 0, 7, 14, and 21 d. Fayetteville, AR (2017).

	Soluble solids (%)	**pH**	**Titratable acidity (%)[y]**	**Malic acid (g/100 g)**	**L***	**Chroma**	**Hue**	**Firmness (N)**	**Skin elasticity (mm)**	**Berry drop (%)**	**Decay (%)**
Storage											
Day 0	15.50 a[z]	3.40 a	0.51 a	0.06 a	32.59 a	8.84 a	198.01 a	3.49 a	5.52 a	0.63 a	0.77 a
Day 7	16.80 a	3.39 ab	0.50 a	0.09 a	33.27 a	7.69 ab	187.96 a	3.73 a	6.15 a	0.86 a	1.37 a
Day 14	16.30 a	3.35 ab	0.53 a	0.08 a	31.62 a	6.51 b	248.24 a	3.55 a	6.14 a	1.41 a	1.77 a
Day 21	16.40 a	3.29 b	0.54 a	0.07 a	32.41 a	7.15 b	215.84 a	3.50 a	5.88 a	2.47 a	2.32 a
P value	*0.1397*	*0.0265*	*0.8148*	*0.5738*	*0.2006*	*0.0034*	*0.1259*	*0.4181*	*0.2508*	0.1309	0.4465
Cultivar											
Faith	17.20 a	3.42 a	0.49 ab	0.09 ab	29.31 bc	5.81 b	215.95 a	3.34 b	4.70 b	2.65 a	3.36 a
Gratitude	13.10 b	3.10 d	0.60 a	0.06 ab	42.73 a	16.57 a	116.76 b	3.25 b	4.48 b	2.04 ab	2.72 ab
Jupiter	17.90 a	3.64 a	0.48 b	0.11 a	27.84 c	2.88 c	281.05 a	3.29 b	5.36 b	0.69 ab	0.10 bc
Mars	16.80 a	3.27 c	0.51 ab	0.03 b	30.01 b	4.94 b	236.29 a	4.39 a	9.14 a	0.00 b	0.05 c
P value	*<0.0001*	*<0.0001*	*0.0274*	*0.0068*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	0.0101	0.0016
Storage x cultivar (p value)	*0.2294*	*0.1157*	*0.5476*	*0.8326*	*0.1281*	*0.1137*	*0.1235*	*0.2639*	*0.4457*	0.5393	0.8628

[z]Genotypes were evaluated in triplicate (n=3). Means with different letter(s) for each attribute within effects are significantly different ($p<0.05$) using Tukey's Honestly Significant Difference test.

[y] Expressed as tartaric acid.

Table 4. Main and interaction effects for organic acid, and marketability attributes of traditionally-grown table grape genotypes stored at 2 °C for 0, 7, 14, and 21 d. Clarksville, AR (2017).

	Skin elasticity (mm)	**Total sugars (g/100 g)**	**Glucose (g/100 g)**	**Fructose (g/100 g)**	**Total organic acids (g/100 g)**	**Tartaric acid (g/100 g)**	**Isocitric acid (g/100 g)**	**Malic acid (g/100 g)**	**Berry drop (%)**	**Decay (%)**
Storage										
Day 0	4.66 a[z]	7.62 a	3.72 a	3.90 a	0.51 a	0.31 a	0.09 a	0.11 a	4.39 b[z]	4.34 c
Day 7	4.72 a	6.33 a	3.16 a	3.17 a	0.44 a	0.27 a	0.08 a	0.09 a	5.06 ab	4.90 bc
Day 14	4.58 a	9.53 a	4.60 a	4.93 a	0.55 a	0.34 a	0.09 a	0.11 a	6.78 ab	6.78 ab
Day 21	4.74 a	7.45 a	3.59 a	3.86 a	0.50 a	0.31 a	0.16 a	0.10 a	7.88 a	7.64 a
P value	*0.8276*	*0.1190*	*0.1651*	*0.0878*	*0.7026*	*0.7538*	*0.4240*	*0.8115*	0.0074	0.0012
Genotype										
A-2497	7.05 a	6.32 a	3.16 a	3.17 a	0.39 a	0.27 a	0.07 b	0.06 b	5.40 ab	5.93 a
A-2755	4.02 c	6.93 a	3.44 a	3.49 a	0.41 a	0.24 a	0.08 b	0.10 b	8.89 a	5.39 a
Gratitude	3.12 d	8.13 a	3.84 a	4.29 a	0.55 a	0.36 a	0.09 ab	0.11 b	2.29 b	7.25 a
Hope	5.25 b	8.28 a	4.08 a	4.20 a	0.56 a	0.38 a	0.07 b	0.11 b	3.41 b	5.44 a
Jupiter	3.88 c	8.04 a	3.95 a	4.08 a	0.53 a	0.24 a	0.09 ab	0.20 a	8.06 a	5.05 a
Mars	4.74 b	8.69 a	4.11 a	4.58 a	0.53 a	0.36 a	0.10 a	0.07 b	8.10 a	6.43 a
P value	*<0.0001*	*0.6743*	*0.7966*	*0.5325*	*0.5181*	*0.3237*	*0.0029*	*0.0008*	*<0.0001*	0.3566
Storage x genotype (p value)	*0.3934*	*0.8609*	*0.8928*	*0.8145*	*0.7313*	*0.4508*	*0.3382*	*0.5503*	*0.9999*	*0.9869*

[z]Genotypes were evaluated in triplicate (n=3). Means with different letter(s) for each attribute within effects are significantly different ($p<0.05$) using Tukey's Honestly Significant Difference test.

Figures

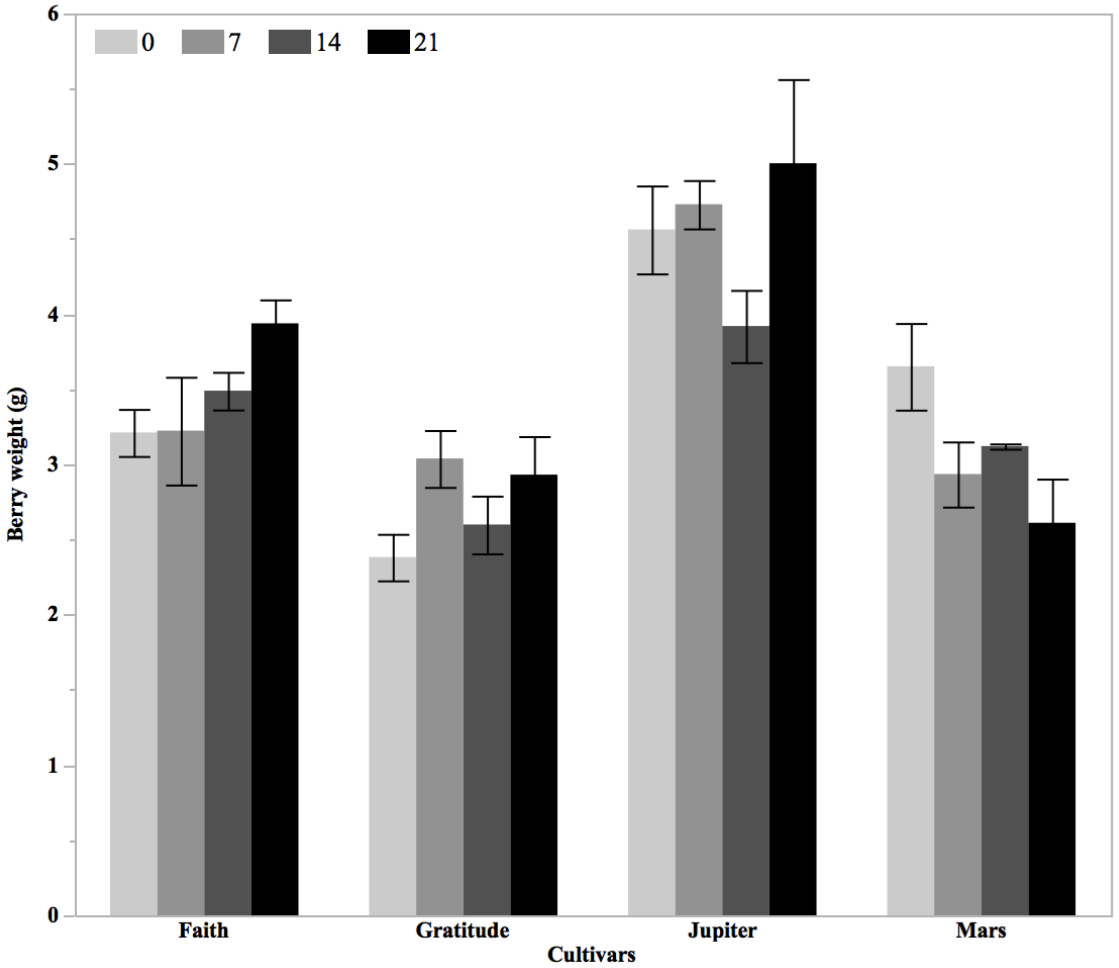


Fig. 1. Berry weight of high-tunnel table grape cultivars during postharvest storage at 2 °C for 0, 7, 14, and 21 d, Fayetteville, AR (2017). Each standard error bar is constructed using 1 standard error from the mean.

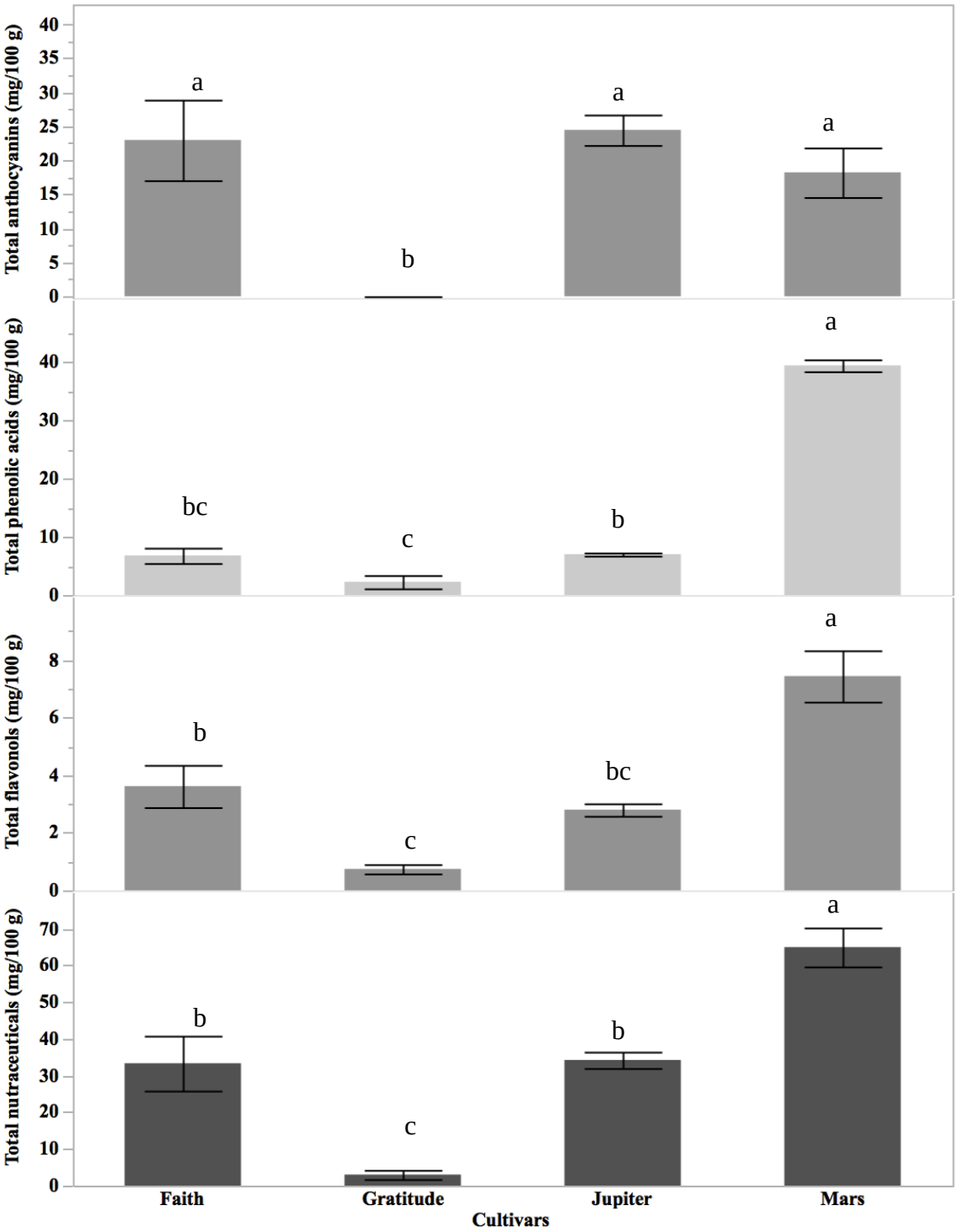


Fig. 2. Effect of cultivar on initial nutraceuticals (total anthocyanins, total phenolic acids, total flavonols) for high-tunnel table grapes, Fayetteville, AR (2017). Each standard error bar is constructed using 1 standard error from the mean. Means with different letter(s) for each attribute are significantly different ($P < 0.05$) using Tukey's Honestly Significant Difference Test.

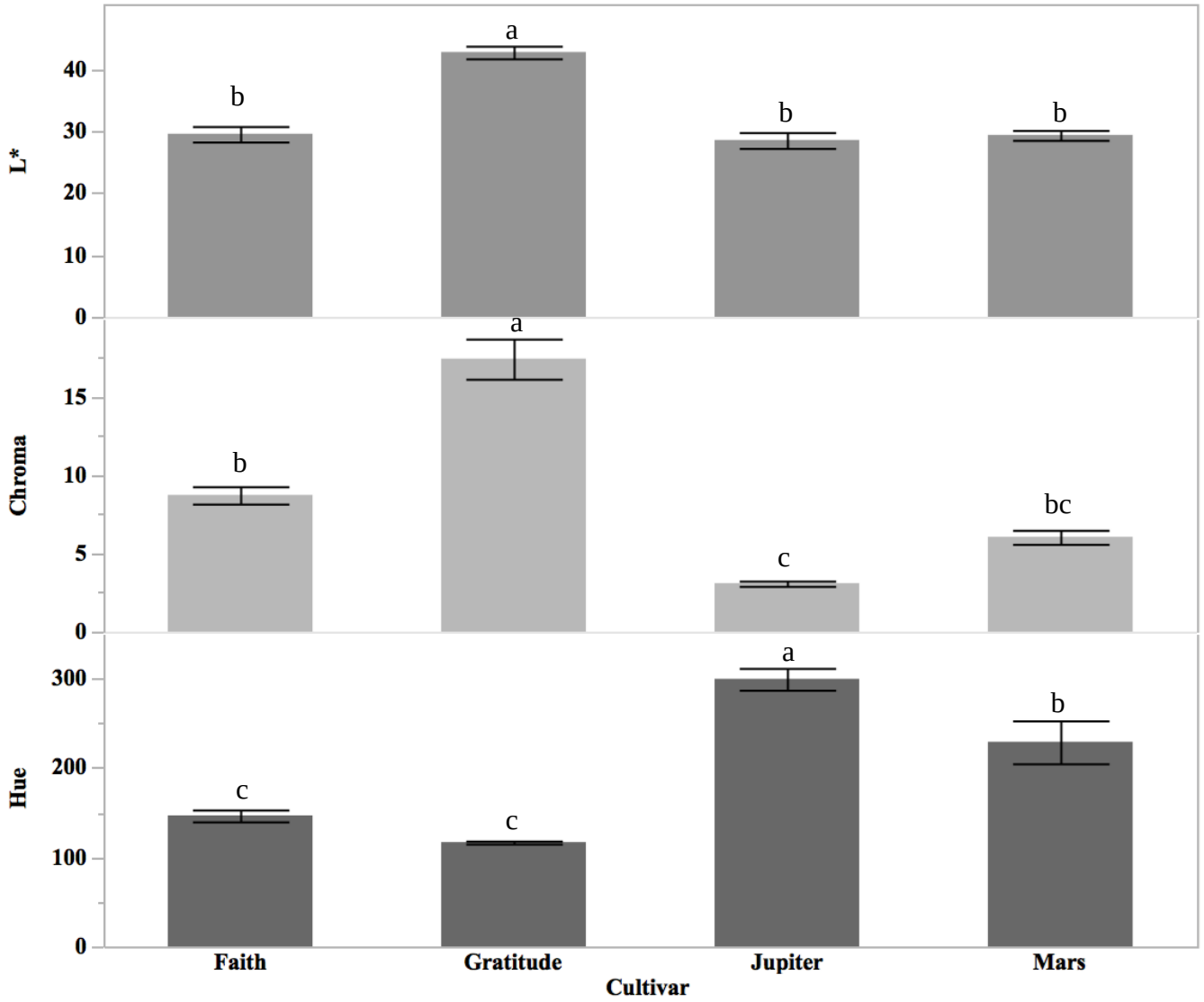


Fig. 3. Effect of cultivar on initial color attributes (L*, chroma, and hue) for high-tunnel table grapes, Fayetteville, AR (2017). Each standard error bar is constructed using 1 standard error from the mean. Means with different letter(s) for each attribute are significantly different ($P < 0.05$) using Tukey's Honestly Significant Difference Test.

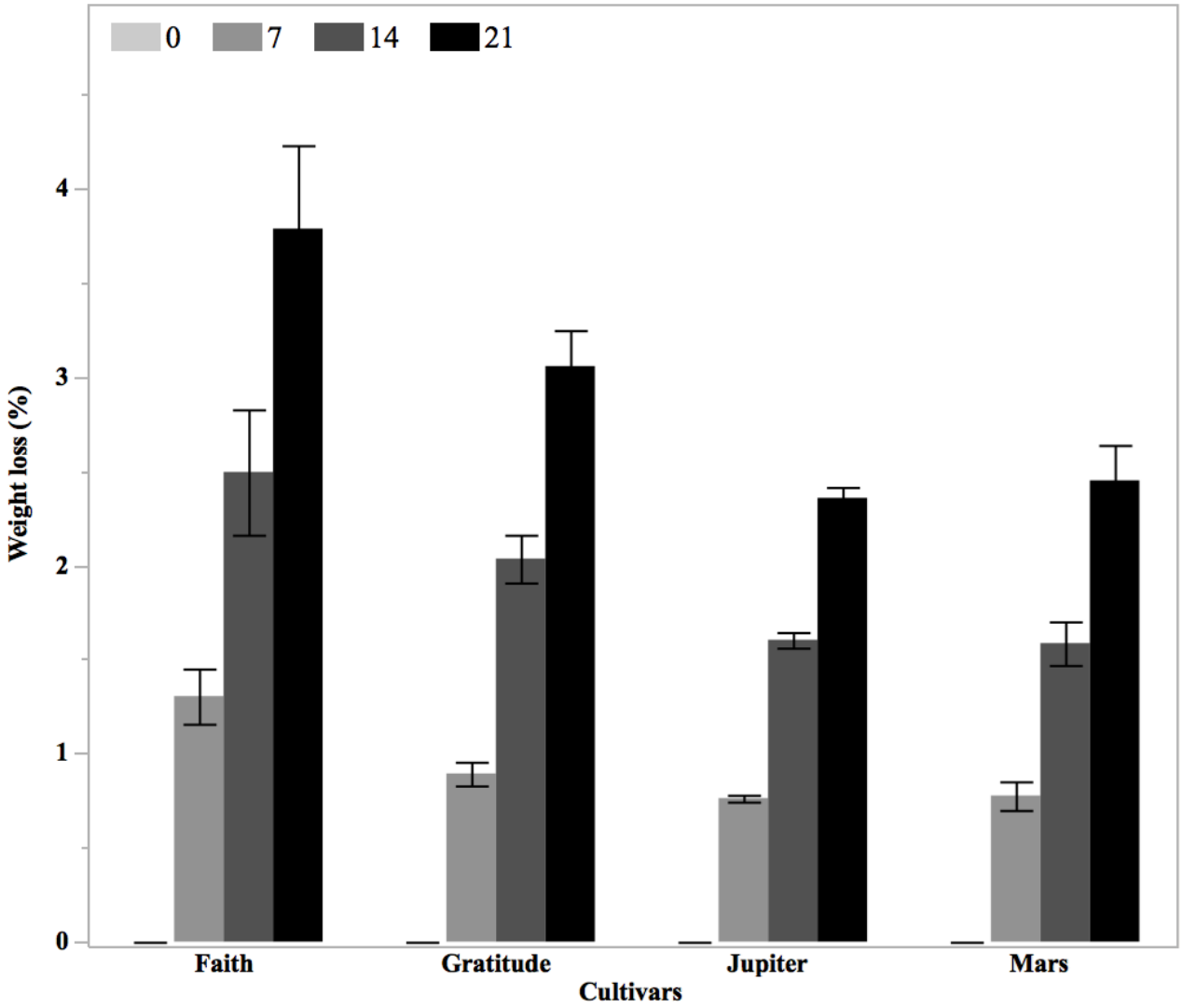


Fig. 4. Weight loss of high-tunnel table grape cultivars during postharvest storage at 2 °C for 0, 7, 14, and 21 d, Fayetteville, AR (2017). Each standard error bar is constructed using 1 standard error from the mean.

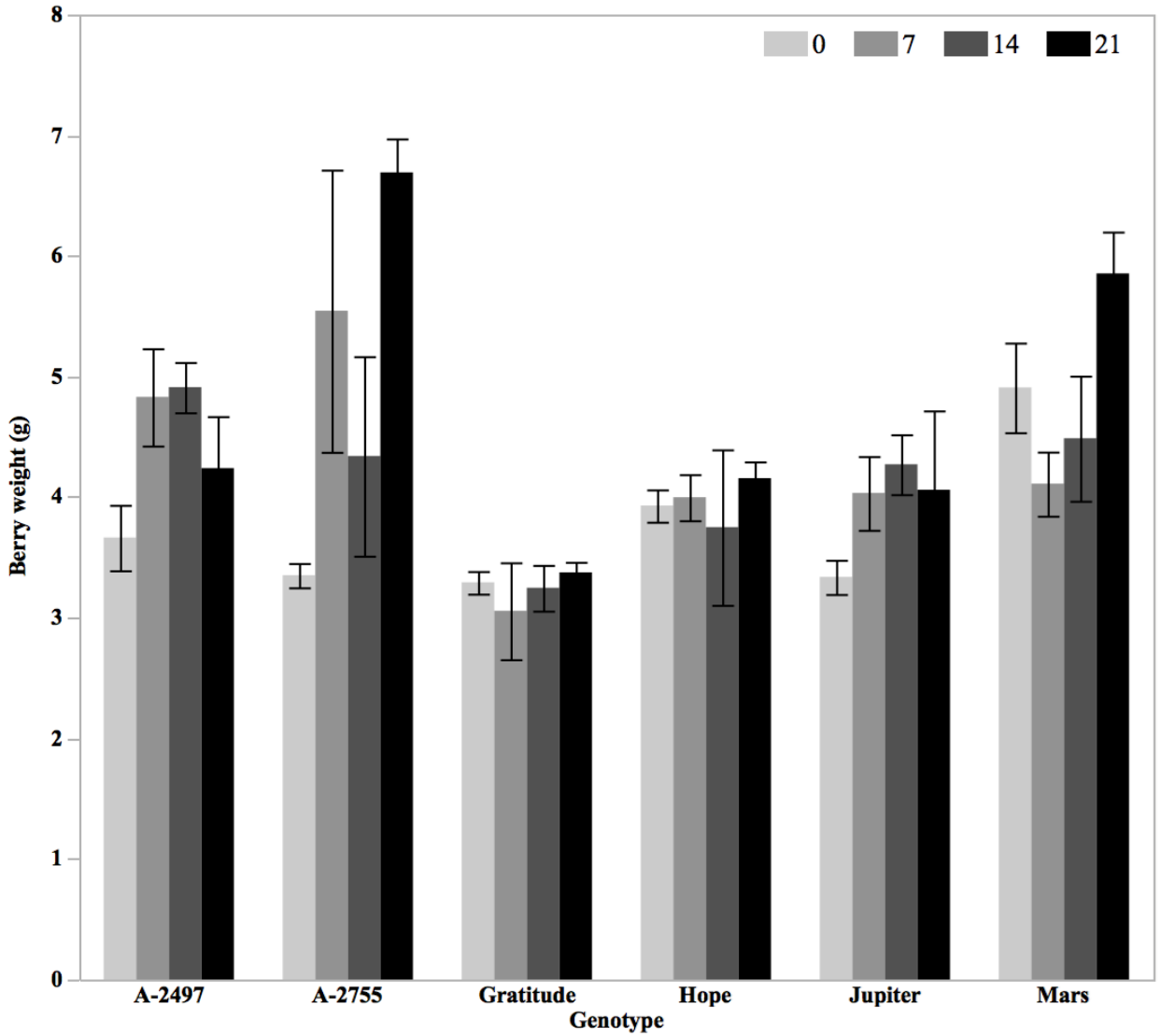


Fig. 5. Berry weight of traditionally-grown table grape genotypes during postharvest storage at 2 °C for 0, 7, 14, and 21 d, Clarksville, AR (2017). Each standard error bar is constructed using 1 standard error from the mean.

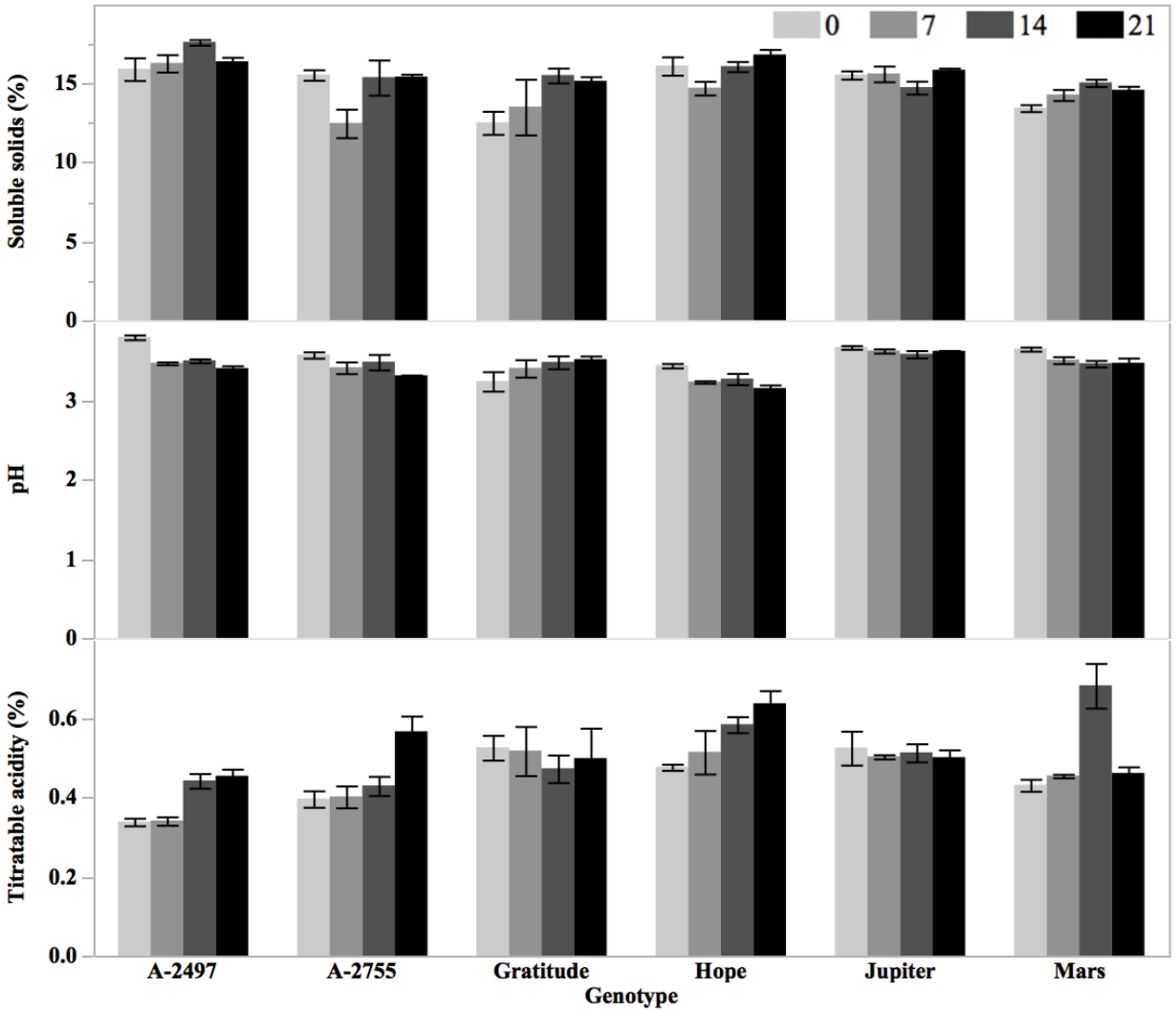


Fig. 6. Composition (soluble solids, pH, and titratable acidity) attributes of traditionally-grown table grape genotypes during postharvest storage at 2 °C for 0, 7, 14, and 21 d, Clarksville, AR (2017). Each standard error bar is constructed using 1 standard error from the mean.

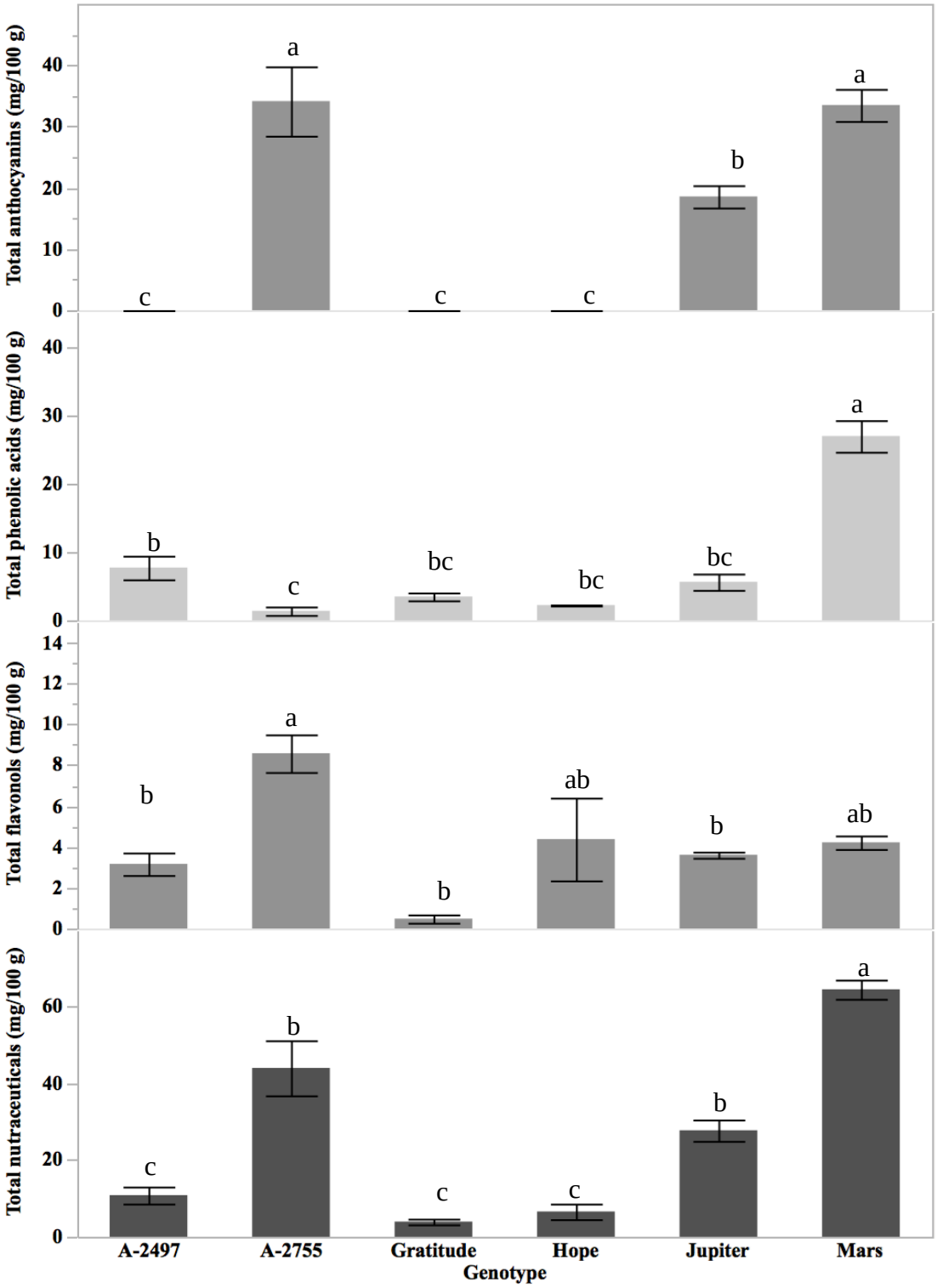


Fig. 7. Effect of genotype on initial nutraceuticals (total anthocyanins, total phenolic acids, and total flavonols) for traditionally-grown table grape genotypes, Clarksville, AR (2017). Each standard error bar is constructed using 1 standard error from the mean. Means with different letter(s) for each attribute are significantly different ($P < 0.05$) using Tukey's Honestly Significant Difference Test.

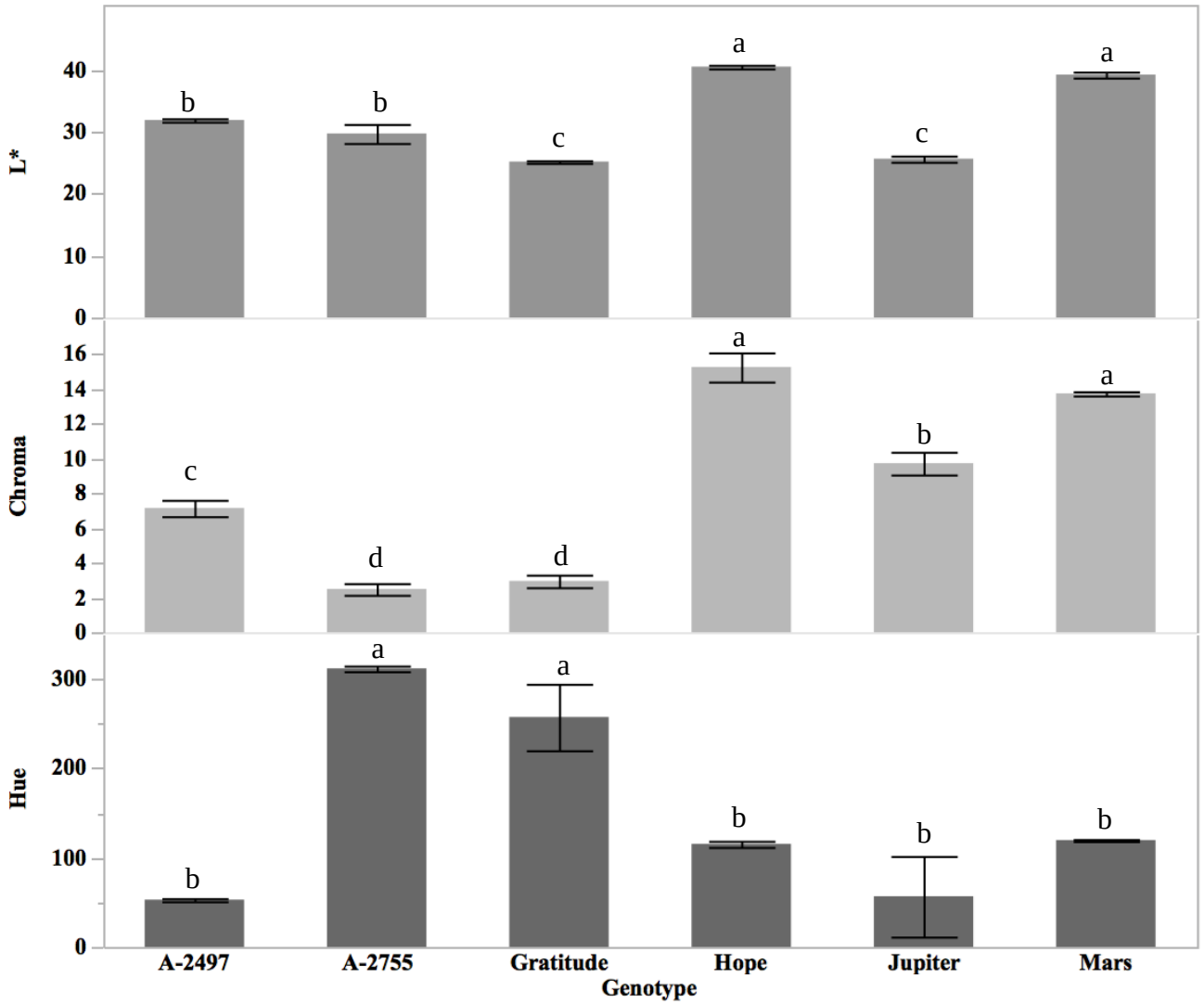
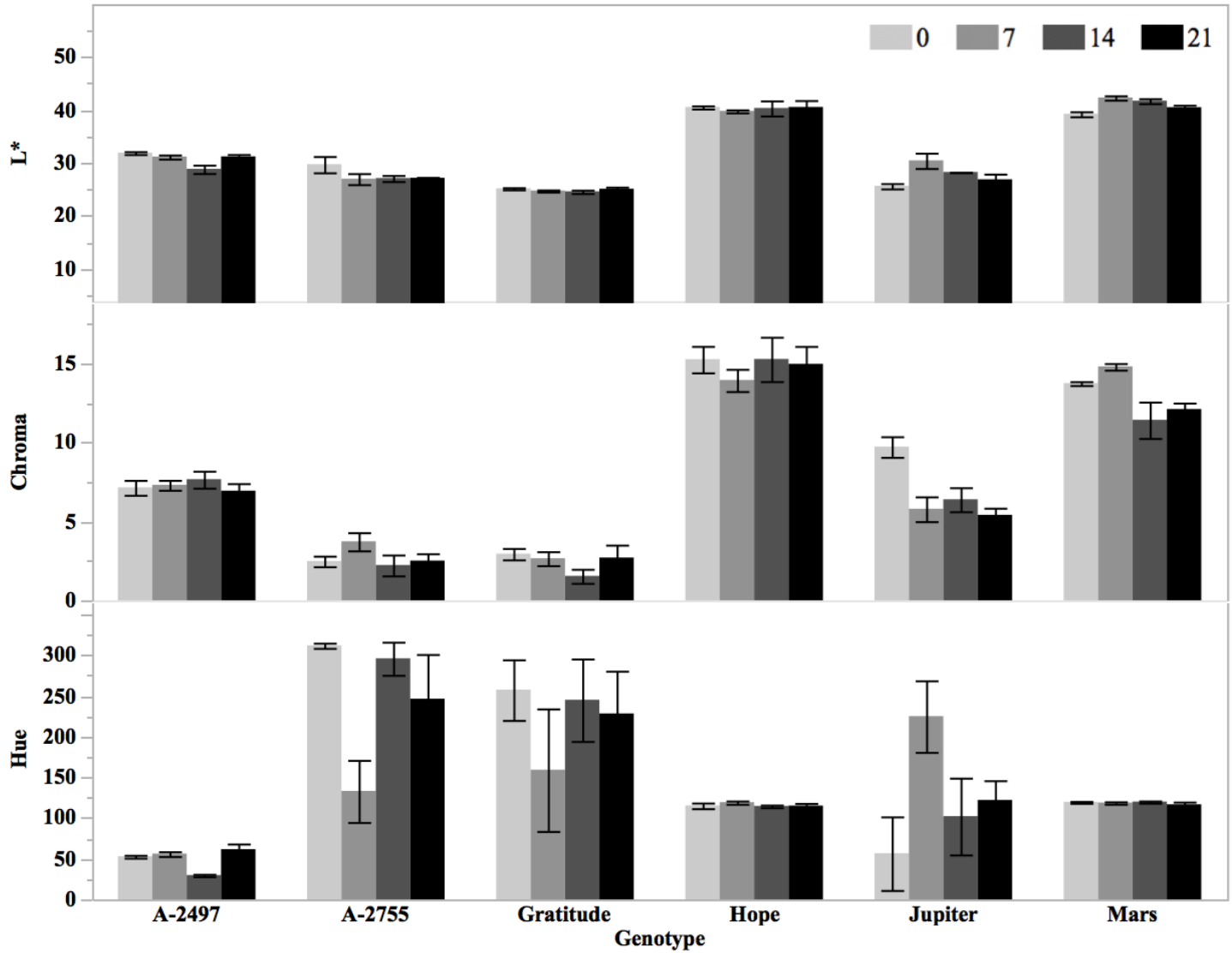


Fig. 8. Effect of genotype on initial color attributes (L*, chroma, and hue) for traditionally-grown table grapes, Clarksville, AR (2017). Each standard error bar is constructed using 1 standard error from the mean. Means with different letter(s) for each attribute are significantly different ($P < 0.05$) using Tukey's Honestly Significant Difference Test.



173 **Fig. 9.** Color (L*, chroma, and hue) attributes of traditionally-grown table grape genotypes during postharvest storage at 2 °C for 0, 7, 14, and 21 d, Clarksville, AR (2017). Each standard error bar is constructed using 1 standard error from the mean.

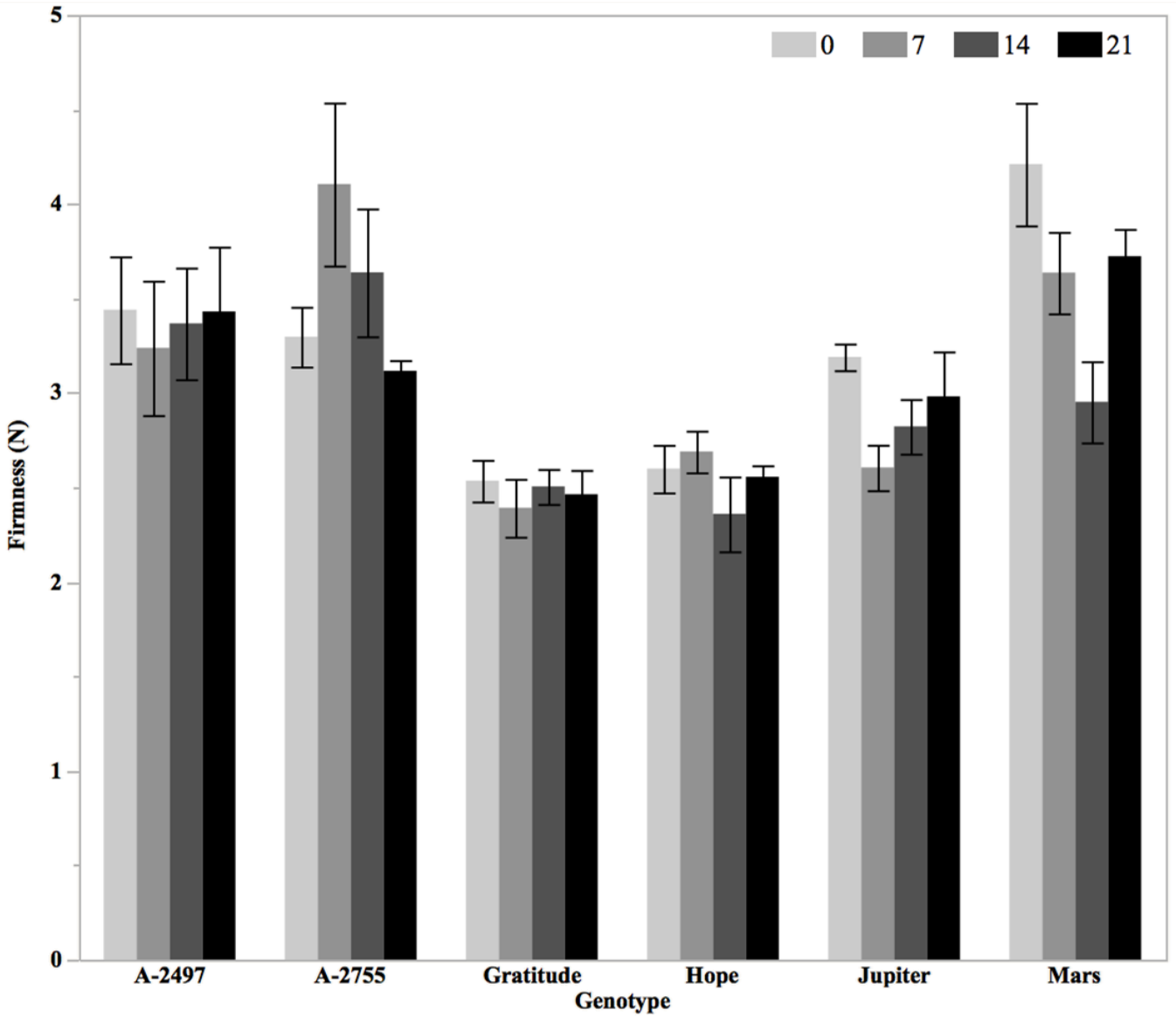


Fig. 10. Firmness of traditionally-grown table grape genotypes during postharvest storage at 2 °C for 0, 7, 14, and 21 d, Clarksville, AR (2017). Each standard error bar is constructed using 1 standard error from the mean.

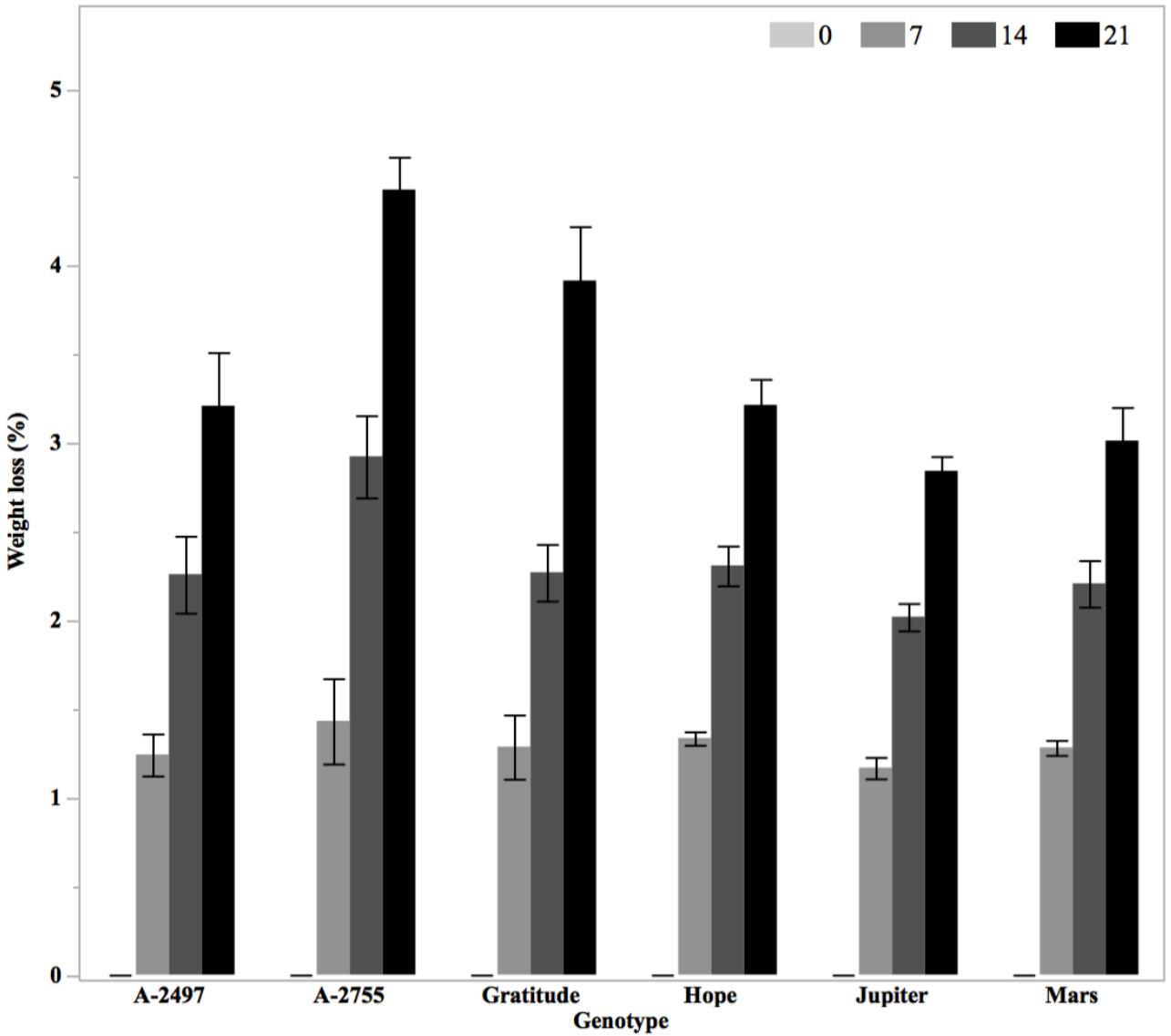


Fig. 11. Weight loss of traditionally-grown table grape genotypes during postharvest storage at 2 °C for 0, 7, 14, and 21 d, Clarksville, AR (2017). Each standard error bar is constructed using 1 standard error from the mean.

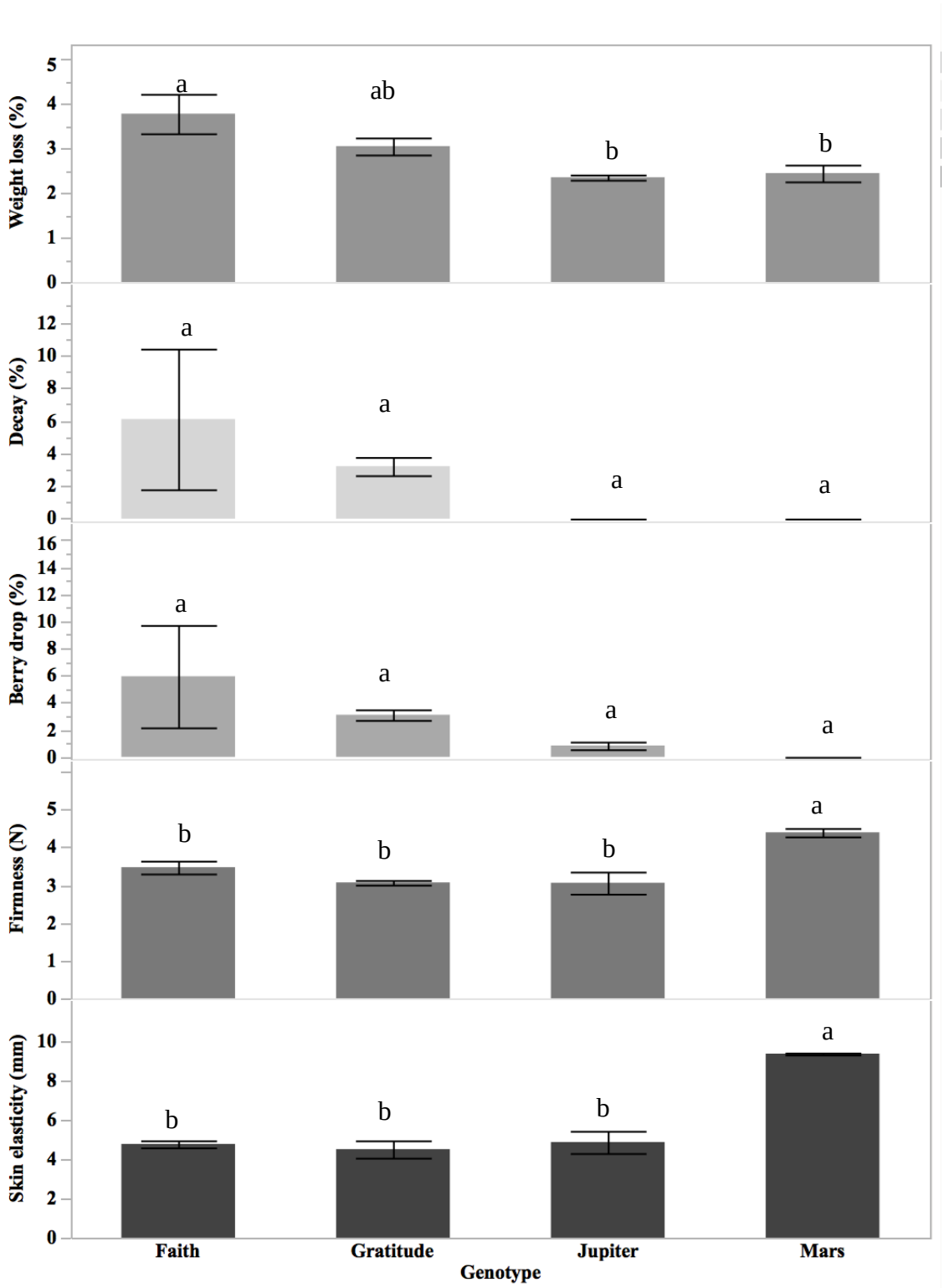


Fig. 12. Marketability and texture attributes of high-tunnel table grape genotypes at 21 days storage at 2 °C, Clarksville, AR (2017). Each standard error bar is constructed using 1 standard error from the mean.

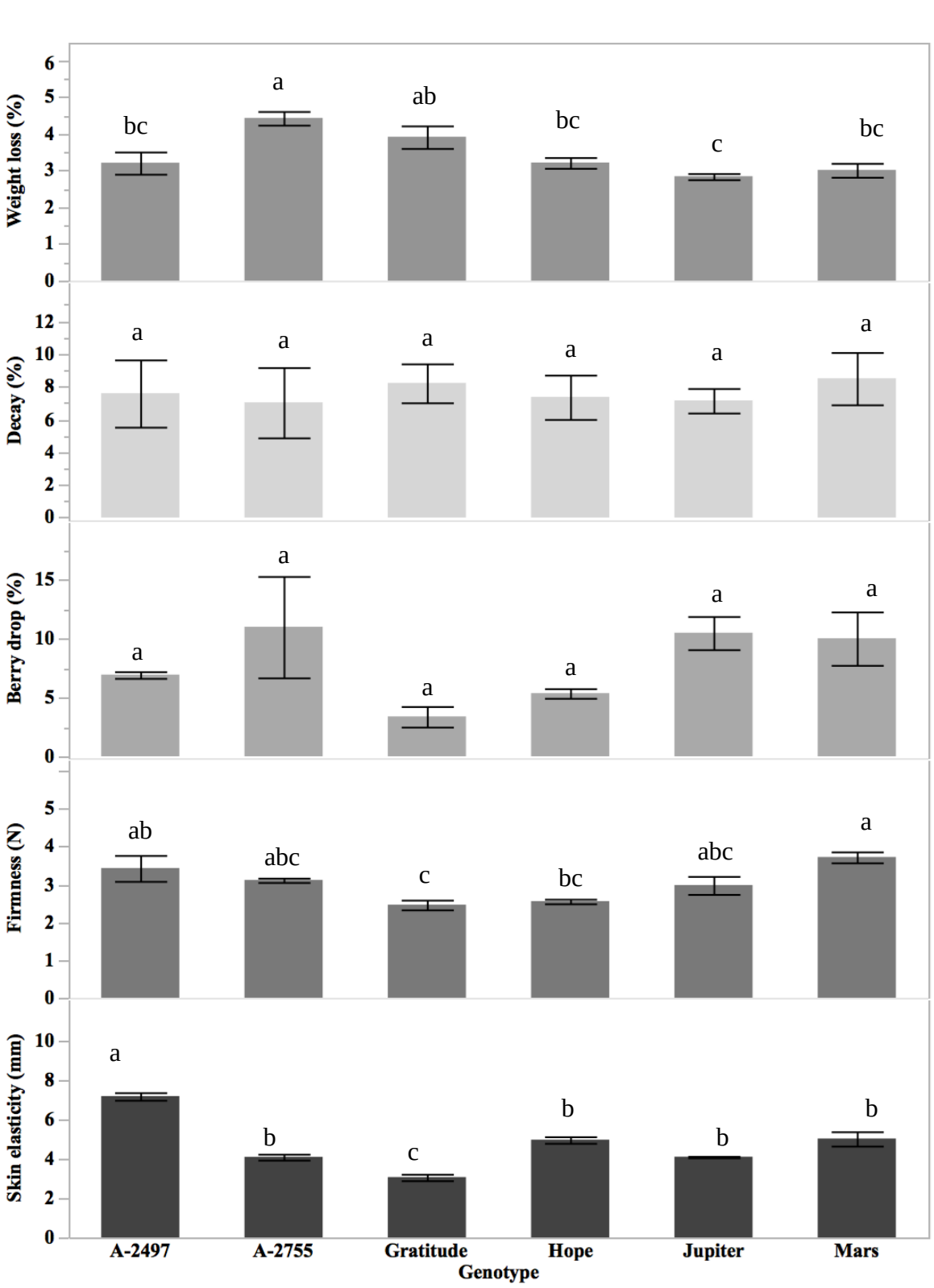


Fig. 13. Marketability and texture attributes of traditionally-grown table grape genotypes at 21 days storage at 2 °C, Clarksville, AR (2017). Each standard error bar is constructed using 1 standard error from the mean.

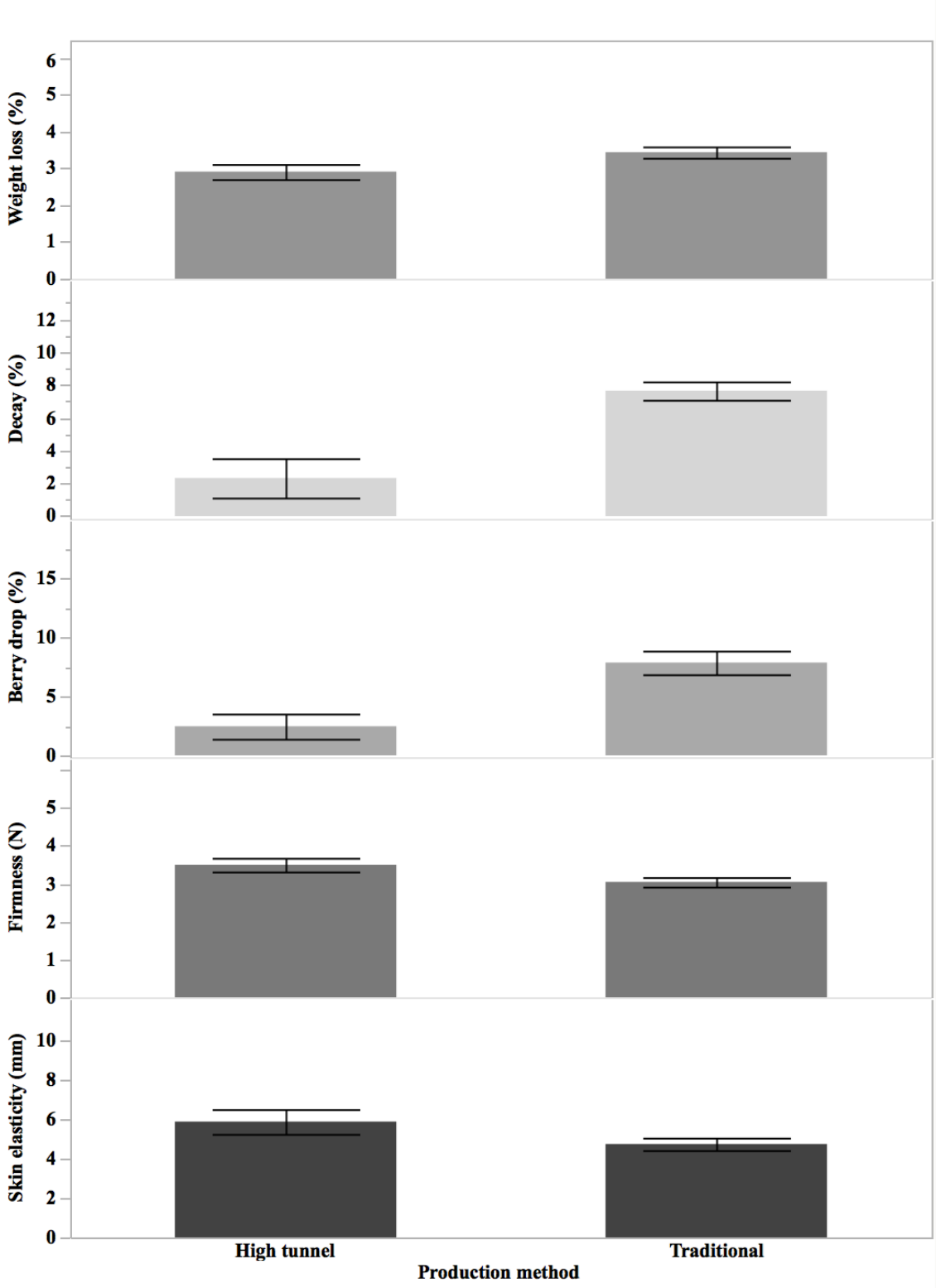


Fig. 14. Marketability and texture attributes of different production methods at 21 days storage at 2 °C, Clarksville and Fayetteville, AR (2017). Each standard error bar is constructed using 1 standard error from the mean.

Chapter IV

Physiochemical, Marketability, and Sensory Analysis of Arkansas-Grown Muscadine Grapes for Fresh Market

Abstract

Understanding how consumer perception is related to physiochemical attributes and how storage affects fruit quality assists in identification of harvest, ripeness, and marketability parameters of muscadine grapes [*Vitis rotundafolia* Michx.]. Three muscadine cultivars (Ison, Nesbitt, and Summit) and three advanced breeding selections (AM-9, AM-74, and AM-83) were harvested at optimum ripeness from the University of Arkansas System Division of Agriculture Fruit Research Station in Clarksville, AR. The physiochemical and sensory attributes of the genotypes were evaluated at harvest (day 0), and physiochemical and marketability attributes were evaluated during postharvest storage (days 0, 7, 14, and 21) at 2 °C. The range of physiochemical attributes of the genotypes at harvest had a range for berry weight (9.25-14.38 g), soluble solids (12.73%-15.40%), pH (2.88-3.33), titratable acidity (0.54%-0.76%), soluble solids/titratable acidity ratio (13.12-28.49), flesh firmness (0.89-2.14 N), and skin firmness (0.85-1.48 N/mm). A trained descriptive sensory panel (n = 8) evaluated the fruit attributes for aroma (n = 9), external appearance (n = 10), internal appearance (n = 3), basic tastes (n = 3), aromatics (n = 10), feeling factors (n = 2), and texture (n = 8). No differences between genotypes were found for texture attributes in the descriptive analysis. The descriptive sensory analysis differentiated among genotypes for external appearance, internal appearance, and basic taste attributes, more specifically with positive attributes rather than negative. Of the physiochemical attributes, glucose and fructose content had the most significant correlations with the descriptive sensory attributes, followed by soluble solids/titratable acidity ratio. Additionally, many significant correlations were seen between analytical color and descriptive sensory attributes indicating that

analytical color is a strong method to evaluate the dewscriptive color attributes of the muscadines. There were significant storage x genotype interactions for the composition and marketability attributes and on day 21, AM-9 had the lowest unmarketable fruit and weight loss. The two bronze genotypes, AM-74 and 'Summit', did not perform as well as the black genotypes with respect to unmarketable fruit as the blemishes were more visible on the lighter colored fruit. Overall, the six muscadine genotypes performed well with low weight loss (<5%) and low unmarketable fruit (<11% for the black genotypes, and <28% for the bronze). Results from this study indicated that descriptive sensory analysis has the potential to describe muscadine grapes for major important attributes, and muscadine grapes had good retention of compositional attributes and marketability indicating strong potential for fresh-market.

Introduction

The muscadine grape (*Vitis rotundifolia* Michx.), sometimes known as the "bull grape" and "scuppernong", is native to the southern United States. Muscadines have a unique berry with a thick skin and musky-flavored pulp. The muscadine vines were first identified in about 1524 by Europeans in the Cape Fear River Valley in North Carolina (Morris and Brady, 2004). While many details about its discovery are unclear, the grape has been cultivated for roughly 200 years in the southern United States and flourishes in that environment. When discovered by Europeans, the muscadine grape was reported in abundance, and the land was described as "so full of grapes... on the sand and on the green soil, on the hills as on the plains, as well as on every little shrub as also climbing towards the tops of tall cedars, that I think in all the world the like abundance is not to be found" (Hendrick, 1908). Muscadine cultivation is far easier than *V. vinifera*, as the plant is adapted to the southern region (Morris and Brady, 2004). Currently, muscadines are grown in Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, North Carolina, Oklahoma, Tennessee, Texas, South Carolina, and Virginia (Olien, 1990).

Due to the high humidity and incidence of disease, grapes grown for commercial production in the southern United States need to be disease tolerant, such as muscadines, other native species (*V. labruscana*), and hybrids. Muscadines are resistant to a variety of diseases and pests such as Pierce's disease (*Xylella fastidiosa*), grape fan leaf virus (*Nepovirus spp.*), and anthracnose (*Elsinoë ampelina* Shear) (Bouquet, 1981; Hopkins, 1974; Ren and Lu, 2002). In addition to disease and pest resistance, the muscadine is capable of being a profitable crop, especially when irrigated (Carpio et al., 2006). Due to the limited production in each state, muscadine yields and profits are not typically recorded by the United States Department of Agriculture, but are categorized as grapes (table, wine, and muscadine). However, a 2006

profitability study found there were 12 southern states with ~2,025 ha of muscadine grapes grown in the United States of which ~90% were the cultivar, 'Carlos', a bronze cultivar (Cline and Fisk, 2006).

The University of Arkansas's fruit breeding program began breeding muscadines in 2005 with a focus on large fruit size, crisp texture, edible skin, self-fruitful flowers, seedlessness, and improved postharvest storability (Barchenger, 2014). An increase in the consumer liking of muscadine grapes, or a product produced from these grapes, is an important consideration in muscadine breeding and production. With fruit breeding efforts, fresh-market muscadines have potential to expand the grape market in the United States and provide a grape that is high in fiber, essential amino acids, minerals, and vitamins to the consumer (Ector, 2001). Improving consumer acceptability of this grape can be quantified with soluble solids and texture analysis during post-harvest storage, as well as through sensory analysis (Brown et al., 2016).

Consumer sensory evaluations on muscadines showed that consumers liked the flavor of the grape but disliked the seeds and tough skin (Degner and Mathis, 1980). In a consumer study by Brown et al. (2016), thinner skins and higher juice pH was associated with greater overall liking of muscadine grapes. However, the majority of studies have been focused on juice rather than the whole muscadine berry (Flora, 1979; Meullenet et al., 2008; Trappey et al., 2007). Additionally, limited published studies have been performed on descriptive sensory analysis of whole, fresh-market muscadine berries. Descriptive sensory analysis quantitatively describes fruit attributes, such as basic tastes, aroma, and texture using trained panelists and was effective in other fruits such as peaches and nectarines (Colaric et al., 2005; Contador et al., 2017). Utilization of this method has the potential to describe how an attribute is perceived by the

consumer. Descriptive sensory analysis provides valuable information for fruit breeders on fruit attributes to identify potential improvements.

Previous research has shown that muscadine grapes, pomace, and juice are rich in nutraceutical compounds and antioxidants (Lee and Talcott, 2002; Threlfall et al., 2007; Wang et al., 2010). These health-promoting compounds have both anticancer and anti-inflammatory properties, which could aid in capturing a portion of the health-focused market (Greenspan et al., 2005; Yi et al., 2005). Previous studies have shown a large portion of the phenolic compounds in muscadines are mostly found in the seeds and skin, and darker-skinned berries have higher total phenolic compounds due to anthocyanins (Pastrana-Bonilla et al., 2003; Sandhu et al., 2010).

Understanding the physiochemical, marketability, and sensory attributes of Arkansas-grown muscadine genotypes (cultivars and advanced selections) is important to demonstrate fresh-market potential. The purpose of this study was to evaluate the physiochemical attributes, marketability attributes, and descriptive sensory attributes of fresh-market muscadines at harvest and evaluate the postharvest storage potential of the fruit.

Materials and Methods

Plants and culture

Six muscadine genotypes (AM-9, AM-74, AM-83, 'Nesbitt', 'Ison', and 'Summit') were harvested from vines grown at the University of Arkansas Fruit Research Station, Clarksville AR [west-central Arkansas, lat. 35◦31'58"N and long. 93◦24'12"W; U.S. Dept of Agriculture (USDA) hardiness zone 7a; soil type Linker fine sandy loam (Typic Hapludult)]. Vines were spaced 6.1 m apart and rows were spaced 3.0 m apart. The vines were 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* Moug.*)*, bitter rot (*Greeneria uvicola* Burk*)*, and ripe rot (*Colletotrichum* spp.). The last application of any fungicide was usually done near the end of June to early July. On average, five fungicide sprays and two insecticide sprays were applied to the grapes.

Harvest

The muscadines were hand harvested in the early morning (prior to 11:00 $_{AM}$) on 19 September. The fruit was harvested at optimal ripeness and was free of major visible blemishes, flaws, or damage. About 5 kg of muscadines were harvested for each genotype. The fruit was harvested into 0.9 kg clamshells (~ six clamshells per genotype), placed in an ice chest chilled with ice packs, and transported to the University of Arkansas Department of Food Science in Fayetteville, AR. Grapes were removed from the clamshells, randomized, placed into new 0.9 kg clamshells, and stored at 2 ˚C (85% to 89% relative humidity). AM-74 and 'Summit' were bronze genotypes, and AM-9, AM-83, 'Ison', and 'Nesbitt' were black. The descriptive sensory

of the muscadines was evaluated at harvest and the physiochemical and marketability attributes were evaluated at harvest and during storage (days 0, 7, 14, and 21) at 2 °C.

Physiochemical analysis

Fruit for physiochemical analysis was done in triplicate per genotype. Each replicate was a clamshell. The physiochemical analysis included berry weight, seed weight, color, firmness, and composition evaluated at 0, 7, 14, and 21 d at 2 °C, and nutraceutical analysis evaluated at day 0. For each genotype and replication, five berries were used for berry weight and firmness, five berries were used for composition, and three berries were used for nutraceutical analysis.

Weight. Berry and seed weight was measured on a digital scale (PA224 Analytic Balance, Ohaus Corporation, Parsippany, NJ).

Color. The exterior color of the berries was analyzed using a Konica Minolta CR-400 Chroma Meter (Konica Minolta Inc, Ramsey, NJ). The color was measured 180° from the stem scar. The L*, chroma, and hue angle were evaluated. Color analysis was done to determine Commission Internationale de l'Eclairage (CIE) Lab transmission values of L*=100, a*=0, and b*=0 (C.I.E. 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 were measured. Hue angle, calculated as arctan (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. Chroma, calculated as $((a^*)^2 + (b^*)^2)^{0.5}$, identified color by which a sample appears to differ from gray of the same lightness and corresponds to intensity of the perceived color.

Firmness. Firmness 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 the 2-mm-diameter probe, at a rate of 2 mm/s with a trigger force of 0.02 N, the flesh firmness and skin firmness was measured. Flesh firmness, the force required to penetrate the fruit, was measured in Newtons (N). Skin firmness, the force required to puncture the skin divided by the distance traveled before the fruit was penetrated, was measured in Newtons/millimeters (N/mm).

Composition. The berries were frozen (-10 °C) then thawed for compositional analysis (soluble solids, pH, titratable acidity, organic acids, and sugars). The berries were thawed and squeezed through cheese cloth to extract juice. The pH and titratable acidity were measured using the Titrino plus 862 compact titrosampler (Metrohm AG, Herisan, Switzerland) with the electrode standardized to pH 4.00, 7.00, and 10.00 buffers. Titratable acidity was determined using ~6 g of juice diluted with 50 mL deionized, degassed water with a titration using 0.1 N sodium hydroxide to an endpoint of pH 8.2. Titratable acidity was expressed as percentage of tartaric acid. Soluble solids (expressed as percent) were measured using an Abbe Mark II refractometer (Bausch and Lomb, Scientific Instrument, Keene, NH). Organic acids and sugars of the fruit were determined using high performance liquid chromatography (HPLC). The remaining juice from compositional analysis was filtered through a 0.45 μm nylon filter (VWR International, Radnor, PA) and analyzed using HPLC. Glucose, fructose, tartaric acids, isocitric acid, and malic acid of the fruit was measured using previously established HPLC procedures (Walker et al., 2003; Segantini et. al., 2018). 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 (Bio-Rad, Hercules, CA). A Bio-Rad Micro-Guard Cation-H refill cartridge (30 × 4.5 mm) was used for a guard column. 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 0.45 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 35 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, isocitric, and malic 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 and acids were expressed as g/100 g, and total sugars (glucose + fructose) and total organic acids (tartaric + isocitric + malic) were expressed as g/100 g.

Nutraceuticals. Total anthocyanins, total phenolic acids (hydroxycinnamic acids), total ellagitannins, and total flavonols were measured by HPLC and ultraviolet-visible (UV-Vis) spectroscopy. Following methods described by Cho et al. (2004 and 2005), and Hager et al. (2008). The fruit was homogenized three times for 1 min in alternating washes of 30 ml of extraction solution containing methanol/water/formic acid (60:37:3 v/v/v) and acetone/water/acetic (70:29.5:0.5 v/v/v) to the smallest particle size using a Euro Turrax T18 Tissuemizer. Homogenates were centrifuged for 5 min at 10,000 rpm and filtered. The samples were taken to a final volume of 250 mL with extraction solvent and stored at -70 °C until analysis. All samples were passed through 0.45 μm filters prior to HPLC analysis. Equivalents

for the table grape nutraceuticals were determined from previous literature for the most common compounds for each class of phenolics (Benmeziane et al., 2016; Mattivi et al., 2006; Striegler et al., 2005). Total nutraceuticals were quantified as the sum (milligrams) of total anthocyanins, total flavonols, total ellagitannins, and total phenolic acids per 100 g fresh fruit weight.

Total anthocyanins and total phenolic acids. Sample extracts (7.5 mL) were dried using a Speed Vac concentrator (ThermoSavant, Holbrook, NY) and resuspended in 1 mL of 5% formic acid. The reconstituted samples were passed through 0.45-mm polytetrafluoroethylene (PTFE) syringe filters (Varian Inc, Palo Alto, CA) before HPLC analysis. The anthocyanin analysis by HPLC was performed based on previous methods (Cho et al., 2004; Hager et al., 2008). Samples (50 µL) were analyzed using a Waters HPLC system equipped with a model 600 pump, a model 717 Plus autosampler and a model 996 photodiode array detector. Separation was carried out using a 4.6 mm × 250 mm Symmetry® C18 column (Waters Corp, Milford, MA) preceded by a 3.9 mm × 20 mm Symmetry® C18 guard column. The mobile phase was a linear gradient of 5% formic acid and methanol from 2% to 60% for 60 min at 1 ml/min. The system was equilibrated for 20 min at the initial gradient prior to each injection. The anthocyanins peaks were quantified at 510 nm with results expressed as milligrams malvidin-3-glucoside equivalents per 100 g fresh fruit weight. The phenolic acid peaks were quantified at 320 nm with results expressed as milligrams of chlorogenic acid equivalents per 100 g of fresh fruit weight.

Total ellagitannins and total flavonols. Sample extracts (3 mL) were dried using a Speed Vac concentrator (ThermoSavant, Holbrook, NY) and resuspended in 1.0 mL of 50% methanol. The reconstituted samples were passed through 0.45-mm PTFE syringe filters before HPLC analysis. The ellagitannins and flavonols were analyzed according to previous methods (Hager et al., 2008, 2010). The samples (50 µL) were then analyzed using a Waters HPLC system (Waters

Corp, Milford, MA) equipped with a model 600 pump, model 717 plus autosampler and model 996 photodiode array detector. Separation was carried out using a 4.6 mm × 250 mm Aqua® C18 column (Phenomenex, Torrance, CA) preceded by a 3.9 mm × 20 mm Symmetry® C18 guard column. The mobile phase was a gradient of 20 g/L acetic acid (A) and 5 g/L acetic acid in water and acetonitrile (50:50 v/v, B) from 10% B to 55% B in 50 min and from 55% B to 100% B in 10 min. The system was equilibrated for 20 min at the initial gradient prior to each injection. The ellagitannins were quantified at 255 nm with results expressed as milligrams of ellagic acid equivalents per 100 g of fresh fruit weight. The flavonols were quantified at 360 nm with results expressed as milligrams (mg) of quercetin-3-O-glucoside equivalents per 100 g of fresh fruit weight.

Marketability analysis

Marketability analysis was performed on fruit in triplicate clamshells. The marketability analysis included total decay and weight loss evaluated at 0, 7, 14, and 21 d at 2 °C for each genotype. Stem scar tear was evaluated at harvest (day 0).

Decay and stem scar tear. The decay (visible mold or rot) and stem scar tear (tear > 2x diameter of stem scar) of the berries were calculated as (number of decayed or torn/total berries) × 100 and expressed as percent.

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

Descriptive sensory evaluation

Descriptive sensory analysis was performed at the Sensory and Consumer Research Center at the University of Arkansas, Fayetteville AR. After harvest, the fruit was stored overnight at 2 °C for sensory. The fruit was removed from cold storage, gently rinsed, and placed

on trays to air-dry. Each panelist evaluated five berries for each genotype in duplicate. The fruit was served monadically (one at a time) at room temperature (25 °C) on plates labeled with three-digit codes in a randomized complete block design. Serving order was randomized across each replication to prevent presentation order bias. Panelists were instructed to cleanse their palates with unsalted crackers and water between samples. Expectorant cups were provided. The panelists were trained to use a modified Sensory Spectrum method, an objective method for describing the intensity of attributes in products using references for the attributes. The eight descriptive panelists developed a lexicon of sensory terms for the muscadines through consensus during orientation and practice sessions (Table 1). The descriptive panel evaluated the fruit attributes for aroma (n = 9), external appearance (n = 10), internal appearance (n = 3), basic tastes (n = 3), aromatics (n = 10), feeling factors (n = 2), and texture (n = 8). The attributes were evaluated using a 15-point scale where 0 = less of an attribute and 15 = more of an attribute.

Design and statistical analysis

After harvest, the fruit from each of the ten genotypes were completely randomized. The fruit was stored at 2 °C for 0, 7, 14, and 21 d. Statistical analyses were conducted using JMP® (version 13.2.0; SAS Institute, Cary, NC). A univariate analysis of variance (ANOVA) was used to determine the significance of main factors (genotype and storage) and interactions. Tukey's Honestly Significant Difference (HSD) test was used to detect significant differences ($p < 0.05$) among means and verify interactions at 95% significance level. Least significant difference (LSD) test was used to detect significant differences ($p < 0.05$) among means for sensory data. Pairwise correlations using multivariate analysis were used to verify the relationship between/within attributes at a p-value of 0.05 at harvest and at 21 d of storage. Physiochemical

and marketability attributes were evaluated in triplicate and sensory attributes were evaluated in duplicate.

Results and Discussion

At harvest, the muscadines were within a commercially acceptable range for berry weight (9.25-14.38 g), soluble solids (12.73%-15.40%), pH (2.88-3.33), titratable acidity (0.54%-0.76%), and flesh firmness (0.89-2.14 N) (Table 2). The fruit was evaluated for physiochemical and descriptive sensory attributes at harvest and physiochemical and marketability attributes during postharvest storage.

Physiochemical attributes at harvest

The muscadines from the six genotypes were evaluated for physiochemical attributes (weight, stem scar, composition, nutraceuticals, color, and firmness). Physiochemical analysis of the genotypes at harvest was significant for all attributes except total organic acids and total sugars (Tables 2 and 3) and individual acids and sugars (data not shown).

Berry and seed weight were evaluated (Table 2). AM-74 (14.38 g) had the highest berry weight and seed weight (0.12 g). 'Summit' (9.25 g) had the lowest berry weight. AM-83 (0.09 g) had the lowest seed weight. There were usually three seeds per berry ranging from one to four (data not shown). Threlfall et al. (2007) found similar berry weight for 'Summit', but slightly lower berry weights for 'Ison' and 'Nesbitt' in Arkansas.

Stem scar tear was evaluated (Table 2). AM-74 (11.01%) had the most stem scar tear, and AM-83 (1.08%) had the least. When muscadines ripen on the vine, the fruit abscises from the stem, but can tear upon abscission. Dry stem scar, or un-torn berries, is a positive attribute for muscadines as it is a positive attribute in muscadine marketability (Clark and Barchenger, 2014).

High incidence in stem scar tear has been shown to increase decay during storage 6-10x more than un-torn berries as the tear allows pathogens to enter the berry (Ballinger and Nesbitt, 1982).

Composition (soluble solids, pH, titratable acidity, and soluble solids/titratable acidity ratio) was evaluated (Table 2). 'Summit' had the highest soluble solids (15.40%) and lowest titratable acidity (0.54%). 'Nesbitt' had the lowest soluble solids (12.73%) and 'Ison' had the highest titratable acidity (1.01%). AM-83 (3.33) had the highest pH, and 'Ison' (2.88) had the lowest. Threlfall et al. (2007) found similar soluble solids, pH, and titratable acidity levels for eight muscadine genotypes grown in Arkansas. The ratio of soluble solids to titratable acidity has proven useful for understanding how consumers perceived the balance of sugar to acid in fruit such as peaches and nectarines (Crisosto and Crisosto, 2005). 'Summit' (28.49) had the highest soluble solids/titratable acidity ratio, and 'Ison' (13.12) had the lowest. Walker et al. (2001) indicated preferred soluble solids/titratable acidity ratios of 24 to 33 for muscadine grapes. Flora (1979) and Threlfall et al. (2007) also found similar preferred ratios for muscadine juice. Using these established parameters, only three of the six genotypes (AM-9, AM-74, and Summit) in this study had an ideal ratio, with the other three having a soluble solid/titratable acidity ratio of <21.

Total organic acids and sugars were evaluated (Table 3). Overall, the total organic sugars ranged from 6.17-9.75 g/100 g, and the total organic acids ranged from 0.50-0.84 g/100 g. In addition, individual acids and sugars were evaluated for these genotypes, but there were no significant differences in glucose, fructose, tartaric, isocitric, or malic acid. At harvest, glucose and fructose were present in the fruit in a ~1:1 ratio with an average glucose content of 4.14 g/100 g and fructose content of 3.81 g/100 g. Tartaric acid was the predominant acid in the muscadines with an average tartaric acid content of 0.37 g/100 g, isocitric acid content of 0.11

g/100 g, and malic acid content of 0.21 g/100 g (data not shown). Similar organic acid and sugar contents have been observed in Arkansas-grown muscadines (Striegler et al., 2005).

Nutraceuticals (total phenolic acids, total flavonols, total ellagitannins, and total anthocyanins) were evaluated (Table 3). The nutraceutical levels were different for these attributes, except for total ellagitannins which were not present in these genotypes. In terms of the highest total nutraceuticals, 'Ison' (423.24 mg/100 g) had the highest, and AM-9 (132.27 mg/100 g) had the lowest. AM-74 (3.38 mg/100 g) had the highest total phenolic acids, and 'Summit' had the lowest total phenolic acids (0.14 mg/100 g) and highest flavonols (396.88 mg/100 g). AM-9 had the lowest flavonols (81.82 mg/100 g). 'Ison' had the highest total anthocyanins (233.38 mg/100 g), and AM-74 and 'Summit' had none (both bronze genotypes). Conner and Maclean (2013) found comparable anthocyanin content in University of Georgia muscadine grapes. A study by Huang et al. (2009) indicated that approximately 90% of the anthocyanins were 3,5-diglucoside of delphinidin, cyanidin, and petunidin as the predominant anthocyanin. However, in another Arkansas muscadine grape report, Striegler et al. (2005) quantified as total anthocyanins using malvidin-3-glucoside equivalents and found similar but slightly lower total anthocyanin content than this study. It is possible berry maturity or crop load could have impacted anthocyanin content. Barchenger et al. (2015) found similar total nutraceuticals (quantified as total phenolics) in Arkansas-grown muscadines.

Exterior berry color attributes (L*, chroma, and hue) were evaluated (Table 2). AM-74 (47.94) had the highest L* value, and AM-9 (23.85) had the lowest. Overall, the bronze genotypes had higher L* values than black genotypes. 'Summit' had the highest chroma (18.36) and hue (93.39) indicating the berry was yellow to green. AM-83 (2.47) had the lowest chroma, and AM-9 (13.89) had the lowest hue, both of which were black-skinned muscadines.

Firmness attributes (skin firmness and flesh firmness) were evaluated (Table 2). AM-83 had the highest skin firmness (1.48 N/mm) and flesh firmness (2.14 N). AM-9 (0.85 N/mm) had the lowest skin firmness, and 'Ison' (0.89 N) had the lowest flesh firmness. Conner (2013) reported flesh firmness ranging from 0.65-3.06 N in a study of 26 muscadine grape genotypes grown in Georgia. In that study, they also determined that flesh force or firmness was one of the most useful characteristics for screening in a breeding program. The findings on firmness in this study were similar to the study by Connor (2013).

Sensory attributes at harvest

As sensory analysis has been shown to explain cultivar characteristics better than instrumental measurements alone, descriptive sensory analysis was used to identify various attributes of the muscadine grapes. During orientation and training, the eight trained panelists created a descriptive sensory lexicon using Arkansas-grown muscadine grapes (Table 1). The panelists used the lexicon to evaluate the six genotypes in duplicate using a 15-point scale where 1 is less of an attribute, and 15 is more of an attribute. The panelists evaluated the fruit on seven categories of attributes (aroma, external appearance, internal appearance, aromatics, basic tastes, feeling factors, and texture). Within each category multiple attributes were evaluated.

The panelists evaluated aroma (grape/overall, grape/muscadine, grape/other, fruity, floral, earthy/dirty, mold/mildew, and overripe) of five whole, intact berries (Table 4). All of the aroma attributes were less than 6.5 on the 15-point scale indicating low-mid aroma intensity. Of the aroma attributes, the panelists detected differences between genotypes in grape/overall, grape/muscadine, and fruity. The panelists did not detect differences in grape/other, floral, earthy/dirty, green/unripe, or mold/mildew, which were low values ($\leq$0.8), and did not detect any overripe aromas. AM-74 had the highest grape/overall and grape/muscadine aroma, and

AM-83 had the least. AM-9 had the greatest fruity aroma, and AM-83 had none. The negative aroma attributes such as earthy/dirty, green/unripe, mold/mildew, and overripe were low for all genotypes (≤0.8).

The panelists then evaluated external appearance (uniformity of color, color-purple, color-bronze, glossiness, uniformity of size, size, shape, amount of blemishes/deformities, and stem scar tear) of five whole, intact berries (Table 5). Of the nine attributes, the panelists detected differences among the genotypes for all attributes except uniformity of size and amount of blemishes/deformities. The panelists found the muscadines were uniform in size (~11.6) and had a low amount of blemishes/deformities (~3.9). AM-9 had the lowest color-bronze, roundest shape, and least stem scar tear. AM-74 had the least color-purple, most color-bronze, largest size, and most stem scar tear. The size of AM-74 was close to reference C =25.4 mm (Fig.1). AM-83 was the most uniform in color, had the most color-purple, least color-bronze, most glossiness, and most oblong shape. 'Nesbitt' had the least uniformity of color and smallest size. 'Summit' had the least glossiness (most dull exterior) and smallest size along with 'Nesbitt'.

Internal appearance (visual separation, number of seeds, and seed size) was evaluated (Table 6). Seed size (~6.9) was not different among the genotypes, with seed size closest to the reference B= 4.9 x 7.1 mm (Fig. 2). AM-83 had the least visual separation and most seeds. AM-9 had the most visual separation, and AM-74 had the least seeds. In a consumer study by Degner and Mathis (1980), the primary reason consumers did not purchase muscadines in Florida was the presence of seeds. AM-74 (~3 seeds) had the least seeds indicating a slight improvement from ~4 seeds in AM-83.

Basic tastes (sweet, sour, and bitter) and feeling factors (astringent and metallic) were evaluated (Table 6). Of the attributes evaluated, the panelists detected differences among the

genotypes for all attributes except bitter (~1.0) and astringent (~6.7). AM-74 was the most sweet and least metallic, and AM-83 was the least sweet. 'Ison' was the most sour and metallic, and 'Summit' was the least sour. The sweetness ranged from 6.3-7.9 with a score of 5 = 5% solution of sucrose. The sourness ranged from 2.7-3.9 with a reference of 2 = 0.05% solution of citric acid.

The panelists evaluated aromatics (overall aromatic impact, grape/overall, grape/muscadine, grape/other, fruity, floral, earthy/dirty, mold/mildew, and overripe) of five berries (Table 4). All of the aromatic attributes were less than 10 on the 15-point scale indicating mid-low aromatic intensity. Of the attributes, the panelists detected differences between genotypes in overall aromatic impact, grape/overall, and overripe, but all other attributes were not significantly different. AM-9 was the most overripe although the value was very low (<1). Although the overripe attribute was significant, these values were mostly zero. AM-83 had the least overall aromatic impact and grape/overall aromatics. 'Summit' had the most overall aromatic impact, however, AM-9 had the most grape/overall aromatics. The panelists found that the fruit had low levels of grape/other (0.4), floral (0.7), earthy/dirty (1.0), green/unripe (1.8), and mold/mildew (0.3).

The panelists evaluated texture (uniformity of berry hardness, berry hardness, moisture release, awareness of skins, pulp crispness, detachability, fibrousness between teeth, and seed separation) of the five-berry sample (Fig. 3). However, no differences were found among the genotypes for these attributes. Uniformity of berry hardness had an average score of 12.13 indicating mid to high uniformity of intensity. All genotypes had a mid-high intensity with respect to awareness of skins (12.95), detachability (11.93), and seed separation (10.32). Panelists found a medium intensity for all genotypes with respect to berry hardness (8.30) and

moisture release (9.88). Finally, low to mid intensity was seen for all genotypes with respect to pulp crispness (3.60) and fibrousness (4.12).

Correlations between physiochemical and sensory attributes at harvest

A multivariate pairwise analysis was done to identify any significant correlations between the descriptive sensory attributes and physiochemical, color, and nutraceutical attributes at harvest (Tables 7 and 8, and Fig. 4). Many correlations were found with respect to physiochemical and descriptive sensory attributes (Table 7). Of the physical attributes, berry weight was positively correlated to size of the muscadine (r = 0.95), floral aromatics (r = 0.86), and moisture release (r = 0.83), and negatively correlated to the number of seeds (r = -0.84). Seed weight was positively correlated to green/unripe aromas (r = 0.87). Seed number was correlated with stem scar tear (r = -0.82), descriptive number of seeds (r = 0.98), floral aromatics (r = -0.94), mold/mildew aromatics (r = 0.92), and uniformity of berry hardness (r = -0.92).

Of the composition attributes, soluble solids was negatively correlated with grape/other aromatics (r = -0.87), showing that increased soluble solids leads to lower other grape aromatics. The pH was negatively correlated with green/unripe aromas (r = -0.86) and positively correlated with pulp crispness (r = 0.83). Therefore, increased pH indicated crisper pulp. Titratable acidity was negatively correlated with grape/other aromas (r = -0.83) and positively correlated with sour (r = 0.90), green/unripe aromatics (r = 0.83), and metallic feeling factor (r = 0.87). Interestingly, titratable acidity was the predominant factor of sour taste in the grapes as indicated by the lack of correlation of pH with sourness. Of the composition attributes, soluble solids/titratable acidity ratio had the most correlations to descriptive attributes. Soluble solids/titratable acidity ratio was positively correlated with grape/other aromas (r = 0.86) and negatively correlated with sour (r = -

0.97), grape/other aromatics (r = -0.89), green/unripe aromatics (r = -0.86), and metallic feeling factor (r = -0.85).

Of the texture attributes, flesh firmness was negatively correlated with the shape of the muscadine (r = -0.82) and visual separation (r = -0.82), and positively correlated with grape/muscadine aromatics (r = 0.83). The firmer the berry the more oval and less detachability of pulp from skin of berry. Skin firmness was positively correlated with the amount of blemishes/deformities (r = 0.97). Therefore, higher skin firmness indicated a less visually desirable berry in this study.

Correlations were found with respect to the total sugars, glucose, fructose, isocitric acid, tartaric acid, malic acid, and total anthocyanins with descriptive sensory attributes, of which glucose and fructose had the most significant correlations (Table 8). Glucose and fructose were both positively correlated (r = 0.85-0.94) to grape/overall aroma, floral aroma, color-bronze, overall aromatic impact, fruity aromatics, and negatively correlated (r = -0.85-0.97) to color-purple, bitter, mold/mildew aromatics and astringent feeling factor. In addition, glucose was negatively correlated with uniformity of color (r = -0.82). Fructose was positively correlated to grape/muscadine aroma (r = 0.82), sweet (r = 0.87), grape/overall aromatics (r = 0.84), uniformity of berry hardness (r = 0.82), and negatively correlated to glossiness (r = -0.83). Total sugars was positively correlated (r = 0.81-0.94) to grape/overall aroma, grape/muscadine aroma, floral aroma, color-bronze, sweet, overall aromatic impact, grape/overall aromatics, fruity aromatics, and negatively correlated (r = -0.86-0.97) to color-purple, bitter, mold/mildew aromatics, and astringent feeling factor (data not shown). From these results, total and individual sugars were clearly important in increasing the presence of desirable aromas and aromatics, such as floral and fruity, as seen by the positive correlations with overall aromatic impact.

Of the organic acids evaluated, isocitric acids was negatively correlated with the shape of the muscadine ($r = -0.82$), tartaric acid was negatively correlated with overripe aromatics ($r = -0.82$), and malic acid was positively correlated to sour ($r = 0.83$) and green/unripe aromatics ($r = 0.85$). Although not the predominant acid, malic acid was the only acid to show correlation to sour taste indicating malic acid may be of greater importance than isocitric or tartaric acid with the perception of sourness in the muscadine grapes. In addition, the presence of tartaric acid had a negative effect on the aromatic attribute of overripe. Total organic acids were not correlated to any of the descriptive sensory attributes.

Of the nutraceuticals analyzed, total anthocyanins had the only significant correlations. Total anthocyanins were negatively correlated with grape/other aroma ($r = -0.84$) and positively correlated with sour ($r = 0.93$), green/unripe aromatics ($r = 0.84$), and metallic ($r = 0.93$). However, no external appearance sensory attributes were correlated to total anthocyanins.

Significant correlations of the analytical berry color attributes were found with external appearance, basic tastes, aromatics, and feeling factor descriptive sensory attributes (Fig. 4). L*, chroma, and hue were negatively correlated to color-purple ($r \geq -0.94$), bitter ($r \geq -0.90$), grape/other aromatics ($r \geq -0.86$), and astringent feeling factor ($r \geq -0.93$), and positively correlated to color-bronze ($r \geq 0.97$) and fruity ($r \geq 0.97$). In addition, L* and chroma were negatively correlated with glossiness ($r = -0.83$), chroma was negatively correlated with mold/mildew aromatics ($r = -0.83$), and hue was negatively correlated with uniformity of size ($r = -0.82$), sour ($r = -0.82$), and metallic ($r = -0.85$) (data not shown). The large amount of significant correlations with respect to berry color indicate that analytical color analysis is a strong method to describe the descriptive color attributes of the fruit. In addition, L* and chroma appeared to describe the glossiness of the fruit well as seen by the strong positive correlation.

Physiochemical and marketability attributes during postharvest storage

During postharvest storage, the six muscadine genotypes were evaluated at 0, 7, 14, and 21 d at 2 °C. F-test significance from ANOVA indicated significant genotype x storage interactions for many of the attributes. There was a storage x genotype interaction for berry weight, soluble solids, pH, titratable acidity, L*, weight loss, and decay. For the physiochemical attributes without significant interactions, there were significant differences across the genotypes for chroma, hue, skin firmness, and flesh firmness. Storage only impacted skin firmness, flesh firmness, isocitric acid, and malic acid (Table 9).

Berry weight was evaluated during storage, and there was a significant storage x genotype interaction (Fig. 5). Berry weight of these genotypes had minimal changes during storage. AM-74 had a greater berry weight on 0 d than 21 d. All other genotypes did not change during storage. On day 21, AM-74 was larger than 'Summit'. Generally, berries are sold by weight, therefore for the grower, retention of berry weight is an important attribute. The minimal changes in berry weight during storage indicate good commercial potential as the fruit will retain weight if stored before reaching the market.

Composition (soluble solids, pH, and titratable acidity) was evaluated during storage, and there was a significant storage x genotype interaction (Fig. 6). For AM-9, AM-74, AM-83, and 'Ison', storage did not affect soluble solids. On day 14, 'Summit' had a higher soluble solids than 0, 7, or 21 d. On day 0, 'Nesbitt' had a lower soluble solids than day 7, but not 14 or 21 d. On day 21, AM-83 had a higher pH than AM-74, 'Summit', 'Nesbitt', and 'Ison', and AM-9 had a higher pH than 'Ison'. Conversely, 'Ison' had a higher titratable acidity on day 21 than all of the other genotypes. In addition, titratable acidity on day 7 was lower than day 0 for all genotypes.

Color attributes (L*, chroma, and hue) were evaluated during storage. There was a significant storage x genotype interaction of L* (Fig. 7). AM-74 and 'Summit' had the highest L* values during storage. On day 21, 'Summit' had a lower L* value than day 0 indicating a darkening of the fruit. AM-9, AM-83, 'Ison', and 'Nesbit' had similar L* values and were not affected by storage. 'Summit' and AM-74 had the highest chroma values (16.10 and 16.05, respectively), and AM-83 had the lowest (2.88) (Table 10). Similarly, Summit' and AM-74 had the highest hue values (86.27 and 89.88, respectively), and 'Ison' had the lowest (13.92). There were no differences in hue within the black genotypes or the bronze genotypes. Storage did not impact chroma or hue.

Firmness attributes (flesh firmness and skin firmness) were evaluated during storage (Table 10). AM-83 had the highest flesh firmness (1.94 N) and skin firmness (1.32 N/mm). 'Nesbitt' (1.06 N) had the lowest flesh firmness, and AM-9 (0.80 N/mm) and 'Ison' (0.80 N/mm) had the lowest skin firmness. Storage impacted flesh firmness and skin firmness. During storage, flesh firmness was greater at day 21 than day 7, and skin firmness at day 21 was less than day 0. There was a trend for increased texture of the muscadines during storage.

Total organic acids and sugars were evaluated during storage, but genotype did not have an impact on these attributes (Table 10). Total sugars were 7.91 g/100 g, and the average amount of glucose and fructose was 3.98 g/100 g, and 3.99 g/100 g, respectively. The average tartaric acid, isocitric acid, and malic acid was 0.28 g/100 g, 0.08 g/100 g, and 0.16 g/100 g, respectively. Storage had a significant effect on isocitric and malic acid. On day 0, isocitric acid was higher than 7, 14, or 21 d. On day 0, malic acid was greater than day 7, but not 14 or 21 d.

Marketability (weight loss and unmarketable fruit) was evaluated during storage, and there was a significant storage x genotype interaction (Fig. 8). On day 21, weight loss was

greater than 0, 7, and 14 d for all genotypes. ‘Ison’ and AM-74 had the most weight loss on day 21, and AM-9 had the least. ‘Summit’ had the most unmarketable fruit on 21 d. There was no difference in unmarketable fruit between AM-9, AM-83, ‘Ison’, and ‘Nesbitt’ during storage. As fruit became more unmarketable due to browning or decay, the intensity of the color increased as indicated by a positive correlation with chroma.

At 21 d of storage at 2 °C, AM-9 performed well with the lowest weight loss and unmarketable fruit (Fig. 9). The two bronze genotypes, AM-74 and ‘Summit’, performed poorly with respect to unmarketable fruit as the blemishes were more visible on the lighter-colored fruit. ‘Ison’ had the most weight loss at 21 d storage, but also had one of the highest flesh firmness values. Overall, no one genotype exceled or failed in all marketability and texture attribute areas, and the fruit performed exceptionally well with low weight loss (<5%) and low unmarketable fruit (<11% for the black genotypes and <28% for the bronze).

Conclusion

In order to improve the consumer acceptance of muscadine grapes, an initial understanding of how the fruit is perceived must first be investigated. Utilizing a combination of physiochemical and sensory analysis, a greater understanding of how the consumer perceives the fruit was obtained. The descriptive sensory analysis differentiated well between genotypes for external appearance, internal appearance, and basic taste attributes, more specifically with positive attributes rather than negative, but poorly with the selected aroma, aromatic, and texture attributes. This indicated that of the attributes evaluated in this study, descriptive sensory analysis was best suited for appearance and basic taste attributes. Conversely, of the texture attributes evaluated by the panelists, no differentiation was seen indicating that better descriptors and references need to be selected for further studies. Physiochemical attributes such as berry

color, composition, and sugars had the most significant correlations with descriptive sensory. For attributes such as soluble solids/titratable acidity ratio, a higher ratio indicated that the fruit was perceived as riper and potentially more desirable as negative attributes such as green/unripe aromatics, sour basic taste, and metallic feeling factor decreased. Additionally, higher levels of glucose and fructose indicated a positive effect on the pleasant aromatics of the fruit, and a negative effect of the displeasing aromatics and external appearance. Retention of native muscadine aroma and aromatics, while improving the grape texture is important moving forward in muscadine breeding programs. Although the panelists were unable to distinguish between genotypes for texture attributes, analytical texture analysis was correlated to external and internal appearance and aromatic attributes, indicating that firmness (skin and flesh) plays a role in how the berry is perceived both visually and aromatically. Results from this study indicated that descriptive sensory analysis has the potential to describe muscadine grapes well, and current analytical evaluation methods describe the fruit appropriately as seen by strong correlations.

Overall, genotype had the most impact on the postharvest quality of fresh-market muscadine grapes grown in Arkansas. Malic acid, isocitric acid, skin firmness, and flesh firmness were affected by storage. The changes in these attributes during storage indicated a change in fruit quality, by decreased malic and isocitric acid, increased flesh firmness, decreased skin firmness. For most genotypes, berry weight, soluble solids, and color (L*, chroma, and hue) did not change during storage indicating no quality degradation from harvest. Additionally, evaluation of the fruit at 21 d postharvest storage at 2 °C indicated that while no one genotype performed well in all categories, AM-9 had exceptional marketability with low weight loss (<2.5%) and unmarketable fruit (<6.0%). The black genotypes performed better than the bronze genotypes with respect to unmarketable fruit as the blemishes were more visible on the lighter

colored fruit. In addition, ‘Ison’ retained texture well at 21 d of storage as seen by a high flesh firmness and low skin firmness. Overall, the muscadine grapes had good retention of compositional attributes and marketability indicating strong potential for fresh-market.

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Tables

Table 1. Lexicon developed for fresh-market peaches and nectarines attributes by a descriptive sensory panel with ten trained panelists.

Term	Definition	Technique	Reference
Aroma (whole berry)			
Grape/overall	Smell associated with fresh grapes	Fresh grapes	Intensities based on universal scale[z]
Grape/muscadine	Smell associated with fresh muscadine	Ripe muscadine	Intensities based on universal scale
Grape/other	Smell associated with other grape species	Any grape aroma other than muscadine i.e. Concord	Intensities based on universal scale
Fruity	Smell associated with fruits other than grapes		Intensities based on universal scale
Floral	Smell associated with floral aromas		Intensities based on universal scale
Earthy/dirty	Smell associated with damp soil or wet foliage	Damp potting soil	Intensities based on universal scale
Green/unripe	Smell associated with freshly cut green vegetation; unripe	Unripe banana	Intensities based on universal scale
Mold/mildew	Smell associated with moldy or mildew aromas	Old mildewed clothes	Intensities based on universal scale
Overripe	Smell associated with overripe aromas		Intensities based on universal scale
Appearance (exterior of whole berry)			
Uniformity of color	Ratio of uniformity of color on the exterior of the muscadines	Observe the five berries and rate the degree to which the sample is uniform in color. (un-uniform to uniform)	Ratio of color uniformity 0%=0, 50%=7.5, 100%=15
Color- red	Intensity of red of the sample		
Color- green	Intensity of green of the sample		

Table 1. (*Continued)*

Term	Definition	Technique	Reference
Glossiness	Degree to which the surface of the berry shines	Observe the sample and determine the degree to which the surface shines. (dull to wet/shiny)	Copy paper = 3.0, Photo paper = 15.0
Uniformity of size	Ratio of uniformity of size	Observe the five berries and rate the degree to which the sample is uniform in size. (un-uniform to uniform)	Ratio of size uniformity 0%=0, 50%=7.5, 100%=15
Size of muscadine	Visual size of the sample	Observe the sample and determine the overall size of the sample. (small to large)	Photo reference of size of circles[y] A=15.0 (1.5 inches), B=11.0 (1.25 inches), C=7.5 (1.0 inches), D=4.0 (0.75 inches), E=1.0 (0.5 inches)
Shape of muscadine	Visual shape of the sample	Observe the sample and determine the overall shape of the sample. (oval to round)	Egg/oval=5.0, 2.5-inch ball =15.0
Amount of specks	Visual ratio of specks on the sample	Observe the berry and determine the amount of specks on the surface. (none to much)	Ratio of specks 0%=0, 50%=7.5, 100%=15
Amount of blemishes/ Deformities	Visual ratio of blemishes/deformities on the sample	Observe the berry and determine the amount of blemishes/deformities on the surface. (none to much)	Ratio of blemishes and deformities 0%=0, 50%=7.5, 100%=15
Stem scar tear	Visual presence of tear of the stem scar	Observe the berry and determine if there is a tear at the scar bigger than the scar. (yes or no)	Yes (=1) or no (=0)
Appearance (pulp of berry cut in half)			
Visual separation	Detachability of pulp from skin of berry	Squeeze half of berry and observe the extent of which the pulp detaches from the skin. (none to much)	
Amount of seeds	Number of seed present in the berry	Count the number of seeds.	
Seed size	Visual size of the seeds	Observe the seeds and determine the overall size. (small to large)	Photo reference of size[x] A=12 (5.3 x 8.5 mm) B=7 (4.9 x 7.1 mm) C=3 (3.9 x 6.1 mm)

Table 1. (*Continued)*

Term	Definition	Technique	Reference
Basic tastes (of remaining four berries)			
Sweet	Basic taste, perceived on the tongue, stimulated by sugars and high potency sweeteners	Solutions of sucrose in spring water	2%=2.0, 5%=5.0, 10%=10.0, 16%=15.0
Sour	Basic taste, perceived on the tongue, stimulated by acids, such as citric acid	Solutions of citric acid in spring water	0.05%=2.0, 0.08%=5.0, 0.15%=10.0, 0.20%=15.0
Bitter	Basic taste, perceived on the tongue, stimulated by sugars and high potency sweeteners	Solutions of caffeine in spring water	0.05%=2.0, 0.08%=5.0, 0.15%=10.0, 0.20%=15.0
Aromatics			
Overall aromatic impact	Overall impact of all aromatics in the muscadine grape		Intensities based on universal scale
Grape/overall	Aromatic associated with fresh grapes	Fresh grapes	Intensities based on universal scale
Grape/muscadine	Aromatic associated with fresh muscadine	Ripe muscadine	Intensities based on universal scale
Grape/other	Aromatic associated with other grape species	Any grape aroma other than muscadine i.e. Concord	Intensities based on universal scale
Fruity	Aromatic associated with fruity aromas		Intensities based on universal scale
Floral	Aromatic associated with floral aromas		Intensities based on universal scale
Green/unripe	Aromatic associated with damp soil or wet foliage	Damp potting soil	Intensities based on universal scale
Earthy/dirty	Aromatic associated with freshly cut green vegetation; unripe	Unripe banana	Intensities based on universal scale
Mold/mildew	Aromatic associated with moldy or mildew aromas	Old mildewed clothes	Intensities based on universal scale
Overripe	Aromatic associated with overripe fruit	Over-ripened fruit	Intensities based on universal scale
Feeling factors			
Astringent	Feeling factor on the tongue or other skin surfaces of the mouth described as puckering or drying	Chew sample to point of swallow, expectorate and feel surfaces of the mouth. Swish references in mouth. Swallow or expectorate and wait 5 seconds.	0.053 g/500 mL water = 6.0 Swish, expectorate, wait 5 seconds
Metallic	Aromatic associated with metals, tinny or iron or a flat chemical feeling stimulated on the tongue by metal coins	Tin foil to bite	Intensities based on universal scale

Table 1. (*Continued)*

Term	Definition	Technique	Reference
Texture (whole berry)			
Uniformity of berry hardness	Ratio of uniformity of hardness	Observe the four berries and rate the degree to which the sample iS uniform in hardness. (un-uniform to uniform)	Ratio of size uniformity 0%=0, 50%=7.5, 100%=15
Berry hardness	Force required to compress the sample	Place the sample in the mouth with the skin facing towards the cheek. Compress or bite through the sample one time with molars or incisors. (soft to hard)	Cream cheese = 1.0, Egg white = 2.5, Am cheese = 4.5, Beef frank = 5.5, Olive = 7.0,Peanut = 9.5, Almond = 11.0
Moisture release	Amount of wetness or moistness felt in the mouth after one bite or chew	Compress the sample with molars one time only. (dry to wet)	Banana = 1.0, Carrot = 2.0, Mushroom = 4.0, Snap beans = 7.0, Cucumber = 8.0, Apple = 10.0, Honeydew = 12.0, Orange = 15.0, (chew refs 5 times)
Awareness of skins	How aware are you of the skins during mastication of the sample	Place sample in mouth and chew 3-5 times. Can also be evaluated in first bite stage. (none to much)	Baked beans = 4.0, Medium lima beans = 8.0
Flesh crispness	Unique, strong, clean, and acute sound produced in first bite of the food with incisors and open lips	Place sample between the incisors (front teeth) and penetrate it. Evaluate the sound intensity produced at the first bite. (none to much)	Ripe banana = 0.0, Granny smith apple = 7.5, Carrot = 15.0
Detachability	Ease with which the pulp separates from the skin of the berries		
Fibrousness between teeth	Amount of grinding of fibers required to chew through the sample. (not including skins)	Place sample between molars and chew 3-5 times. Evaluate during chewing, but ignore the skin. (none to much)	Apple = 2.0, Apricot = 5.0, Salami = 7.0, Celery = 9.0, Toasted oats (4-5) = 10.0, Bacon = 12.0, Beef jerky = 20.0
Seed separation	Ease with which the seeds separate from the pulp of the berry		

[z]Intensities based on universal scale (saltine = 3.0; applesauce = 7.0; orange juice = 10.0; grape juice = 14.0; Big Red Gum® = 15.0).
[y]See Figure 1 for photo reference.
[x]See Figure 2 for photo reference.

Table 2. Initial berry and seed weight, composition, color, firmness, and stem scar tear attributes for fresh-market muscadine genotypes, Clarksville, AR (2017).

Genotype	Berry weight (g)	Seed weight (g)	Stem scar tear (%)	Soluble solids (%)	pH	Titratable acidity (%)[z]	Soluble solids/ titratable acidity ratio	L*	Chroma	Hue	Skin firmness (N/mm)	Flesh firmness (N)
AM-9	10.68 b[y]	0.11 bcd	1.11 c	14.23 ab	3.27 a	0.57 c	24.93 ab	23.85 c	3.72 c	13.89 c	0.85 b	1.18 ab
AM-74	14.38 a	0.12 a	11.01 a	13.63 bc	3.08 bc	0.57 c	24.36 ab	47.94 a	17.23 a	92.93 a	1.36 ab	1.13 ab
AM-83	9.92 b	0.09 d	1.08 c	13.27 bc	3.33 a	0.64 bc	20.73 bc	25.06 bc	2.47 c	34.67 ab	1.48 a	2.14 a
Ison	10.01 b	0.12 ab	8.01 abc	13.20 bc	2.88 d	1.01 a	13.12 d	24.86 b	4.58 bc	12.39 ab	0.88 b	1.34 ab
Nesbitt	10.10 b	0.12 abc	10.17 ab	12.73 c	3.03 cd	0.76 b	16.91 cd	26.62 bc	7.24 c	30.31 c	1.40 ab	0.89 b
Summit	9.25 b	0.10 cd	2.47 bc	15.40 a	3.19 ab	0.54 c	28.49 a	47.62 a	18.36 a	93.39 a	1.18 ab	1.72 ab
P value	*<0.0001*	0.0003	0.0441	0.0002	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	0.0017	0.0073	0.0149

[z] Titratable acidity expressed as % tartaric acid.

[y] Genotypes were evaluated in triplicate (n=3). Means with different letter(s) for each attribute within effects are significantly different ($p<0.05$) using Tukey's Honestly Significant Difference test.

Table 3. Initial total sugars, total organic acids, and nutraceutical attributes for fresh-market muscadine genotypes, Clarksville, AR (2017).

Genotype	Total sugars (g/100 g)	Total organic acids (g/100 g)	Total phenolic acid (mg/100 g)	Total flavonols (mg/100 g)	Total anthocyanins (mg/100 g)	Total nutraceuticals (mg/100 g)
AM-9	6.94 a[z]	0.50 a	0.90 bc	81.82 b	49.56 bc	132.27 b
AM-74	9.75 a	0.63 a	3.38 a	128.94 b	0.00 c	132.32 b
AM-83	6.17 a	0.65 a	0.91 bc	93.81 b	60.01 bc	154.73 b
Ison	6.99 a	0.81 a	2.55 ab	187.31 b	233.38 a	423.24 a
Nesbitt	8.16 a	0.84 a	1.63 bc	99.36 b	111.41 b	212.40 b
Summit	9.72 a	0.74 a	0.14 c	396.88 a	0.00 c	397.02 a
P value	*0.9276*	*0.9309*	*0.0003*	*<0.0001*	*<0.0001*	*0.0003*

[z] Genotypes were evaluated in triplicate (n=3). Means with different letter(s) for each attribute within effects are significantly different ($p<0.05$) using Tukey's Honestly Significant Difference test.

Table 4. Descriptive sensory aroma and aromatic attributes of muscadine genotypes evaluated on a 15-point scale (0 = less of the attribute; 15 = more of the attribute in terms of intensity), Clarksville, AR (2017).

	Aroma			Aromatics		
Genotype	**Grape/ overall**	**Grape/ muscadine**	**Fruity**	**Overall aromatic impact**	**Grape/ overall**	**Overripe**
AM-9	4.6 b[z]	5.2 ab	1.0 a	8.1 abc	6.7 ab	0.6 a
AM-74	6.1 a	6.4 a	0.7 ab	8.3 ab	6.9 a	0.0 b
AM-83	0.7 d	0.5 d	0.0 c	7.1 d	5.9 d	0.1 b
Ison	3.5 c	3.4 c	0.4 abc	7.7 c	6.2 cd	0.0 b
Nesbitt	4.1 bc	4.1 bc	0.3 bc	7.9 bc	6.4 bc	0.0 b
Summit	5.8 a	5.9 a	0.7 ab	8.4 a	6.8 ab	0.0 b
P value	<0.0001	<0.0001	0.0330	<0.0001	<0.0001	<0.0001

[z]Genotypes were evaluated in duplicate by eight trained panelists. Means with different letter(s) for each attribute are significantly different ($P < 0.05$) using least significant difference.

Table 5. Descriptive sensory external appearance attributes of muscadine genotypes evaluated on a 15-point scale (0 = less of the attribute; 15 = more of the attribute in terms of intensity), Clarksville, AR (2017).

Genotype	Uniformity of color	Color-purple	Color-bronze	Glossiness	Uniformity of size	Size of muscadine	Shape of muscadine	Amount of blemishes/ deformities	Stem scar tear
AM-9	13.0 a[z]	11.5 a	0.0 b	7.1 b	12.5 a	7.8 ab	12.9 a	3.2 a	0.0 c
AM-74	10.2 b	3.1 c	8.7 a	6.6 b	11.1 a	8.4 a	12.7 a	4.3 a	0.9 a
AM-83	13.9 a	12.1 a	0.0 b	8.3 a	11.7 a	7.4 bc	8.5 b	4.5 a	0.2 bc
Ison	10.6 b	10.1 b	0.5 b	7.9 a	11.8 a	7.3 bc	12.6 a	3.3 a	0.4 b
Nesbitt	10.0 b	9.5 b	0.6 b	8.0 a	11.6 a	7.2 c	12.7 a	4.0 a	0.8 a
Summit	10.3 b	3.5 c	7.9 a	6.5 b	11.3 a	7.2 c	12.5 a	3.9 a	0.2 bc
P value	*<0.0001*	<0.0001	<0.0001	<0.0001	*0.3560*	*0.0010*	<0.0001	*0.1820*	<0.0001

[z]Genotypes were evaluated in duplicate by eight trained panelists. Means with different letter(s) for each attribute are significantly different ($P < 0.05$) using least significant difference.

Table 6. Descriptive sensory internal appearance, basic taste, and feeling factor attributes of muscadine genotypes evaluated on a 15-point scale (0 = less of the attribute; 15 = more of the attribute in terms of intensity), Clarksville, AR (2017).

	Internal appearance			Basic tastes			Feeling factors	
Genotype	**Visual separation**	**Number of seeds**	**Seed size**	**Sweet**	**Sour**	**Bitter**	**Astringent**	**Metallic**
AM-9	12.1 a[z]	3.3 ab	6.9 a	7.4 abc	3.2 bcd	1.4 a	6.9 a	1.4 abc
AM-74	11.7 a	2.6 c	6.9 a	7.9 a	2.9 cd	0.7 a	6.5 a	1.2 d
AM-83	9.2 b	3.6 a	6.3 a	6.3 d	3.3 bc	1.1 a	6.8 a	1.4 bc
Ison	12.2 a	3.5 a	7.4 a	6.7 cd	3.9 a	1.1 a	7.0 a	1.6 a
Nesbitt	12.1 a	3.0 bc	6.7 a	7.0 bcd	3.7 ab	1.0 a	6.8 a	1.5 ab
Summit	11.8 a	3.4 ab	7.0 a	7.6 ab	2.7 d	0.7 a	6.4 a	1.3 cd
P value	<0.0001	*0.0040*	*0.5080*	*0.0020*	*0.0010*	*0.0960*	0.0940	*0.0010*

[z]Genotypes were evaluated in duplicate by eight trained panelists. Means with different letter(s) for each attribute are significantly different ($P < 0.05$) using least significant difference.

Table 7. Multivariate pairwise analysis of physiochemical and descriptive sensory attributes of muscadine genotypes Clarksville, AR (2017).

Descriptive attributes	Berry weight	Seed weight (g)	Seed (#)	Soluble solids (%)	pH	Titratable acidity (%)	Soluble solids/ titratable acidity ratio	Flesh firmness (N)	Skin firmness (N/mm)	Stem scar tear (%)
Aromas										
Grape/other	-0.13	-0.50	-0.23	0.73	0.59	**-0.83**[z]	**0.86**	0.26	0.36	-0.38
Floral	0.27	0.33	-0.63	0.60	-0.13	-0.45	0.59	-0.50	-0.12	0.25
Green/unripe	0.27	**0.87**	-0.58	-0.06	**-0.86**	0.36	-0.23	-0.67	-0.10	**0.82**
External appearance										
Size of muscadine	**0.95**	0.31	-0.63	0.00	0.10	-0.42	0.35	-0.29	0.04	-0.68
Shape of muscadine	0.24	0.70	-0.45	0.22	-0.57	0.10	0.06	**-0.82**	-0.53	0.28
Amount of blemishes/ deformities	0.28	-0.23	-0.39	-0.18	0.33	-0.39	0.19	0.40	**0.97**	0.47
Stem scar tear	0.62	0.76	**-0.82**	-0.52	-0.58	0.17	-0.30	-0.57	0.51	**0.95**
Internal appearance										
Visual separation	0.12	0.70	-0.33	0.16	-0.63	0.24	-0.06	**-0.82**	-0.59	0.46
Number of seeds	**-0.84**	-0.65	**0.98**	0.17	0.26	0.28	-0.18	0.69	-0.31	-0.74
Basic tastes										
Sour	-0.30	0.38	0.36	-0.79	-0.58	**0.90**	**-0.97**	-0.29	-0.22	0.33
Aromatics										
Grape/muscadine	-0.14	-0.80	0.38	-0.03	0.76	-0.35	0.20	**0.83**	0.50	-0.60
Grape/other	-0.22	0.20	0.36	**-0.87**	-0.32	0.73	**-0.89**	-0.21	-0.07	0.20
Fruity	0.41	0.22	-0.69	0.45	-0.11	-0.43	0.52	-0.02	0.40	0.36
Floral	**0.86**	0.70	**-0.94**	-0.16	-0.41	-0.13	0.08	-0.50	0.37	**0.81**
Green/unripe	-0.43	0.44	0.22	-0.65	-0.66	**0.83**	**-0.86**	-0.41	-0.15	0.41
Mold/mildew	-0.69	-0.64	**0.92**	-0.04	0.42	0.18	-0.20	0.44	-0.37	-0.76
Texture										
Berry hardness	-0.53	-0.80	0.58	0.18	0.77	-0.36	0.26	0.34	-0.10	**-0.83**
Moisture release	**0.83**	0.70	-0.81	0.14	-0.43	-0.14	0.23	-0.49	-0.02	0.66
Pulp crispness	-0.19	-0.77	0.35	-0.16	**0.83**	-0.40	0.16	0.51	0.41	-0.61
Uniformity of berry hardness	0.66	0.45	**-0.92**	-0.06	-0.21	-0.32	0.23	-0.30	0.65	0.68
Feeling factors										
Metallic	-0.60	0.17	0.61	-0.52	-0.48	**0.87**	**-0.85**	-0.12	-0.39	0.05

[z]Bold values are significant correlations ($P<0.05$) using a multivariate pairwise analysis.

Table 8. Multivariate pairwise analysis of organic acids, sugars, anthocyanins, and descriptive sensory attributes of muscadine genotypes Clarksville, AR (2017).

Descriptive attributes	Glucose (g/100 g)	Fructose (g/100 g)	Isocitric acid (g/100 g)	Tartaric acid (g/100 g)	Malic acid (g/100 g)	Total anthocyanins (mg/100 g)
Aromas						
Grape/overall	**0.85**[z]	**0.86**	-0.66	0.12	-0.14	-0.39
Grape/muscadine	0.80	**0.82**	-0.71	0.02	-0.20	-0.42
Grape/other	0.54	0.59	0.32	0.13	-0.72	**-0.84**
Floral	**0.87**	**0.87**	-0.48	0.21	-0.25	-0.50
External appearance						
Uniformity of color	**-0.82**	-0.70	0.33	-0.72	-0.48	-0.11
Color-purple	**-0.95**	**-0.97**	0.20	-0.33	0.20	0.54
Color-bronze	**0.89**	**0.94**	-0.16	0.19	-0.33	-0.63
Glossiness	-0.76	**-0.83**	0.49	0.15	0.49	0.66
Shape of muscadine	0.57	0.51	**-0.82**	0.16	0.24	0.08
Basic tastes						
Sweet	0.80	**0.87**	-0.61	-0.09	-0.40	-0.61
Sour	-0.55	-0.68	-0.03	0.23	**0.83**	**0.93**
Bitter	**-0.86**	**-0.85**	-0.16	-0.57	0.05	0.42
Aromatics						
Overall aromatic impact	**0.83**	**0.83**	-0.62	0.09	-0.22	-0.44
Grape/overall	0.77	**0.84**	-0.63	-0.09	-0.40	-0.59
Fruity	**0.93**	**0.94**	0.01	0.42	-0.22	-0.57
Green/unripe	-0.25	-0.44	0.02	0.54	**0.85**	**0.84**
Mold/mildew	**-0.87**	**-0.88**	0.29	-0.40	-0.03	0.34
Overripe	-0.49	-0.38	-0.40	**-0.82**	-0.48	-0.16
Texture						
Uniformity of berry hardness	0.77	**0.82**	-0.03	0.41	-0.11	-0.47
Feeling factors						
Astringent	**-0.83**	**-0.89**	-0.14	-0.25	0.52	0.80
Metallic	-0.57	-0.73	0.06	0.26	0.79	**0.93**

[z]Bold values are significant correlations ($P<0.05$) using a multivariate pairwise analysis.

Table 9. F-test significance from analysis of variance (ANOVA) for physiochemical and marketability of muscadine genotypes stored at 2 °C for 0, 7, 14, and 21 d, Clarksville, AR (2017).

Attributes	Genotype	Storage day	Genotype x storage day
Physiochemical			
Berry weight (g)	<0.0001	0.1572	0.0110
Soluble solids (%)	<0.0001	<0.0001	0.0012
pH	<0.0001	<0.0001	<0.0001
Titratable acidity (%)	<0.0001	<0.0001	<0.0001
Glucose (g/100g)	0.9578	0.9489	0.9203
Fructose (g/100g)	0.9036	0.9444	0.8859
Total sugars (g/100g)	0.9368	0.9777	0.9039
Isocitric acid (g/100g)	0.6470	0.0004	0.9745
Tartaric acid (g/100 g)	0.7851	0.1448	0.9321
Malic acid (g/100g)	0.5270	0.0201	0.9080
Total organic acids (g/100g)	0.8284	0.0609	0.9127
L*	<0.0001	0.0113	0.0177
Chroma	<0.0001	0.1791	0.2094
Hue	<0.0001	0.2122	0.8377
Skin firmness(N/mm)	<0.0001	<0.0001	0.8993
Flesh firmness (N)	<0.0001	0.0219	0.0646
Marketability			
Weight loss (%)	<0.0001	<0.0001	<0.0001
Decay (%)	<0.0001	<0.0001	<0.0001

Table 10. Main and interaction effects for color, texture, sugars, and organic acids of muscadine genotypes stored at 2 °C for 0, 7, 14, and 21 d. Clarksville, AR (2017).

	Chroma	Hue	Flesh firmness (N)	Skin firmness (N/mm)	Total sugars (g/100 g)	Glucose (g/100 g)	Fructose (g/100 g)	Total organic acids (g/100 g)	Isocitric acid (g/100 g)	Tartaric acid (g/100 g)	Malic acid (g/100 g)
Storage											
Day 0	8.93 a[z]	46.26 a	1.40 ab	1.19 a	7.96 a	4.14 a	3.81 a	0.70 a	0.11 a	0.37 a	0.21 a
Day 7	8.38 a	41.53 a	1.28 b	1.01 b	7.96 a	4.05 a	3.91 a	0.38 a	0.07 b	0.23 a	0.08 b
Day 14	8.48 a	37.04 a	1.35 ab	1.02 b	7.60 a	3.67 a	3.93 a	0.53 a	0.08 b	0.26 a	0.18 ab
Day 21	8.12 a	37.83 a	1.60 a	0.92 b	8.37 a	4.06 a	4.31 a	0.49 a	0.08 b	0.25 a	0.16 ab
P value	*0.1791*	*0.2122*	*0.0219*	*<0.0001*	*0.9777*	*0.9489*	*0.9444*	*0.0609*	*0.0004*	*0.1448*	*0.0201*
Genotype											
AM-9	3.85 cd	14.43 b	1.19 cd	0.80 b	8.06 a	3.98 a	4.08 a	0.46 a	0.08 a	0.22 a	0.16 a
AM-74	16.05 a	89.88 a	1.23 bcd	1.17 a	8.76 a	4.26 a	4.50 a	0.52 a	0.08 a	0.28 a	0.16 a
AM-83	2.88 d	25.38 b	1.94 a	1.32 a	7.38 a	3.70 a	3.68 a	0.59 a	0.10 a	0.30 a	0.19 a
Ison	4.48 c	13.92 b	1.46 bc	0.80 b	6.76 a	3.45 a	3.31 a	0.59 a	0.08 a	0.31 a	0.20 a
Nesbitt	7.51 b	14.11 b	1.06 d	1.19 a	8.34 a	4.22 a	4.12 a	0.54 a	0.09 a	0.32 a	0.13 a
Summit	16.10 a	86.27 a	1.57 b	0.94 b	8.53 a	4.28 a	4.24 a	0.44 a	0.08 a	0.25 a	0.11 a
P value	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*0.9368*	*0.9578*	*0.9036*	*0.8284*	*0.6470*	*0.7851*	*0.5270*
Storage x genotype (p value)	*0.2094*	*0.8377*	*0.0646*	*0.8993*	*0.9039*	*0.9203*	*0.8859*	*0.9127*	*0.9745*	*0.9321*	*0.9080*

[z]Genotypes were evaluated in triplicate (n=3). Means with different letter(s) for each attribute within effects are significantly different ($p<0.05$) using Tukey's Honestly Significant Difference test.

Figures

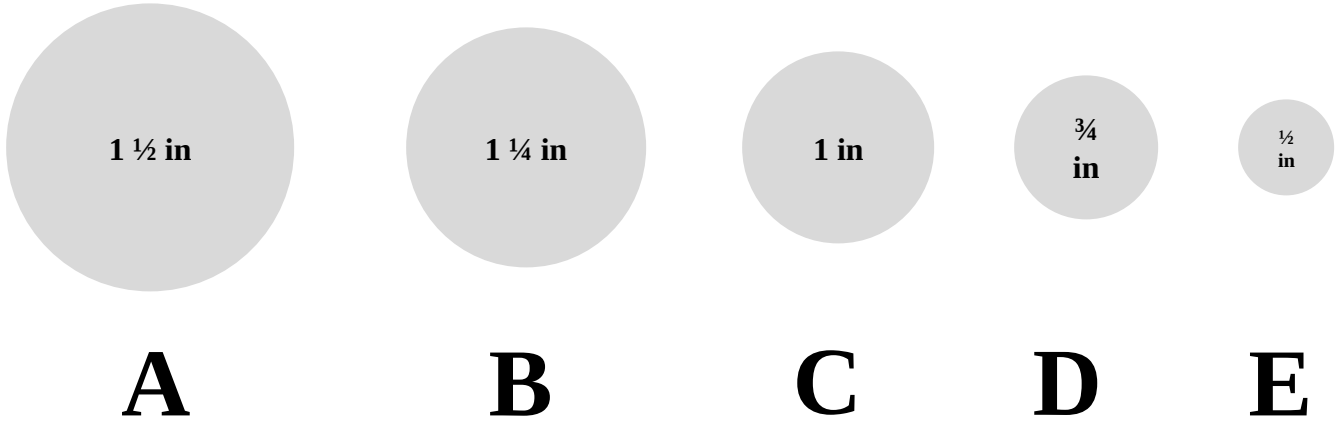

Fig. 1. Berry size reference for descriptive sensory analysis of fresh-market muscadine genotypes, Clarksville, AR (2017). A=15.0 (1.5 inches or 38.1 mm), B=11.0 (1.25 inches or 31.8 mm), C=7.5 (1.0 inches or 25.4 mm), D=4.0 (0.75 inches or 19.0 mm), and E=1.0 (0.5 inches or 12.7 mm) (0 = less of the attribute; 15 = more of the attribute).

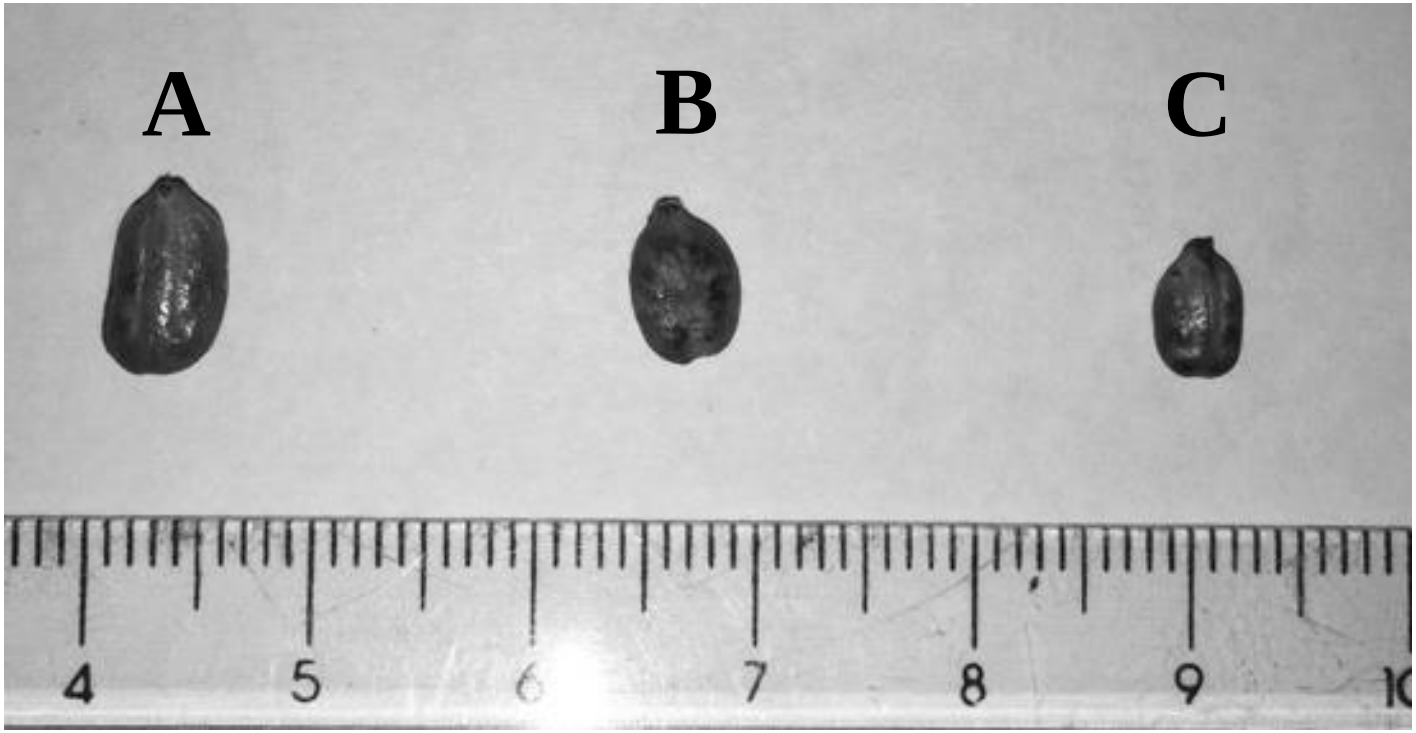

Fig. 2. Seed size reference for descriptive sensory analysis of fresh-market muscadine genotypes, Clarksville, AR (2017). A=12 (5.3 x 8.5 mm), B=7 (4.9 x 7.1 mm), and C=3 (3.9 x 6.1 mm) (0 = less of the attribute; 15 = more of the attribute).

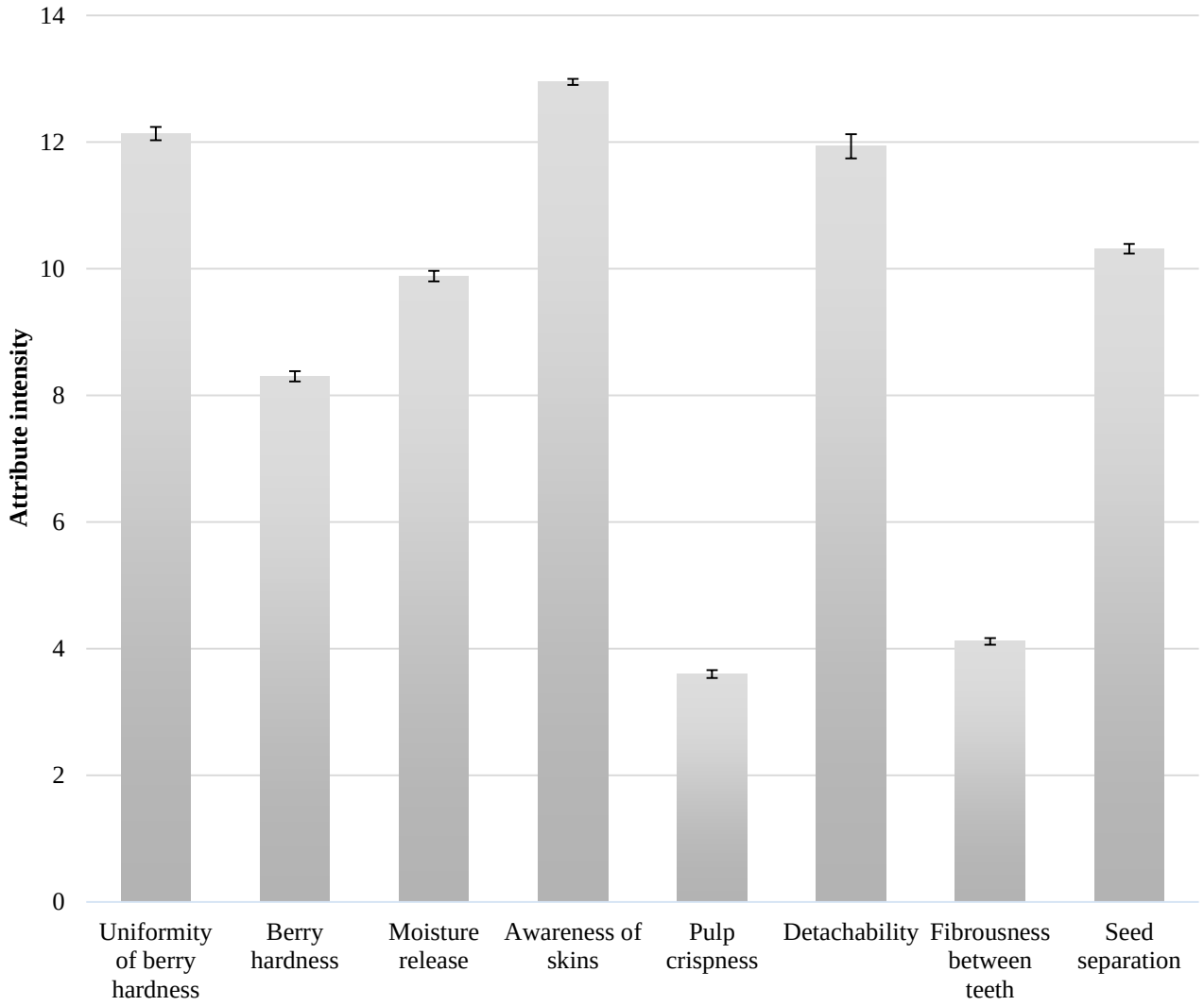

Fig. 3. Descriptive sensory texture attributes of fresh-market muscadine genotypes evaluated on a 15-point scale (0 = less of the attribute; 15 = more of the attribute in terms of intensity), Clarksville, AR (2017).

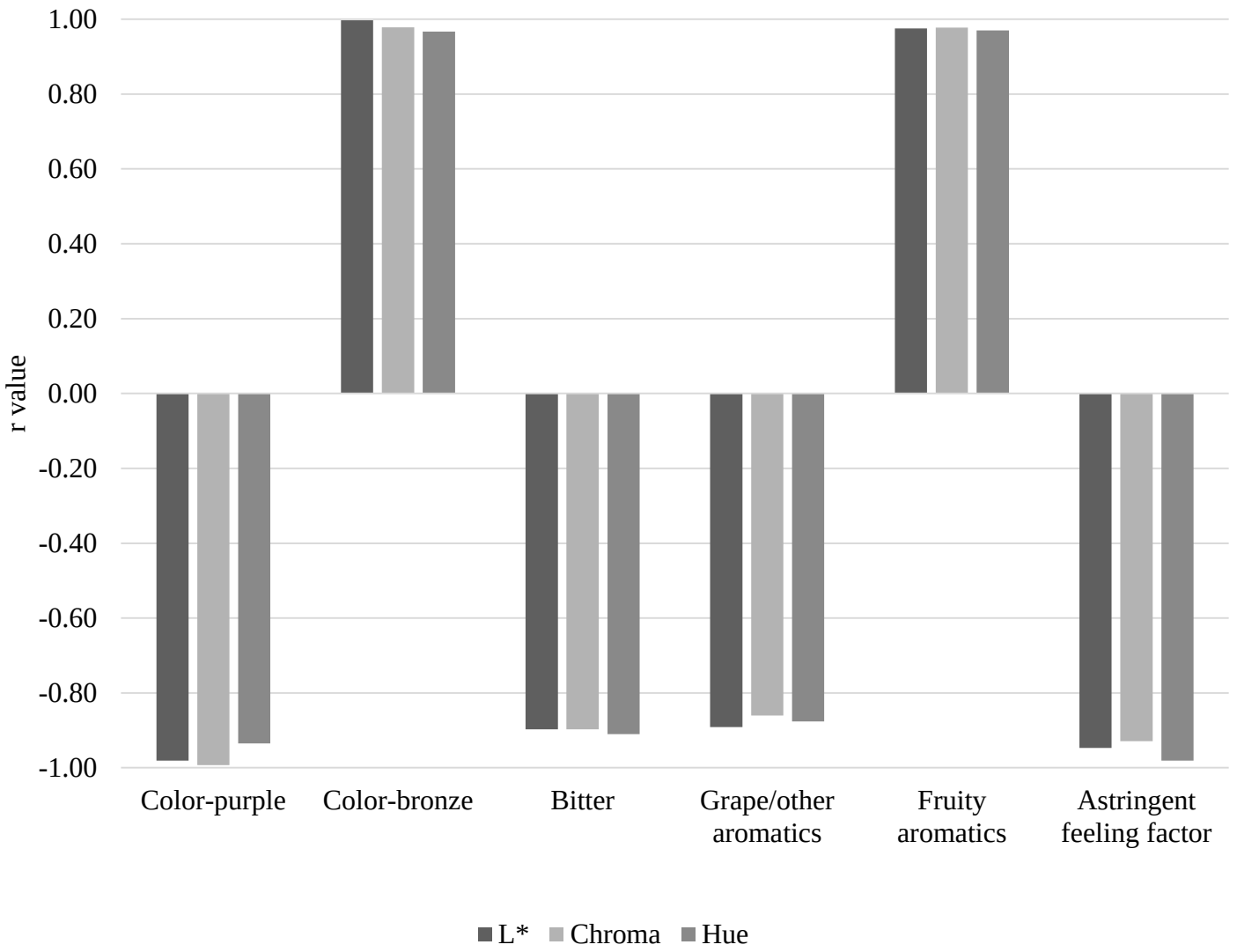

Fig. 4. Multivariate pairwise analysis of color attributes and descriptive sensory attributes of fresh-market muscadine genotypes, Clarksville, AR (2017).

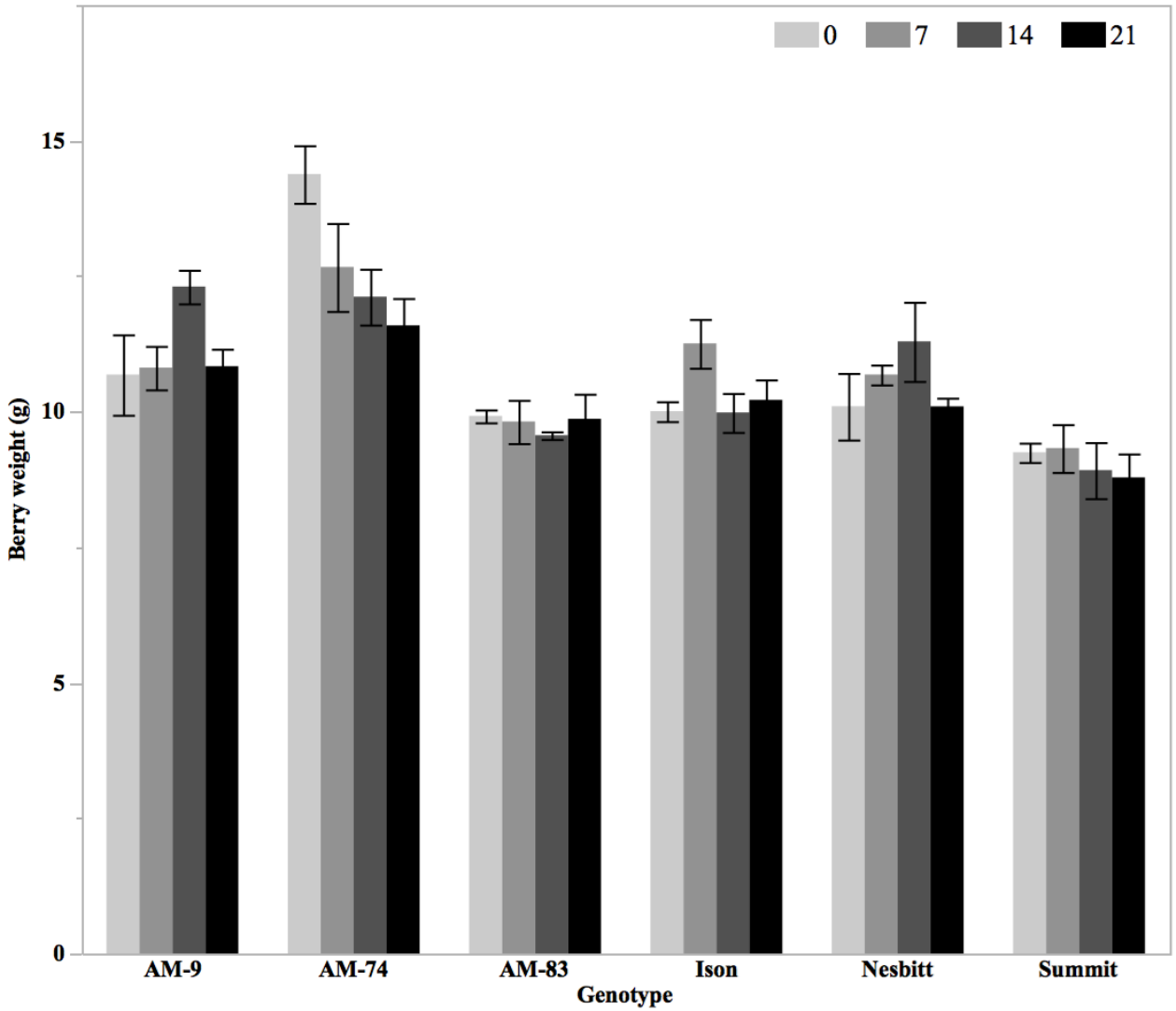

Fig. 5. Berry weight of fresh-market muscadine genotypes during postharvest storage at 2 °C for 0, 7, 14, and 21 d, Clarksville, AR (2017). Each standard error bar is constructed using 1 standard error from the mean.

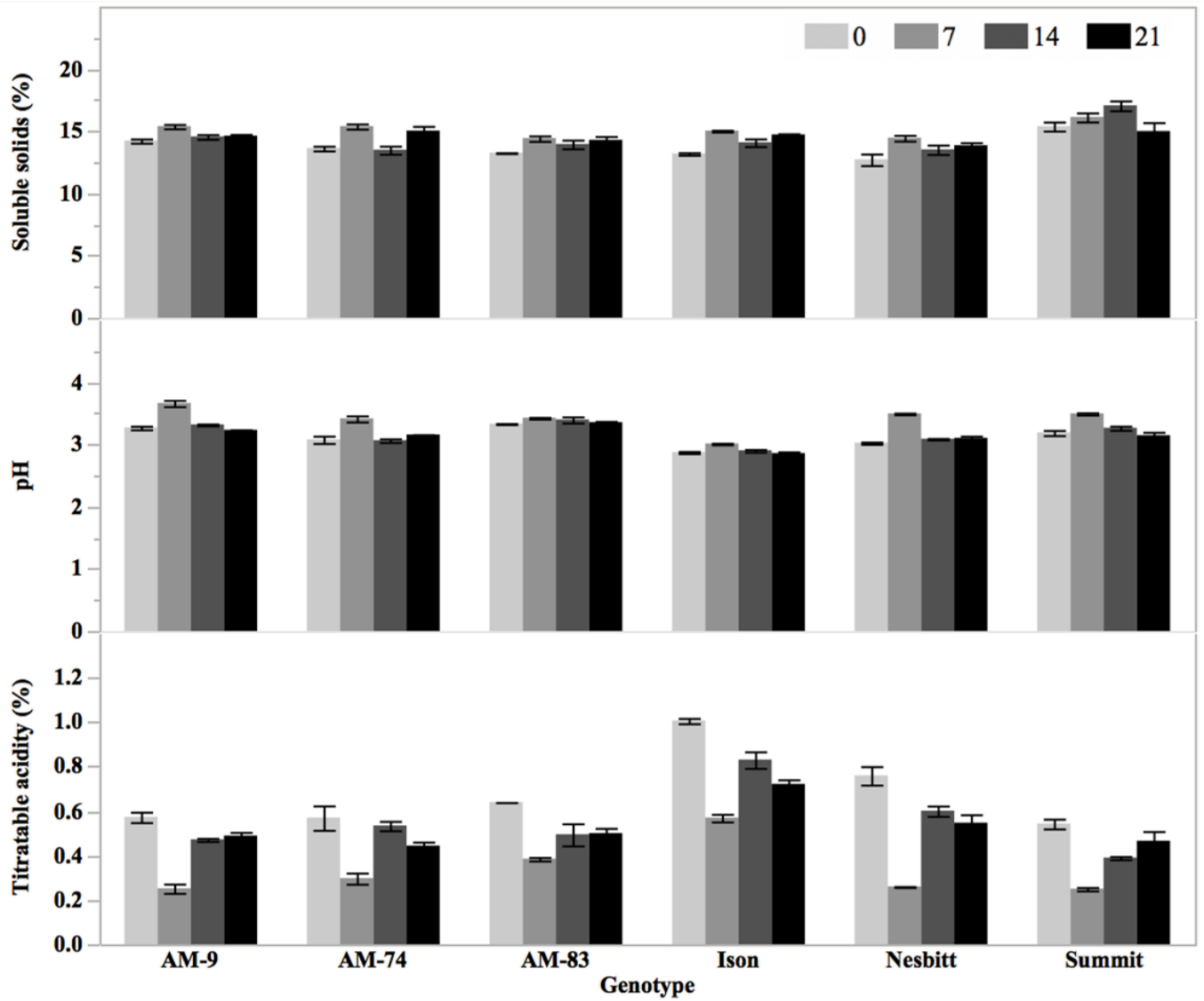

Fig. 6. Composition (soluble solids, pH, and titratable acidity) of fresh-market muscadine genotypes during postharvest storage at 2 °C for 0, 7, 14, and 21 d, Clarksville, AR (2017). Each standard error bar is constructed using 1 standard error from the mean.

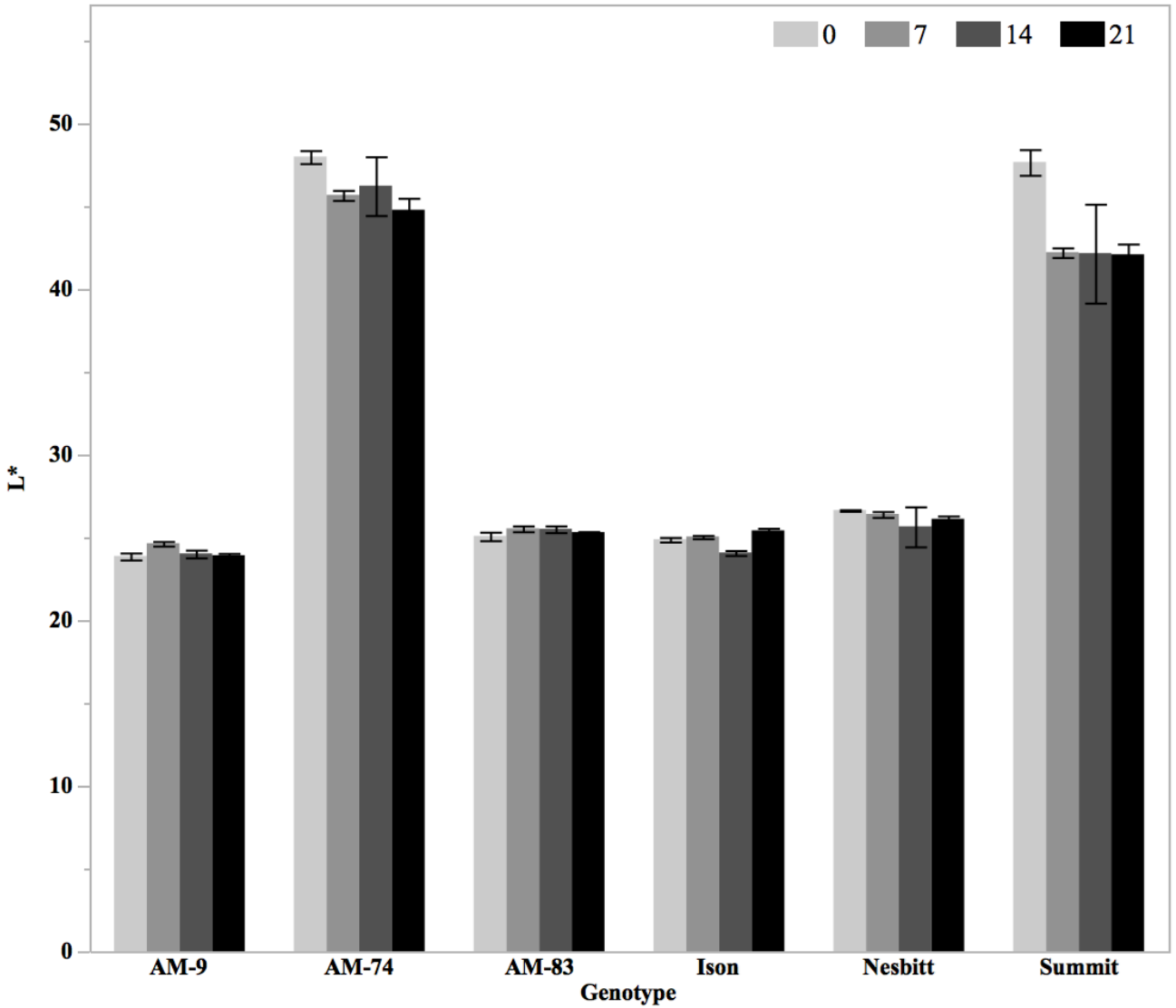

Fig. 7. L*of fresh-market muscadine genotypes during postharvest storage at 2 °C for 0, 7, 14, and 21 d, Clarksville, AR (2017). Each standard error bar is constructed using 1 standard error from the mean.

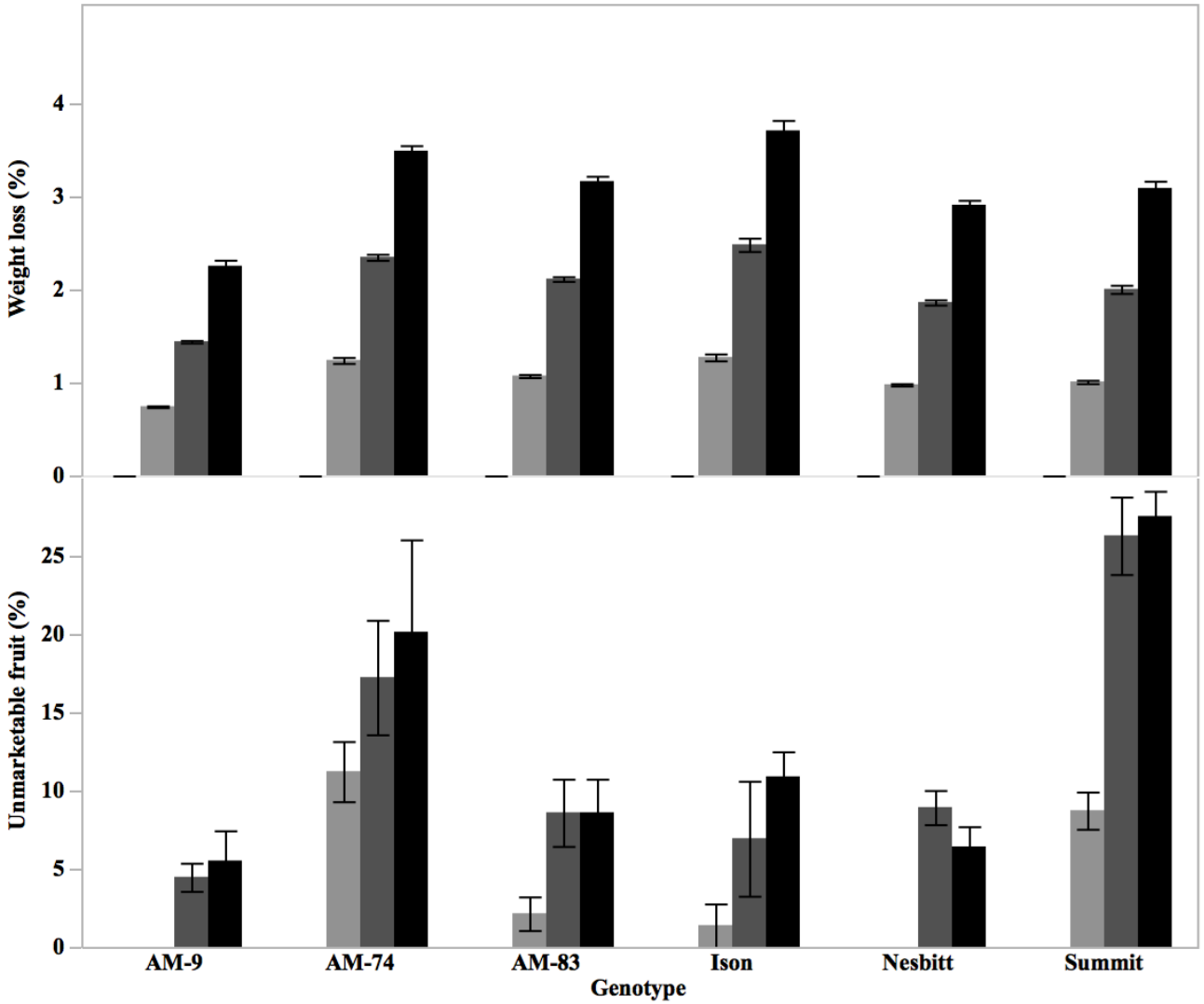

Fig. 8. Marketability (weight loss and unmarketable fruit) of fresh-market muscadine genotypes during postharvest storage at 2 °C for 0, 7, 14, and 21 d, Clarksville, AR (2017). Each standard error bar is constructed using 1 standard error from the mean.

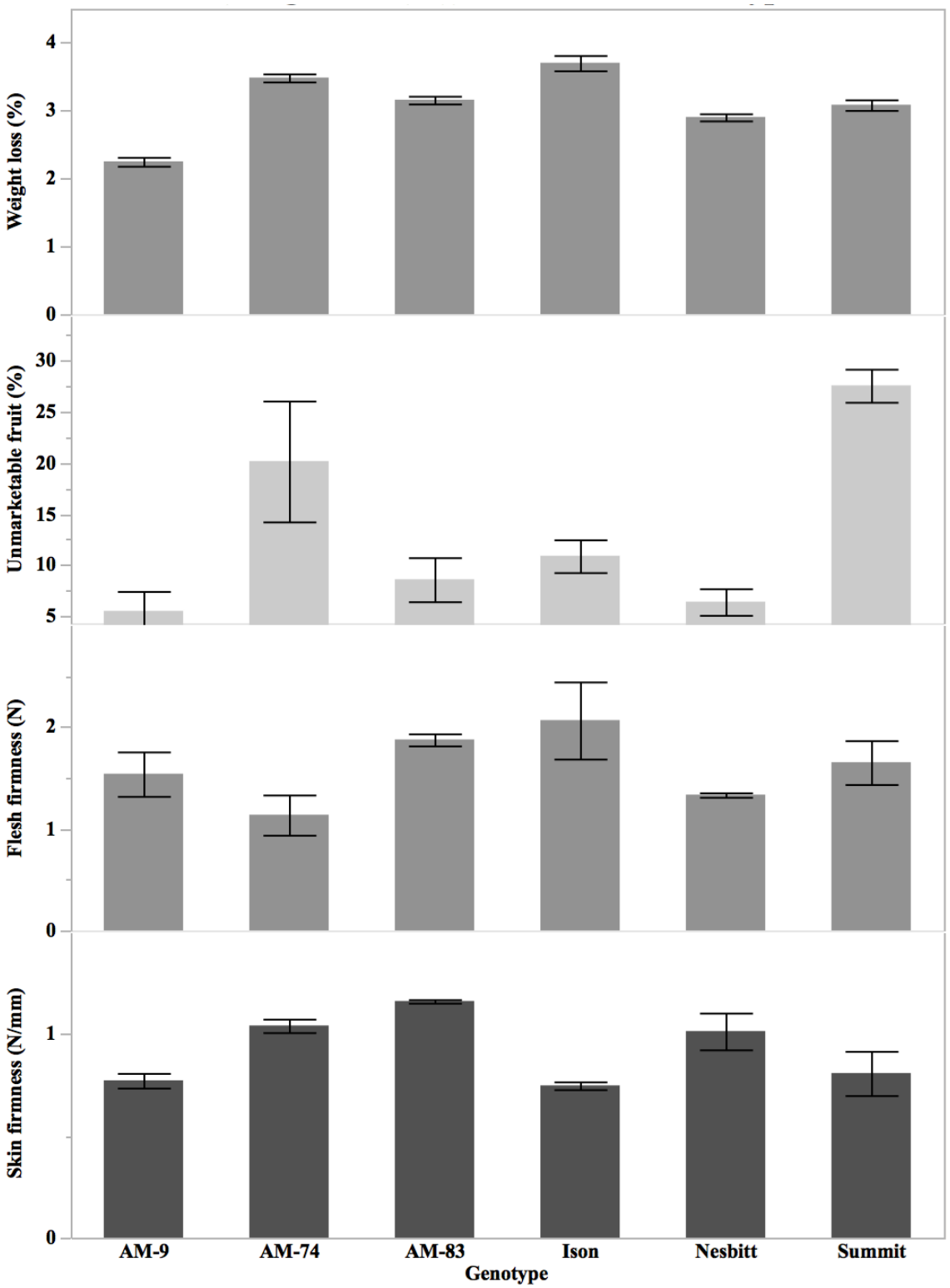

Fig. 9. Marketability and texture attributes of fresh-market muscadine genotypes after 21 d storage at 2 °C, Clarksville, AR (2017). Each standard error bar is constructed using 1 standard error from the mean.

Overall Conclusions

The evaluation of fresh-market potential of Arkansas-grown blackberries, peaches, table grapes, and muscadine grapes provided insight into the parameters for both harvest and postharvest storage. Regardless of the fruit, genotype played a critical role in fresh-market potential. During postharvest storage, fruit quality was impacted by how the fruit was grown (tables grapes in high tunnel versus traditional vineyard), how the fruit was harvested (blackberries harvested in the morning), what temperature the fruit was stored (blackberries stored at a lower temperature), and the ripeness attributes of the fruit at harvest (composition and firmness of blackberries, peaches, table grapes, and muscadine grapes). It was important that descriptive sensory lexicons were created to evaluate peach/nectarine and muscadine genotypes for this study to compare to analytical measurements, but to also use the lexicons for further research on these Arkansas-grown fresh-market fruits. The advanced selections in this study showed commercial potential as they performed as well if not better than the released cultivars. After 14 or 21 d of storage, the fruit genotypes generally showed low decay and low unmarketable fruit indicating strong fresh-market potential. Overall, of the genotypes and fruit types evaluated, it was apparent that if the genotype is well adapted to the region, high quality fruit production with good storage potential is possible in Arkansas.

Appendix

UNIVERSITY OF ARKANSAS

Office of Research Compliance
Institutional Review Board

July 18, 2017

MEMORANDUM

TO:	Renee Threlfall Molly Felts Tonya Tokar Margaret Worthington
FROM:	Ro Windwalker IRB Coordinator
RE:	New Protocol Approval
IRB Protocol #:	17-07-002
Protocol Title:	*Identifying Marketable Attributes in Commercial and University of Arkansas Muscadine Grape Genotypes*
Review Type:	☒ EXEMPT ☐ EXPEDITED ☐ FULL IRB
Approved Project Period:	Start Date: 07/14/2017 Expiration Date: 07/13/2018

Your protocol has been approved by the IRB. Protocols are approved for a maximum period of one year. If you wish to continue the project past the approved project period (see above), you must submit a request, using the form *Continuing Review for IRB Approved Projects*, prior to the expiration date. This form is available from the IRB Coordinator or on the Research Compliance website (https://vpred.uark.edu/units/rscp/index.php). As a courtesy, you will be sent a reminder two months in advance of that date. However, failure to receive a reminder does not negate your obligation to make the request in sufficient time for review and approval. Federal regulations prohibit retroactive approval of continuation. Failure to receive approval to continue the project prior to the expiration date will result in Termination of the protocol approval. The IRB Coordinator can give you guidance on submission times.

This protocol has been approved for 300 participants. If you wish to make *any* modifications in the approved protocol, including enrolling more than this number, you must seek approval *prior to* implementing those changes. All modifications should be requested in writing (email is acceptable) and must provide sufficient detail to assess the impact of the change.

If you have questions or need any assistance from the IRB, please contact me at 109 MLKG Building, 5-2208, or irb@uark.edu.

109 MLKG • 1 University of Arkansas • Fayetteville, AR 72701-1201 • (479) 575-2208 • Fax (479) 575-6527 • Email irb@uark.edu

UNIVERSITY OF ARKANSAS

Office of Research Compliance
Institutional Review Board

March 27, 2017

MEMORANDUM

TO:	Renee Threlfall Molly Felts Tonya Tokar Margaret Worthington
FROM:	Ro Windwalker IRB Coordinator
RE:	New Protocol Approval
IRB Protocol #:	17-03-556
Protocol Title:	*Identifying Marketable Attributes in Commercial and University of Arkansas Fresh-market Peach/Nectarine Genotypes*
Review Type:	☒ EXEMPT ☐ EXPEDITED ☐ FULL IRB
Approved Project Period:	Start Date: 03/27/2017 Expiration Date: 03/26/2018

Your protocol has been approved by the IRB. Protocols are approved for a maximum period of one year. If you wish to continue the project past the approved project period (see above), you must submit a request, using the form *Continuing Review for IRB Approved Projects*, prior to the expiration date. This form is available from the IRB Coordinator or on the Research Compliance website (https://vpred.uark.edu/units/rscp/index.php). As a courtesy, you will be sent a reminder two months in advance of that date. However, failure to receive a reminder does not negate your obligation to make the request in sufficient time for review and approval. Federal regulations prohibit retroactive approval of continuation. Failure to receive approval to continue the project prior to the expiration date will result in Termination of the protocol approval. The IRB Coordinator can give you guidance on submission times.

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