Southern Region Small Fruit Consortium

Progress Report Research

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Public Abstract

Muscadine grapes (*Vitis rotundifolia* Michx.), a disease-resistant specialty crop native to the southeastern United States has had major advances in U.S. muscadine breeding efforts resulting in unique traits to expand commercial, fresh-market potential. Retaining the unique flavors and aromas of muscadines are a focus in creating new cultivars for the commercial fresh markets. Six seeded muscadines genotypes were harvested from the University of Arkansas (UA) System Fruit Research Station in Clarksville, AR in 2021. Berry weight, composition, and volatile attributes of the muscadines were evaluated at the UA System Food Science Department, and each of these attributes were significantly impacted by genotype. Berry weight ranged from 5.67 g (AM-77) to 13.88 g (AM-135), soluble solids ranged from 14.00% (AM-77) to 19.47% (AM-135), pH ranged from 3.04 (AM-77) to 3.89 (AM-135), titratable acidity ranged from 0.25% (AM-154) to 0.88% (AM-77), and soluble solids/titratable acidity ratio ranged from 16.06 (AM-77) to 70.34 (AM-135). In the six genotypes harvested in Arkansas, 191 volatile aroma compounds were identified across nine compound classes including 47 esters, 38 monoterpenes, 28 alcohols, 30 sesquiterpenes, 25 aldehydes, 16 ketones, four lactones, two aromatic hydrocarbons, and one epoxide. AM-154 (5,746 µg/kg) had the highest total volatiles and AM-77 (2,151 µg/kg) had the lowest. AM-154 had the highest levels of geraniol (floral monoterpene) (1,276 µg/kg) and was the only genotype to contain 2-phenylethanol (floral alcohol) (624 µg/kg) and phenylacetaldehyde (green/floral aldehyde) (89 µg/kg). Seven compounds with a high aromatic impact were also identified including ethyl butanoate (fruity ester), ethyl 2-methylbutanoate (ester with fruity, green apple notes), hexanal (aldehyde with grassy and fruity aromas), ethyl hexanoate (ester with tropical fruit notes), phenylacetaldehyde (aldehyde with green and floral aromas), geraniol (monoterpene with floral and fruity aromas), and 2-phenylethanol (alcohol with rosy aromas). Geraniol had the highest level in most genotypes (5-1,276 µg/kg). In Arkansas-grown muscadines, two principle components explained 79.93% of the data. Clustering indicated that AM-135, AM-26, and AM-70 were positively correlated with

ketones, lactones, and alcohols, but negatively correlated with esters and aromatic hydrocarbons, while AM-154 was positively correlated with monoterpenes, sesquiterpenes, epoxides, and aldehydes. AM-148 and AM-77 were negatively correlated with aldehydes, monoterpenes, sesquiterpenes and epoxides. Data generated from this project provided information on physical, composition, and volatile attributes of muscadine grapes that can be used to support future muscadine breeding efforts.

Introduction

Muscadine grapes (*Vitis rotundifolia* Michx.) are a disease-resistant specialty crop native to the southeastern United States with potential for increased fresh-market expansion. Advances in U.S. muscadine breeding have resulted in unique traits emerging with commercial, fresh-market potential providing opportunity to strengthen the market presence for the muscadines. This research from the University of Arkansas System Division of Agriculture (UA System) identified attributes unique to muscadine grapes that can be used as a baseline for further breeding efforts.

Muscadines Aromas and Flavors

Muscadine grapes, and the juice and wine produced from muscadine grapes, have unique fruity and floral aromas and flavors. Flavor of grapes arises from perception of basic taste (sweet, sour, salty, bitter, and umami), volatile aroma compounds, and chemical sensitivity. **Volatile aroma compounds play a critical role in flavor perception.** Threlfall et al. (2007) found that commercial muscadine juices from Arkansas had cooked muscadine, apple, pear, cooked grape, green/unripe, and slightly musty aromas and flavors. Meullenet et al. (2008) found correlations between general muscadine flavor and musty flavor, general grape flavor and metallic flavor, green/unripe flavor and sourness/astringency, and sweetness and floral, apple, and pear flavors for Arkansas muscadine juice. Most research on muscadine flavor has been conducted with juice from processing cultivars, especially ‘Carlos’ and ‘Noble’. However, Felts et al. (2018) developed a sensory lexicon for fresh-market muscadine grapes grown at the UA System Fruit Research Station and found that panelists detected differences between genotypes in grape/overall, grape/muscadine, and fruity.

Important Muscadine Flavor Volatiles

Lamikanra (1987) determined that higher alcohols and fatty acid ethyl esters were numerically the largest classes of volatile aroma compounds in ‘Noble’ muscadine wine. Lamikanra et al. (1996) found that 2-phenylethanol (rose and honey aroma) was predominantly synthesized during fermentation of muscadine wines but was also present in fresh muscadine grape skins. In an evaluation of Noble wine, Mayfield (2020) found that fruity esters were the largest class of volatile aroma compounds, followed by higher alcohols, notably 2-phenylethanol (rose and honey aroma). Baek et al. (1997) analyzed volatile aroma compounds in juice from ‘Carlos’ grapes and found that furaneol and o-aminoacetophenone were likely responsible for characteristic candy and foxy-like aroma notes of muscadine grape juice. **It is important to note that there are only a few of these studies on volatiles assessments of muscadine grapes, especially fresh-market muscadine cultivars.**

New Aromas and Flavors in UA System Breeding Selections

The UA System muscadine breeding program began in 2006 and since then, over 19,000 seedlings have been planted and 300 selections have been made. A group of advanced selections are currently being considered for cultivar release. These selections are notable for their interesting flavors. While some advanced selections have the intense grape flavor typically associated with muscadines, others have more tropical/pineapple or rosy/floral aromas. It is unknown which volatile compounds are responsible for the range of muscadine flavors in our breeding program. **This research will identify the important volatile compounds contributing to perception of standard, 'rosy', and 'tropical' flavors in fresh-market muscadine grapes.**

Objectives

Note: In February 2021, extreme freezing temperatures to -15 °F (-26 °C) in Arkansas destroyed muscadine plants to the ground or damaged the plants for many genotypes in the UA System breeding program. In addition, a late freeze in April caused additional damage to these muscadines. Since muscadine fruit from Arkansas was limited, the sensory evaluation of the muscadine fruit aroma was not done for this project. The project final report was delayed because the muscadines were harvested in late September 2021, and the equipment for volatile analysis was being used for another project. Volatile analysis and volatile identification of the muscadines was completed in June 2022.

Objectives:

1. Evaluate berry weights and composition attributes of muscadine grapes

Measure berry weights and composition attributes of muscadines grown in Arkansas

2. Evaluate volatile attributes of muscadine grapes

Measure volatile attributes of muscadines grown in Arkansas

Materials and Methods

The berry weight, composition, and volatile attributes of Arkansas-grown muscadines were evaluated. Fruit from six genotypes were harvested from the UA System Fruit Research Station, Clarksville on September 20, 2021 (Fig. 1 and Table 1). The six muscadine genotypes evaluated were AM-26 (bronze), AM-70 (dark/black), AM-77 (dark/black), AM-135 (bronze), AM-148 (dark/black), and AM-154 (pink/red). Approximately 1.8 kg of berries (four 1-quart clamshells) were harvested for each genotype. The berry weights, composition, and volatile attributes of fresh-market muscadines were evaluated at the UA System Department of Food Science, Fayetteville. The experiment was as a completely randomized design with three replicates per genotype.

1. Evaluate berry weights and composition attributes of muscadine grapes

Measure berry weights and composition attributes of muscadines grown in Arkansas

Berry weight and composition attribute analysis

The berry weight and composition (soluble solids, pH, titratable acidity, and soluble solids/titratable acidity ratio) attributes of each of the fresh-market muscadines were evaluated. The berry weights were measured at harvest, and the berries for composition were placed in zip-type bags and stored at -10 °C until analysis.

Berry weight. Five berries per genotype and replication were evaluated for berry weight. Each berry was weighed (g) on a digital scale.

Composition. Five to ten berries (depending on the size of the berries) per genotype and replication were evaluated for composition attributes. Berries were placed in cheesecloth to extract the juice from the berries. The juice from the berry samples was used to determine composition attributes.

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

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

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

Soluble solids/titratable acidity ratio. The soluble solids/titratable acidity ratio was calculated as the soluble solids divided by the titratable acidity.

Objective 2. Evaluate volatile attributes of muscadine grapes

Measure volatile attributes of muscadines grown in Arkansas

Volatile attribute analysis

The volatile attributes of the Arkansas muscadines were evaluated. After harvest, the berries for volatile analysis were placed in zip-type bags and stored at -10 °C until analysis.

Volatile aroma. Five berries per genotype and replication were used for volatile aroma attribute analysis. The seeds were removed from the muscadine berries before analysis. Gas chromatography analysis was performed using a Shimadzu GC-2010 Plus Gas Chromatograph equipped with a Flame Ionization Detector (GC-FID) and a GCMS-QP2010 SE Mass Spectrometer (GC-MS). The analysis includes identification and quantitation of odor-active compounds. For the analysis of muscadine volatiles, frozen berries (5 g), deionized water (10 mL), and NaCl (3 g) were mixed using a ratio of 1:1:0.3 (w/v/w). Two samples (one for GC-MS and one for FID) of 4 mL berry/deionized water/NaCl solution were placed in 20 ml headspace vials. The vials were incubated for 20 minutes with agitation and heat at 65 °C, and then the volatiles were absorbed using an 85 µm DVB/CAR/PDMS Solid Phase Microextraction (SPME) fiber was placed in the headspace above the sample for an additional 30 minutes. The SPME fiber was removed from the vial and placed into GC injection ports. Samples were analyzed on both GC-FID and GC-MS and separation was performed on each using a HP-5 (30 m × 0.25 mm inner diameter, 5% phenyl-methylpolysiloxane, 1.0 µm film thickness) capillary column. For both GC-MS and GC-FID analysis, the injector temperature was 250 °C. Helium was used as the carrier gas and column flow rate was 1.92 mL/min for GC-FID and 1.20 mL/min for GC-MS. The oven temperature was programmed for a 4 min hold at 30 °C, then 30 °C to 180 °C at 6 °C/min, then from 180 °C to 280 °C at 8 °C/min, and with a 3 min hold at 280 °C. The GC-FID detector temperature was 280 °C, and the interface temperature for the GC-MS had an ion source temperature of 230 °C and an interface temperature of 250 °C. GC-MS was performed in full scan mode, with a scan range of 20-300 m/z. The volatiles were identified by comparison of their mass spectra with the spectral library, literature data, and retention indices, standards, and expressed as µg/kg.

Statistical analysis

For berry weight and composition attributes, all genotypes were evaluated in triplicate. The data was analyzed by analysis of variance (ANOVA) using JMP® (version 16.1.0; SAS Institute Inc., Cary, NC). Tukey's Honestly Significant Difference was used for mean separations ($p \leq 0.05$). Data for volatiles was presented as means and standard deviations of the three replicates. Associations among all dependent variables were determined using multivariate pairwise correlation coefficients of the mean values using JMP®. Principal component analysis (PCA) was done using XLStat (Addinsoft Inc., New York, NY).

Results and Discussion

Berry weight

Genotype significantly impacted berry weight in Arkansas-grown muscadines. Berry weight ranged from 5.67 g (AM-77) to 13.88 g (AM-135). AM-77 (5.67 g) had a significantly lower berry weight than the other genotypes. AM-135 (13.88 g) had the highest berry weight and was larger than AM-26 (11.08 g), AM-77 (5.67 g), AM-148 (11.86 g), or AM-154 (9.61 g) but not AM-70 (13.50 g). Xu et al. (2017) found that muscadines range from 3-23 g, however, consumers prefer a muscadine that is slightly larger than other grapes. All of the Arkansas-grown berries (5.67-13.88 g) examined in this study were within established commercial ranges (9-14 g) (Barchenger et al., 2015; Brown et al., 2016; Felts et al., 2018; Threlfall et al., 2007).

Composition attributes

Genotype significantly impacted all of the composition attributes in Arkansas-grown muscadines with soluble solids ranged from 14.00 to 19.47%, pH 3.04 to 3.89, titratable acidity 0.25 to 0.88%, soluble solids/titratable acidity ratio 16.06 to 70.34. Walker et al. (2001), Threlfall et al. (2007), and Felts et al. (2018) indicated a preferred soluble solids/titratable acidity ratio of muscadine grapes and juice of 20-35. While the majority of the muscadines examined in this study were within this range, AM-77 (16.06) had values below this rang, while AM-135 (70.31), AM-70 (66.06), and AM-154 (68.92) were above this range. AM-135 had the highest soluble solids (19.47%) and soluble solids/titratable acidity ratio (70.31). AM-70 and AM 135had the highest pH (3.89). AM-77 (a processing genotype) had the highest titratable acidity (0.88%) and the lowest pH (3.04), soluble solids (14.00%), and soluble solids/titratable acidity ratio (16.06).

Volatile attributes

In the six genotypes harvested in Arkansas, 191 volatile aroma compounds were identified across nine compound classes including 47 esters, 38 monoterpenes, 28 alcohols, 30 sesquiterpenes, 25 aldehydes, 16 ketones, four lactones, two aromatic hydrocarbons, and one epoxide (Fig. 2 and Table 1). AM-154 (5,746 µg/kg) had the highest volatile concentration, followed by AM-70 (4,361 µg/kg), AM-135 (4,217 µg/kg), AM-26 (3,732 µg/kg), and AM-148 (2,468 µg/kg) with AM-77 (2,151 µg/kg) containing the lowest. AM-154 had the highest levels of geraniol (floral monoterpene) (1,276 µg/kg) and was the only genotype to contain 2-phenylethanol (floral alcohol) (624 µg/kg) and phenylacetaldehyde (green/floral aldehyde) (89 µg/kg). This classification was similar to major constituents for grape volatiles previously reported (Deng, 2021; Golombek et al., 2021; Ju et al., 2021; Lee et al., 2016; Lin et al., 2019; Mencarelli and Bellincontro, 2018; Wu et al., 2020)

The total volatile concentration does not give the most accurate representation of a sample's aroma profile because some compounds have a larger overall impact on the perceived aroma than others. Compounds that are impactful have a high odor active value (OAV), so examining these compounds gives a better representation of how consumers will perceive muscadine flavors and aromas. In muscadine juice, Baek et. al. (1997) identified high odor active comprised of six esters (ethyl acetate, ethyl butanoate, ethyl 2-methylbutanoate, ethyl hexanoate, ethyl 3-hydroxybutanoate, and phenethyl acetate), four alcohols (3-methyl-1-butanol, (E,Z)-2,6-Nonadien-ol, (E)-Geraniol, and 2-phenylethanol), four aldehydes (hexanal, 3-(methylthio)propanal, (E,Z)-2,6-nonadienal, and phenylacetaldehyde), four ketones (2,3-butanedione, 1-octen-3-one, 2,5-dimethyl-4-hydroxy-3 (2H)-furanone, o-Aminoacetophenone), two acids (acetic acid and 3-methyl butanoic acid), and one phenol (p-vinylguaiacol). In the Arkansas muscadines, seven of these impactful compounds were identified including ethyl butanoate (0.3-99.7 µg/kg) (fruity ester), ethyl 2-methylbutanoate (97.5-140.4 µg/kg) (ester with fruity, green apple notes), hexanal (0.6-82.3 µg/kg) (aldehyde with grassy and fruity aromas), ethyl hexanoate (0.0-14.1 µg/kg) (ester with tropical fruit notes), phenylacetaldehyde (0.0-88.9 µg/kg) (aldehyde with green and floral aromas), geraniol (5.4-1276.3 µg/kg) (alcohol with fruity and floral aromas), and 2-phenylethanol (0.0-624.3) (alcohol with rosy aromas) (Fig 3.). AM-154 had the highest levels of impactful volatiles. AM-148 had the lowest levels of impactful volatiles, followed by AM-77. Geraniol (floral monoterpene) had the highest level of these impactful volatiles found in most muscadine genotypes, followed by ethyl 2-methylbutanoate (fruity ester) and ethyl butanoate (fruity ester). El Hadi et al. (2013) also indicated that some compounds were more impactful in certain cultivars of grapes due to synergistic effects between different volatile compounds. This could explain why certain genotypes had low levels of impactful volatile compared to other genotypes.

Principal component analysis

Principal component analysis was used to separate compound categories and Arkansas muscadine genotypes into different groups with two components explaining 79.93% of the data (Table 3). Wu et al. (2016) examined table grapes in China and found that 'Kyoho' (*V. vinifera* and *V. labrusca* hybrid) had high levels of esters, while muscat grapes had higher levels of monoterpenes. Wu et al. (2016) also postulated that grouping aroma compounds into similar descriptors was useful for determining organoleptic profiles.

PC1 (52.56%) had positive loadings for the following compound classifications: lactones, alcohols, monoterpenes, aldehydes, ketones, sesquiterpenes, and epoxides, and also for genotypes AM-135, AM-26, AM-154, and AM-70. PC1 had negative loadings for esters and aromatic hydrocarbons, as well as AM-148 and AM-77 genotypes. PC2 (27.37%) had positive loadings for alcohols, ketones, and lactones, as well as genotypes AM-148 AM-26, AM-77, AM-135, and AM-70. Aromatic hydrocarbons, sesquiterpenes, epoxides, esters, monoterpenes, aldehydes and the AM-154 genotype were negatively associated with PC2. Clustering indicated that AM-135, AM-26, and AM-70 were positively correlated with ketones, lactones, and alcohols, but negatively correlated with esters and aromatic hydrocarbons, while AM-154 was positively correlated with monoterpenes, sesquiterpenes, epoxides, and aldehydes. AM-148 and

AM-77 were not positively correlated with any compound classifications, however, they were both negatively correlated with aldehydes, monoterpenes, sesquiterpenes and epoxides.

Conclusion

Berry weight, composition, and volatile attributes of muscadines grapes grown in Arkansas were significantly impacted by genotype. The berry weights and composition were within typical ranges for muscadines. The muscadine breeding genotype, AM-148, had lower total volatiles, while AM-154 had higher total volatiles. The muscadine genotypes with high levels of geraniol (AM-26, AM-135, AM-70 and AM-154) will have a much stronger rosy and floral aromas than other genotypes, especially AM-154 in which the floral aromas of phenylacetaldehyde and 2-phenylethanol will have a synergistic effect. Genotypes with higher concentrations of esters (AM-77 and AM-148) will have a fruitier and more tropical aroma when compared to other genotypes. Because these muscadine breeding genotypes have unique profiles, additional research to better establish what the impactful volatiles are in some of these new breeding genotypes would be greatly beneficial for future breeding efforts. Data generated from this project provided information on berry weight, composition, and volatile attributes of muscadine grapes grown in Arkansas that can be used to support breeding efforts.

Impact Statement

This project provided information on berry weight, composition, and volatile attributes of advanced breeding selections of muscadine grapes from the University of Arkansas System Division of Agriculture. Of the six muscadine grape selections were evaluated, AM-154 had the highest total volatiles. AM-26, AM-135, AM-70, and AM-154 had strong rosy and floral aromas, especially AM-154. AM-77 and AM-148 had fruity and tropical aromas. Data generated on thesis muscadine grape attributes can be used to support future breeding efforts and the release of cultivars.

Literature Cited

Baek, H.H., and K.R. Cadwallader, E. Marroquin, and J.L. Silva. 1997. Identification of predominant aroma compounds in muscadine grape juice. J. Food Sci. 62(2):249-252 https://doi.org/10.1111/j.1365-2621.1997.tb03978.x

Barchenger, D.W., J.R. Clark, R.T. Threlfall, L.R, Howard, and C.R. Brownmiller. 2015. Evaluation of physicochemical and storability attributes of muscadine grapes (*Vitis rotundifolia Michx.*). HortScience, 50:104-111, http://dx.doi.org/10.21273/HORTSCI.50.1.104

Brown, K., C. Sims, A. Odabasi, L. Bartoshuk, P. Conner, and D. Gray. 2016. Consumer acceptability of fresh market muscadine grapes. J. Food Sci. 11(81):S2808-S2816. https://doi.org/10.1111/1750-3841.13522

Conner, P.J. 2010. A Century of muscadine grape (*Vitis rotundifolia Michx*.) breeding at the University of Georgia. J. Amer. Pomological Soc. 64:78-82, https://doi.org/10.17660/ActaHortic.2009.827.83

Deng, H., R. He, M. Long, Y. Li, Y. Zheng, L. Lin, D. Liang, X. Zhang, M.A. Liao, X. Lv, and Q. Deng. 2021. Comparison of the fruit volatile profiles of five Muscadine grape cultivars (Vitis rotundifolia Michx.) using HS-SPME-GC/MS combined with multivariate statistical analysis. Frontiers in plant sci. 2302.

El Hadi, M. A. M., F. J Zhang, F. F. Wu, C. H. Zhou, and J. Tao. 2013 Advances in fruit aroma volatile research. Molecules.18(7): 8200-8229.

Felts, M., R.T. Threlfall, J.R Clark, and M.L. Worthington. 2018. Physiochemical and descriptive sensory analysis of Arkansas muscadine grapes. HortScience, 53:1570-1578, https://doi.org/10.21273/HORTSCI13296-18

Golombek, P., M. Wacker, N. Buck, and D. Durner. 2021. Impact of UV-C treatment and thermal pasteurization of grape must on sensory characteristics and volatiles of must and resulting wines. Food Chem. 338: 128003.

Ju, Y. L., X. F. Yue,.X. Y. Cao, X. F. Wei, and Y. L. Fang. 2021. First study on the fatty acids and their derived volatile profiles from six Chinese wild spine grape clones (Vitis davidii Foex). Scientia Horticulturae, 275: 109709.

Lamikanra, O. 1987. Aroma constituents of muscadine wine. J. Food Qual. 10:57-66. https://doi.org/10.1111/j.1745-4557.1987.tb00289.x

Lamikanra, O., C.C. Grimm, and I.D. Inyang. 1996. Formation and occurrence of flavor components in Noble muscadine wine. Food Chem. 56:373376. https://doi.org/10.1016/0308-8146(95)00183-2

Lee, B., P. Lin, H.S. Cha, J. Luo, and F. Chen. 2016. Characterization of volatile compounds in Cowart muscadine grape (*Vitis rotundifolia*) during ripening stages using GC-MS combined with principal component analysis. Food Sci. Biotechnol. 25:1319-1326. https://doi.org/10.1007/s10068-016-0207-3

Lin, J., M. Massonnet, and D. Cantu. 2019. The genetic basis of grape and wine aroma. Horticulture Research. 6.

Mayfield, S.E. 2020 Techniques to enhance the attributes of wines produced from grapes grown in Arkansas. Univ. of Ark. Fayetteville, PhD Diss.

Mencarelli, F., and A. Bellincontro. 2020. Recent advances in postharvest technology of the wine grape to improve the wine aroma. Journal of the Science of Food and Agriculture, 100(14), 5046-5055.

Meullenet, J.F., C. Lovely, R. Threlfall, J.R. Morris, and R.K. Striegler, 2008. An ideal point density plot method for determining an optimal sensory profile for Muscadine grape juice. Food Qual. Preference 19:210-219. https://doi.org/10.1016/j.foodqual.2007.06.011

Threlfall, R.T., J.R. Morris, J.F. Meullenet, and R.K. Striegler. 2007. Sensory characteristics, composition, and nutraceutical content of juice from *Vitis rotundifolia* (muscadine) cultivars. Amer. J. Enol. Viticult. 58:268-273.

Walker, T.L., J.R. Morris, R.T. Threlfall, G.L. Main, O. Lamikanra, and S. Leong. 2001. Density separation, storage, shelf life, and sensory evaluation of ‘Fry’ muscadine grapes. HortScience 36:941-945, http://dx.doi.org/10.21273/HORTSCI.36.5.941

Xu, C., Y. Yagiz, L. Zhao, A. Simonne, J.Lu, M. R. Marshall. 2017. Fruit quality, nutraceutical and antimicrobial properties of 58 M=muscadine grape varieties (*Vitis torundifolia* Michx.) grow in United States. J. Food Chem. 215:149-156.

Wu, Y., S. Duan, L. Zhao, Z. Gao, M. Luo, S. Song, W. Xu, C. Zhang, C. Ma, and S. Wang. 2016. Aroma characterization based on aromatic series analysis in table grapes. Sci Reports 6(1), 1-16.

Wu, Y. W. Zhang, S. Song, W. Xu, C. Zhang, C. Ma, and S. Wang. 2020. Evolution of volatile compounds during the development of Muscat grape ‘Shine Muscat’(Vitis labrusca× V. vinifera). Food Chem. 309: 125778.

Table 1. Berry weight and composition attributes at harvest of muscadine grapes grown and evaluated at the University of Arkansas System Division of Agriculture, Clarksville, AR (2021).

Genotype [z]	Skin color	Seeds	Berry weight (g)	Soluble solids (%)	pH	Titratable acidity (%)[y]	Soluble solids/titratable acidity ratio
AM-26	Bronze	Seeded	11.08 b	16.23 b	3.62 b	0.50 b	32.65 b
AM-70	Dark/black	Seeded	13.50 a	18.90 a	3.89 a	0.29 c	66.06 a
AM-77	Dark/black	Seeded	5.67 d	14.00 c	3.04 c	0.88 a	16.06 c
AM-135	Bronze	Seeded	13.88 a	19.47 a	3.89 a	0.28 c	70.31 a
AM-148	Dark/black	Seeded	11.86 b	16.30 b	3.67 b	0.54 b	30.53 b
AM-154	Pink/Red	Seeded	9.61 c	16.93 b	3.58 b	0.25 c	68.92 a
P-value			*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*

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

Table 2. Volatile aroma compounds[z] identified in muscadine genotypes grown at the University of Arkansas System Division of Agriculture Fruit Research Station, Clarksville, AR (2021)

Compound Name	Retention Index	Aroma Category	Aroma Descriptor	AM-26	AM-70	AM-77	AM-135	AM-148	AM-154
Totals				**3732.14±309.46**	**4360.6±634.62**	**2150.66±1899.88**	**4217.32±1922.96**	**2468.38±407.58**	**5745.62±317.42**
Alcohols									
2-Butanol	610	Fruity	sweet apricot	3.46±2.36	2.52±3.34	18.1±23.82	18.68±13.2	8.98±9.94	27.5±23.12
1-Butanol	644	Fermented	fusel oily sweet balsamic whiskey	5.16±6.68	7.52±6.52	0.68±1.2	12.88±8.8	7.2±6.8	3.08±2.68
1-Penten-3-ol	683	Green	ethereal horseradish green radish chrysanthemum vegetable tropical fruity	27±37.32	19.12±26.28	29.72±42.6	10.28±8.2	12.2±10.56	44.64±64.72
2-Methyl-1-butanol	735	Ethereal	fusel ethereal alcoholic fatty greasy winey whiskey leathery cocoa	0±0	0±0	0±0	0±0	8.04±7	11.64±8.36
3-Methyl-3-buten-1-ol	739	Fruity	sweet fruity	0±0	20.56±27.36	27.28±40.64	28.08±45.48	40.68±34.36	13.32±23.08
1-Pentanol	763	Fermented	pungent fermented bready yeasty fusel winey solvent	26.44±23.60	71.00±104.00	8.56±8.4	125.28±189.88	4.04±3.56	10.96±9.72
3-Methyl-1-butanol	767	Fermented	fusel alcoholic pungent ethereal cognac fruity banana molasses	0±0	0±0	0±0	12.32±21.32	12.64±10.04	50.72±7.44
2-Penten-1-ol	769	Green	green	0±0	0±0	0±0	1.8±3.16	0±0	2.2±3.8
3-Hexen-1-ol	781	Green	leafy	0±0	15.08±14.96	37.08±32.8	49.44±51.28	0±0	0±0
2-Hexen-1-ol	836	Fruity	fruity green leafy	635.2±418.04	515.52±571.6	6±5.2	326.12±290.12	162.64±162.28	5.4±1.2
2 Heptanol	861	Citrus	fresh lemongrass herbal sweet floral fruity green	42.68±72.36	116.08±200.36	348.48±305.72	232.52±401.84	72.08±67.72	294.4±29.64
1-Hexanol	871	Herbal	ethereal fusel oily fruity alcoholic sweet green	130.52±223.8	2.08±3.6	1.72±1.52	0.48±0.4	0±0	3.96±6.4
5-Methyl-1-heptanol	894	-	-	1.2±1.04	7.76±5.08	2±1.8	2.88±2.04	8.12±3.96	2.48±2.72
2-Methyl-1-heptanol	900	-	-	9.6±4.32	15.24±11.48	26±22.84	8.84±13.84	12.64±11.8	18.76±0.12
2-Methyl-6-hepten-3-ol	919	-	-	0±0	0±0	0.92±1.64	0.84±1.2	1±0.16	1.88±0.32
2-methyl-2-heptanol	933	-	-	0.44±0.4	1.08±1.4	27.24±26.88	0.52±0.48	2.8±1.2	1.24±0
1-Octen-3-ol	960	Earthy	mushroom earthy green oily fungal raw chicken	1.52±2.2	1.36±2.36	1.92±1.68	5.44±9.44	46.56±15.44	0±0
1- Heptanol	973	Green	musty leafy violet herbal green sweet woody peony	4.16±3.8	11.4±19.8	0±0	0±0	7.8±13.52	0±0
2-Ethylhexanol	1034	Citrus	citrus fresh floral oily sweet	5.96±1.44	11.72±4.88	16.76±25.76	16.68±6.6	5.64±2.12	0±0
1-Octanol	1074	Waxy	waxy green orange aldehydic rose mushroom	0±0	0±0	0±0	2.68±1.08	2.52±1.24	2.64±0.16
1-Phenylethanol	1127	Floral	fresh sweet almond gardenia hyacinth	170.44±80.72	958.72±300.12	127.48±134.32	1207.84±690.8	610.4±408.6	0±0
2-Phenylethanol	1129	Floral	floral rose dried rose	0±0	0±0	0±0	0±0	0±0	624.48±16.72
1-Nonanol	1176	Floral	fresh clean fatty floral rose orange dusty wet oily	2.2±1.12	3.92±1.2	6.16±9.52	2.16±0.76	2.24±1.64	4±0.96
1-Decanol	1277	Fatty	fatty waxy floral orange sweet clean watery	0±0	5.68±2.16	4.4±4.16	0.28±0.24	1.96±0.52	0±0
4,8-Dimethylnonan-1-ol	1289	-	-	113.04±32.88	80.76±27.8	46.8±52.2	115.16±119.92	76.72±25.64	179±19.8
Eugenol	1371	Spicy	sweet spicy clove woody	0±0	1.84±1.6	0.88±1.56	1.08±0.96	1.8±1.56	0.96±1.28
1-Dodecanol	1480	Waxy	earthy soapy waxy fatty honey coconut	1.56±0.84	2.44±0.96	2.04±1.92	1±0.8	1±0.04	1.6±0.4
1-Hexadecanol	1887	Waxy	waxy clean greasy floral oily	4.68±3.76	3.16±1.16	2.52±2.88	1.4±0.6	0.8±0.04	1.52±0.24
Totals	**28**			**1188.72±919.04**	**1877.08±1341.36**	**760.84±772.88**	**2203.36±1895.64**	**1119.48±809.68**	**1333.88±246**
Aldehydes									
3-Methylbutanal	643	Aldehydic	ethereal aldehydic chocolate peach fatty	11.54±10.22	12.5±19.9	0±0	0±0	6.74±9.92	1.06±1.86
2-Butenal	654	-	-	3.3±4.72	4.5±6.94	7.44±6.44	4.56±7.18	7.74±7.66	3.6±2.78
2-Methylbutanal	669	Cocoa	musty cocoa phenolic coffee nutty malty fermented fatty alcoholic	0.98±1.2	3.24±0.92	0.54±0.46	1.12±1.6	5.52±4.26	2.48±2.6
Pentanal	701	Fermented	fermented bready fruity nutty berry	16.4±3.7	9.84±4.34	11.46±10.12	4.4±1.2	7.42±2.94	1.46±0.14
Tiglic aldehyde	728	Green	pungent green ethereal nutty anisic fruity	23.26±12.54	4.66±6.74	2.9±2.54	17.66±2.22	2.62±0.92	5.16±4.46
3-Methylpentanal	746	-	-	90.64±153.32	2.56±3.08	0.32±0.3	2.66±3.38	1.76±1.04	0.32±0.28
2-Pentenal	754	Green	pungent green apple orange tomato	3.86±4.16	3.18±1.86	2.78±2.52	6.82±3.14	3.6±2.46	2.38±0.4
2-Butenal, 3-methyl	787	Fruity	sweet fruity pungent brown nutty almond cherry	1.4±2.44	4.02±2.54	6.46±5.78	3.28±0.16	3.04±5.28	3.28±2.66

Hexanal	804	Green	fresh green fatty aldehydic grassy leafy sweaty	0.58±0.64	5.34±5.1	1.5±2.62	11.52±14.76	15.16±20.72	82.26±142.06
2-Hexenal	845	Green	sweet almond bitter fruity green leafy apple plum vegetable	159.04±155.88	197.88±245.08	110.5±107.8	141.6±35.32	50.14±26.66	266.72±39.34
Heptanal	892	Green	fresh aldehydic fatty green herbal cognac ozone	0.42±0.36	0.18±0.08	0.08±0.06	0.06±0.1	0.7±0.22	0.06±0.06
2-Heptenal	957	Green	green fatty	1.44±2.52	3.86±5.22	1.46±1.72	3.94±1.9	1.2±0.86	1.7±0.14
Benzaldehyde	966	Fruity	sharp sweet bitter almond cherry	49.16±21.72	60.98±53.08	60.54±53.74	24.4±32.26	13.96±13.8	51.56±49.82
Octanal	1002	Aldehydic	aldehydic waxy citrus orange peel green herbal fresh fatty	17.12±23.74	29.44±25.94	19.42±16.98	10.52±12.68	4.52±3.94	22±3.08
Phenylacetaldehyde	1059	Green	green sweet floral hyacinth clover honey cocoa	0±0	0±0	0±0	0±0	0±0	88.9±10.64
2-Octenal	1066	Fatty	fatty green herbal	0±0	0±0	0±0	27.12±43.2	0.04±0.1	56.84±9.74
3-Methylbenzaldehyde	1090	Fruity	sweety fruity cherry almond bitter phenolic	0±0	0±0	0±0	0±0	0±0	0.32±0.06
4-Methylbenzaldehyde	1093	Fruity	fruity cherry phenolic	0.46±0.36	0.46±0.34	0.18±0.18	1.44±0.76	0.38±0.66	0.54±0.02
Nonanal	1103	Aldehydic	waxy aldehydic rose fresh orris orange peel fatty	6.2±10.76	10.44±18.08	22.06±19.14	9.22±16	0±0	19.84±5.1
Alpha-campholenal	1144	Herbal	herbal green woody amber leafy	2.82±0.4	7.7±4.62	3.5±3.78	6.64±2.22	4.98±1.86	3.32±0.64
2-Nonenal	1170	Fatty	fatty green waxy cucumber melon	2.14±3.5	0.16±0.28	0±0	0.32±0.28	0±0	0±0
Decanal	1212	Aldehydic	sweety aldehydic waxy orange peel citrus floral	4.1±1.02	3.46±0.88	0.4±0.7	5.78±2.96	1.56±1.36	1.88±2.18
Citral	1282	Citrus	sharp lemon sweet	55.28±12.08	92.32±18.4	50.52±45.62	41.86±42.94	55.96±10.84	57.92±9.16
Dodecanal	1419	Aldehydic	soapy waxy aldehydic citrus green floral	0.22±0.2	0.54±0.58	0.82±1.04	0.36±0.22	0.4±0.12	0.34±0.18
Pentadecanal	1721	Waxy	fresh waxy	2.58±1.82	1.16±0.66	0.82±0.88	1.54±1.8	0.6±0.1	0.5±0.1
Totals	**25**			**452.94±427.3**	**458.42±424.66**	**303.7±282.42**	**326.82±226.28**	**188.04±115.72**	**674.44±287.5**
Aromatic Hydrocarbons									
Toluene	777	Sweet	benzene	0±0	0±0	0±0	0.08±0.14	21.6±36.96	0.9±1.56
1,3-Cyclododecadiene, (E,Z)-	1653	-	-	0.22±0.22	0±0	0±0	0±0	0±0	0±0
Totals	**2**			**0.22±0.22**	**0±0**	**0±0**	**0.08±0.14**	**21.6±36.96**	**0.9±1.56**
Epoxides									
Humulene epoxide I	1620	Herbal	-	0.28±0.08	0.42±0.18	0.26±0.24	0.26±0.1	0.16±0	0.38±0.24
Totals	**1**			**0.28±0.08**	**0.42±0.18**	**0.26±0.24**	**0.26±0.1**	**0.16±0**	**0.38±0.24**
Esters									
Butanoic acid, methyl ester	709	Fruity	fruity apple sweet banana pineapple	0±0	0±0	4.16±7.2	0.54±0.64	0±0	0±0
Ethyl propionate	713	Fruity	sweet fruity rummy juice fruity grape pineapple	1.22±1.06	1.12±0.98	5.56±9.06	2.74±2.92	1.18±1.14	1.98±3.42
Propanoic acid, ethyl ester	721	Fruity	sweet fruity rummy juice fruity grape pineapple	3±4.74	3.5±3.28	0.28±0.5	2.74±2.56	0.74±0.8	0.5±0.88
Methyl butanoate	731	Fruity	pungent ethereal fruity fusel fermented creamy	6±1.84	2.38±3.14	2.62±3.76	1.26±2.18	1.86±0.76	0±0
Butanoic Acid	771	Cheesy	sharp acetic cheesy buttery fruity	110.52±187.5	7.76±7.38	7.66±6.82	36.46±53.56	37.7±62.74	7.72±0.86
Methyl 2-methylbutanoate	783	Fruity	ethereal estery fruity tutti frutti apple green apple lily of the valley powdery fatty	0±0	0±0	0±0	5.96±5.68	20.24±34.82	2.12±2.72
Ethyl butanoate	799	Fruity	fruity juicy fruit pineapple cognac	0.3±0.28	24.22±39.06	78.24±68.14	0.78±0.34	14.52±9.58	99.68±84.26
Butyl acetate	809	Ethereal	ethereal solvent fruity banana	12.84±15.96	5.2±6.04	62.34±55.48	3.36±2.94	2.86±3.1	7.14±6.2
Methyl 3-methylbutanoate	814	Fruity	apple fruity pineapple	76.88±129.4	5.24±2.52	4.42±4.78	52.64±43.26	6.08±2.46	7.04±2.62
Ethyl 2-methylbutanoate	850	Fruity	sharp sweet green apple fruity	134.46±118.76	97.98±34.74	97.52±85.18	125.18±3.46	131.58±65.4	140.4±18.46
Ethyl 2-methylbutyrate	857	Fruity	sharp sweet green apple fruity	0±0	0±0	2.88±4.98	0±0	44.46±77.02	0±0
Isobutyl isobutyrate	886	Fruity	ethereal fruity tropical pineapple grape banana	1.22±0.84	2.64±2.98	2.6±3.34	3.46±2.34	0.84±1.26	1.66±2.88
Hexanoic acid, methyl ester	904	Fruity	ethereal pineapple fruity apricot strawberry banana bacon	0±0	0±0	4.38±7.58	1.46±1.16	3±1.9	1.24±0.3
Propanoic acid	911	Acidic	acidic dairy fruity	3.14±2.1	0.68±0.04	2.76±2.4	1.54±1.42	2.44±1.62	2.94±0.72
Methyl hexanoate	923	Fruity	ethereal fruity pineapple apricot strawberry fruit banana bacon	0±0	0±0	3±5.2	1.04±0.84	5.14±3.68	0±0
4-methylpentyl 4-methylpentanoate	931	Fruity	fruity waxy soapy herbal	0.48±0.08	5.46±3.86	1.76±2.54	0.92±0.92	5.3±1.74	3.94±1.12
Ethyl Butyrate	940	Fruity	fruity juicy pineapple cognac	0.46±0.28	1.5±1.46	7.28±11.68	0.46±0.8	0.72±0.32	1.3±0.16
2-Methylbutyl propionate	950	Fruity	sweet fruity ethereal rummy	4.3±2.92	1.94±3.36	0.76±0.86	0±0	2.56±1.5	0±0
Isobutyl 2-methylbutyrate	976	Fruity	sweety fruity melon	2.42±2.68	3.82±4.74	9.76±8.66	13±12.8	3.4±4.22	11.4±0.88
Heptanoic acid, methyl ester	986	Fruity	sweet fruity green orris waxy floral berry	9.86±12.82	9.84±13.68	6.54±6.16	37.5±26.76	10.72±5.88	4.8±0.82
2-Methylbutanoic acid	993	Acidic	pungent acidic cheesy roquefort cheese cheesy	18.38±19.86	23.9±23.06	32.84±28.44	13.46±23.3	19.24±19.8	47.1±6.2

Ethyl hexanoate	996	Fruity	sweet fruity pineapple waxy green banana	14.12±18.66	13.72±20.34	0±0	8.64±7.56	7.94±0.96	0±0
Hexyl acetate	1005	Fruity	fruity green apple banana sweet	8.98±5.14	20.16±11.44	75.8±71.9	24.36±5.2	56.44±24.74	0±0
Geranyl isovalerate	1008	Fruity	green fruity apple blueberry pineapple	0±0	0±0	0±0	0±0	0.14±0.26	0.26±0
Butanoic acid, 3-methylbutyl ester	1013	Fruity	fruity green apricot pear banana	7.16±5.02	11.58±8.44	5.38±9.34	18.5±20.24	6.04±4.5	17.14±14.84
Methyl heptanoate	1027	Fruity	sweet fruity green orris waxy floral berry	10.22±8.2	21.54±24.48	5.66±6.68	10.08±3.24	6.92±2.32	0.98±1.7
Heptanoic acid	1031	Cheesy	rancid sour cheesy sweaty	0±0	0±0	0±0	0±0	12.46±11.48	9.62±0.4
3-Methylbutyl 2-methylbutanoate	1087	Fruity	sweet fruity citrus cherry blueberry apple	1.56±0.54	2.72±0.24	7.42±9.94	2.74±3.62	330.2±29.48	18.52±0.64
4-Octenoic acid, methyl ester	1114	-	-	7.32±2.1	7.38±2.64	3.86±5.38	4.24±1.94	8.52±5.24	12.64±0.74
Valeric acid	1149	Cheesy	acidic sweaty rancid	4.16±2.7	8.38±1.24	7.9±8.32	7.06±2.42	1.98±0.82	19.32±2.42
Octanoic acid	1163	Fatty	fatty waxy rancid oily vegetable cheesy	11.12±1.64	25.54±5.54	7.14±6.52	33.34±15.74	23.12±12.6	41.14±4.02
Nonanoic acid	1181	Waxy	waxy dirty cheesy dairy	1.36±0.68	1.4±0.22	3.9±6.52	1.64±0.94	0.9±0.62	2.06±0.06
Methyl nonanoate	1209	Fruity	sweet fruity pear waxy tropical winey	1.72±1.52	0.38±0.3	0.82±0.72	1.54±1.68	1.42±0.22	0.56±0.56
Methyl dec-5-enoate	1296	-	-	1.76±0.44	2.7±0.38	1.54±1.34	1.18±0.98	1.3±0.44	1.8±0.24
4-Decenoic acid	1299	Fruity	-	6.42±1.78	5.12±0.6	3.14±2.92	5.28±4.44	5.2±1.9	5.14±0.5
Decenoic acid	1309	Waxy	waxy buttery oily creamy dairy green lactonic plum skin	10.54±2.78	13.16±2.64	8.64±9.78	11.36±5.5	13.8±4.78	11.66±1.98
Methyl 5-bromo-5-hexenoate	1314	-	-	5.84±1.38	5.1±0.18	3.56±3.16	0.14±0.26	0±0	0±0
trans-Geranic acid methyl ester	1323	Waxy	waxy green fruity floral	6.84±2.5	2.2±0.14	1.18±2.06	7.38±4.82	0±0	0±0
Methyl decanoate	1327	Fermented	oily winey fruity floral	4.1±1.36	3.38±0.96	4.38±3.98	0±0	1.72±0.74	4.92±0.6
Methyl 3-undecenoate	1355	-	-	3.24±1.22	6.22±1.3	3.88±3.38	45.42±73.76	3.98±2.14	254.54±31.58
Decanoic acid	1360	Fatty	rancid sour farty citrus	0.04±0.08	4.58±4.92	2.74±3.04	0.8±1	0±0	0.8±0.84
Geranyl acetate	1383	Floral	floral rose lavender green waxy	29.7±19.02	14.92±2.16	8.4±8.78	13.8±12.82	13.1±4.26	9.1±4.84
Geranyl isobutyrate	1514	Floral	Sweet/fruity, waxy	0.66±0.18	1.74±0.88	1.22±1.14	1.04±0.48	2.36±1.38	1.02±0.8
Methyl dodecanoate	1526	Waxy	waxy soapy creamy coconut mushroom	1.34±0.16	2.38±0.52	1.4±1.26	1.1±0.5	0.8±0.06	1.1±0.12
Dodecanoic acid	1556	Fatty	fatty coconut bay	0.2±0.04	0.66±0.14	1.14±0.98	0.86±0.8	0.32±0.1	0.38±0.16
Hexyl octanoate	1589	Green	fruity green waxy berry apple estery	0.58±0.66	0.98±0.48	0.22±0.2	0.38±0.08	0.2±0.22	0.36±0.12
Ethyl dodecanoate	1595	Waxy	sweet waxy floral soapy clean	0.46±0.4	0.84±0.74	0.62±0.66	0.76±0.04	0.46±0.18	0.14±0.26
Totals	**47**			**524.92±579.32**	**373.96±241.24**	**497.3±490.76**	**506.14±355.94**	**813.9±409.18**	**754.16±199.92**
Ketones									
3-Buten-2-one, 3-methyl-	677	-	-	18.32±16.06	3.46±1.2	4.04±4.86	13.3±11.74	2.14±1.88	3.06±2.14
1-Penten-3-one	687	Spicy	pungent peppery mustard garlic onion	0±0	0±0	13.3±23.04	27.58±25.08	13.06±10.32	46.42±36.78
Methyl Isobutyl Ketone	716	Green	sharp solvent green herbal fruity dairy spicy	0±0	0±0	0±0	0±0	0±0	3.1±1.38
2-Hexanone	793	Fruity	fruity fungal meaty buttery	87.98±109.48	18.94±20.56	6.7±5.92	60±94.46	9.3±15.04	3.26±2.68
2-Heptanone	883	Cheesy	fruity spicy sweet herbal coconut woody	1.36±1.18	2.56±0.4	0.36±0.32	2.46±0.06	0.94±0.62	2.8±3.06
4-Methyl-2-heptanone	945	-	-	1.38±2.04	2.04±3.36	0.16±0.3	4.08±3.18	0.72±0.24	0.26±0.04
Acetophenone	1083	Floral	sweet pungent hawthorn mimosa almond acacia chemical	1.42±1.04	3.88±3.6	54.82±89.86	8.92±5.52	25.3±21.92	12.24±1.06
2-Decanone	1159	Floral	orange floral fatty peach	7.68±8	29.08±4.38	3.64±3.2	13.6±11.64	11.64±0.5	22.52±8.8
7-Decen-2-one	1164	-	-	1.26±2.2	15.04±4.68	18.74±20.66	2±3.46	3.2±5.56	4.62±4.08
Decanone	1193	-	-	122.46±75.36	146.26±37.5	10.06±8.8	15±17.3	3.98±2.86	9.68±8.66
Undec-2-en-6-one	1262	-	-	135.24±50.48	168.82±42.8	15.8±13.68	24.26±18.7	8.42±0.94	29.18±8.58
2-Dodecanone	1342	Citrus	fruity citrus floral orange	25.34±12.86	49.32±12.86	15.34±13.36	26.08±23.56	5.34±1.24	1.42±0.22
2-Nonadecanone	1359	-	-	0.74±0.52	1.74±0.48	0.46±0.4	0.52±0.46	0.62±0.2	0±0
Damascenone	1391	Floral	natural sweet fruity rose plum grape raspberry sugar	44.98±23.14	79.26±28.4	4.34±7.54	22.54±12.24	23.58±4.3	38.12±11.98
Ethyl decanoate	1397	Waxy	sweet waxy fruity apple grape oily brandy	1.32±0.94	8.66±0.86	6.94±6.14	2.14±0.4	6.9±1.52	3.4±0.14
(Z)-6-Pentadecen-2-one	1660	-	-	0.7±0.34	0.4±0.38	0.34±0.36	0.56±0.3	0.3±0.02	0.28±0.06
Totals	**16**			**450.18±303.64**	**529.46±161.46**	**155.04±198.44**	**223.04±228.1**	**115.44±67.16**	**180.36±89.66**
Lactones									
Gamma-hexalactone	1055	Tonka	herbal coconut sweet coumarinic tobacco	65.08±11.8	88.5±15.82	50.64±44.04	78.06±21.3	43.8±6.94	21.66±9.5
Alpha-ionone	1454	Floral	sweet woody floral violet orris tropical fruity	0±0	0±0	0±0	0.72±1.26	1.5±0.46	0±0
Geranylacetone	1454	Floral	fresh green fruity waxy rose woody magnolia tropical	1.44±0.4	2.12±1.84	2.58±2.36	2.7±0.78	0.38±0.16	1.66±0.16
Gamma-decalactone	1488	Fruity	fresh oily waxy peach coconut buttery sweet	0.86±0.9	0.84±0.08	0.56±0.62	1±1.08	0.42±0.14	0±0
Totals	4			**67.38±13.1**	**91.46±17.74**	**53.78±47.02**	**82.48±24.42**	**46.1±7.7**	**23.32±9.66**
Monoterpenes									

Alpha-thujene	933	Woody	woody green herbal	1.34±2.32	5.04±8.76	29.38±36.6	4.2±1.06	18.34±21.62	0±0
Myrcene	971	Spicy	peppery terpenic spicy balsamic plastic	4.52±5.9	9.68±16.76	0±0	37.98±30.74	33.82±13.46	32.46±28.46
Beta-pinene	980	Herbal	dry woody resinous pine hay green eucalyptus camporeous	27.66±41	7.32±2.28	2.14±3.72	4.1±7.12	13.4±3.52	11.16±0.78
Beta-myrcene	991	Spicy	pepper terpenic spicy balsamic plastic	34.54±37.96	63.2±33.96	27.26±24.08	121.9±161.46	49.96±30.52	285.72±29.12
alpha-Phellandrene	1011	Terpenic	citrus herbal terpenic green woody pepper black pepper	0±0	0±0	0±0	0±0	5.44±9.42	10.84±18.78
alpha-Terpinene	1017	Woody	woody terpenic lemon herbal medicinal citrus	2.48±3.04	8.78±9.3	1.56±1.36	1.28±1.14	0±0	4.9±8.48
Beta-phellandrene	1019	Minty	minty terpenic	4.96±1.76	22.32±18.44	15.86±25.16	12.86±4.58	5.48±5.02	9.5±8.3
Terpinolene	1024	Herbal	herbal spicy chamomile green basil	12.42±8.94	14.48±17.44	10.32±14.06	12.48±12.2	10.76±1.14	18.2±4.62
Alpha-phellandrene	1037	Terpenic	citrus herbal terpenic green woody pepper black pepper	8.58±1.88	7.48±7.58	6.24±10.52	11.68±5.76	5.52±0.8	33.14±3.24
cis-beta-Ocimene	1040	Floral	warm floral herbal sweet	0±0	0±0	0±0	0±0	0±0	11.18±0.34
D-Limonene	1045	Citrus	citrus orange fresh sweet	4.9±3.64	12.16±14.36	0.98±1.12	22.14±4.26	1.52±2.64	0±0
cis-beta-ocimene	1048	Floral	warm floral herbal sweet	1.74±2.08	14.5±12.84	1.3±1.36	5.62±9.76	6.12±3.02	30.98±4.28
trans-beta-Ocimene	1053	Floral	citrus tropical green terpenic woody green	0.34±0.32	0.44±0.78	1.36±1.42	0.8±1.12	2.96±2.04	9.14±3.6
Cymene	1063	Terpenic	fresh citrus terpenic woody spicy	27.38±5.88	24.6±8.68	8.62±7.48	2.86±2.66	2.64±0.32	0.2±0.34
gamma-Terpinene	1069	Terpenic	oily woody terpenic lemon lime tropical herbal	1.56±1.82	1.42±0.24	16.9±27.04	8.24±8.12	3.66±6.34	20.36±1.72
beta-Terpineol	1097	Woody	pungent earthy woody	24.52±27.78	33.2±28.18	7.24±10.06	62.92±42.8	22.24±8.72	11.36±0.04
Linalool	1100	Floral	citrus floral sweet bois de rose green blueberry	22.24±13.3	43.3±21.46	21.48±19.48	57.82±51.82	34.08±8.14	231.64±21.28
Dehydro-p-cymene	1105	Phenolic	phenolic spicy styreen clove guaiacol	0.34±0.42	1.24±0.14	0.06±0.1	1.42±0.52	2.12±1.5	0±0
Cosmene	1118	-	-	53.84±35.02	173.82±55.96	7.92±6.9	97.48±52.8	38.96±15.98	85.26±22.98
Allo-ocimene	1146	Floral	sweet floral nut skin pepper herbal tropical	0.24±0.44	3.64±6.32	4.3±5.2	5.42±4.84	0±0	10.38±0.2
Neo-allo-ocimene	1151	-	-	3.74±0.6	16.92±0.86	7.38±6.7	8.24±7.24	16.16±3	13.54±1.32
6-Camphenol	1185	-	-	13.96±3.24	15.36±3.86	12.24±10.6	21.94±9.84	23.14±8.36	24.14±3.1
Terpinen-4-ol	1190	Spicy	peppery woody earthy musty sweet	12.62±10.94	0±0	11.28±10.62	21.58±11.6	8.48±4.28	42±12.14
Myrcenol	1196	Floral	fresh floral lavender citrus	46.42±21.62	57.64±16.4	17.72±28.62	10.54±18.26	1.28±1.18	7.3±6.66
alpha-Terpineol	1198	Terpenic	pine terpenic lilac citrus woody floral	14.56±25.22	75.38±24.94	58.42±50.9	95.74±40.86	27.56±13.78	270.98±23.56
alpha-Terpineol acetate	1201	Herbal	herbal bergamot lavender lime citrus	40.38±12.54	162.68±41.32	93.46±81.94	112.54±68.14	60.26±15.22	43.28±4.9
Myrtenol	1218	Herbal	woody pine balsamic sweet minty medicinal	3.8±3.74	2.14±0.98	12.16±18.56	8.1±9.2	9.7±2.22	4±1.14
Myrtenal	1220	Spicy	sweet spicy cinnamon tonka terpenic camporeous jammy	0±0	0±0	0.52±0.9	0±0	0±0	5.92±0.26
trans-Geraniol	1224	Floral	sweet floral fruity rose waxy citrus	128.5±43.14	134±57.36	79.84±76.26	136.78±76.66	50.38±11.6	339.2±31.76
Verbenone	1230	Camphoreous	camphor menthol celery	8.24±1.54	13.84±2.08	2.74±2.38	17.28±13.64	1.24±0.2	10.44±1.6
Citronellol	1236	Floral	floral leathery waxy rose citrus	11.76±3.4	9.14±3.1	5.26±4.72	11.54±6.14	8.32±1.56	14.64±3.7
Carveol	1244	Minty	minty spearmint cooling green herbal caraway spicy	29.68±5.76	37.2±5.78	3.84±4.02	50.54±33.06	12.1±3.26	58.68±9
beta-Cyclocitral	1248	Tropical	tropical saffron herbal clean rose sweet tobacco green fruity	2.64±4.56	12.96±4.42	104.94±181.76	4.08±7.06	4.7±0.86	0±0
2-Carene	1253	-	-	147.14±254.84	131.12±227.12	35.7±61.86	0±0	120.38±58.66	0±0
Geraniol	1256	Floral	sweet floral fruity rose waxy citrus	728.46±365.86	531.6±244.28	73.54±65.32	589.2±370.7	5.42±9.4	1276.34±147.24
d-Carvone	1267	Minty	spicy bready caraway	3.56±1.9	35.4±8.28	13.08±11.34	16.74±7.46	7.26±2.32	16.62±4.14
Geranial	1273	Citrus	citrus lemon	164.94±50.48	205.14±28.82	17.18±14.9	353.38±155.06	65.54±18.68	444.96±32.74
Methyl geranate	1326	Waxy	waxy green fruity floral	0±0	4.98±0.96	0±0	0±0	4.44±1.66	0±0
Totals	**38**			**1594±1002.88**	**1892.12±934.04**	**712.22±827.06**	**1929.42±1237.68**	**683.38±290.44**	**3388.46±439.82**
Sesquiterpenes									
gamma-Elemene	1308	-	-	2.22±0.96	3.68±0.48	2.18±1.88	1.84±1.28	1.48±0.36	1.8±0.18
Cedrene	1368	Woody	woody cedar sweet fresh	15.46±10	5.88±4.42	5.82±5.9	9.18±8.76	6.4±2.82	5.3±5.34
alpha-Cubebene	1378	Herbal	herbal waxy	0±0	5.1±2.02	4.12±4.32	3.56±3.62	0.34±0.6	15.56±8.16
Longifolene	1401	Woody	sweet woody rose medicinal fir needle	0.66±0.2	1.16±0.1	3.48±5.02	0.66±0.42	1.74±1.38	1.22±0.18
Ylangene	1405	-	-	0.44±0.46	1.38±0.18	0.92±0.86	0.66±0.22	0.5±0.14	0.5±0.1
Copaene	1408	Woody	woody spicy honey	0.56±0.26	1.16±0.46	0.46±0.44	0.4±0.28	0.56±0.1	0.28±0.48
gamma-Caryophyllene	1414	Spicy	sweet woody spicy clove dry	0±0	0±0	0±0	0±0	0±0	0.7±0.88
epsilon-Muurolene	1423	-	-	0±0	0±0	0±0	0±0	0±0	0.56±0.06
gamma-Muurolene	1430	Woody	herbal woody spicy	0.3±0.14	0.82±0.78	0.8±0.74	0.36±0.04	0.38±0.02	0.46±0.34
beta-Panasinsene	1439	-	-	0.68±0.22	0.66±0.56	0.22±0.38	0.44±0.32	0.3±0.02	0.16±0.28
beta-Copaene	1440	-	-	0.32±0.14	0.42±0.14	0.1±0.2	0.56±0.24	0.54±0.08	1.02±0.94
Caryophyllene	1451	Spicy	sweet woody spicy clove dry	0.64±0.28	8.42±9.18	1.14±1.08	0.7±0.7	2.3±0.38	1.38±0.3
alpha-Elemene	1458	-	-	0.2±0.2	0.18±0.2	0.18±0.32	0.06±0.12	0±0	0.36±0.24
trans-.beta.-Famesene	1462	Woody	woody citrus herbal sweet	0.26±0.14	0.58±0.44	0.38±0.34	0.18±0.16	0.28±0.12	0.34±0.16

beta-Farnesene	1469	Woody	woody citrus herbal sweet	2.22±1.54	1.46±0.4	1.08±1.1	1.3±1.4	0.9±0.18	0.68±0.54
gamma-Muurolene	1483	Woody	herbal woody spicy	2.22±0.66	5.56±1.98	3.82±3.88	3.04±1.72	3.72±1.26	3.28±0.78
beta-Selinene	1501	Herbal	-	0.76±0.3	1.98±0.54	0.6±0.56	0.8±0.44	1.02±0.2	0.84±0.12
alpha-Selinene	1505	-	amber	0.44±0.2	2.4±1.4	0.44±0.4	3.72±1.5	0.94±0.08	3.06±2.04
gamma-Cadinene	1520	-	-	0.38±0.16	1.2±0.54	0.6±0.52	0.5±0.22	0.14±0.14	0.8±0.56
Guaiol	1534	-	-	0.88±0.12	0.78±0.08	0.54±0.52	0.78±0.4	0.48±0.12	0.4±0.12
.alpha.-Muurolene	1539	-	-	0±0	0±0	0±0	0±0	0±0	0.76±0.14
Cubenene	1541	Spicy	spicy fruity mango	0.76±0.14	1.08±0.14	0.9±0.98	0.9±0.34	0.66±0.18	0±0
beta-Cadinene	1547	Woody	green woody	1.12±0.38	2.08±0.78	1.12±1.02	1.24±0.72	1.34±0.86	1.72±0.46
alpha-Cadinene	1563	Woody	woody dry	0±0	0±0	0±0	0±0	0.24±0.04	0.24±0.06
Cadina-1,4-diene	1572	Spicy	spicy fruity mango	0.64±0.32	0.94±0.2	0.36±0.34	0.52±0.36	0.36±0.04	0.4±0.14
alpha-Calacorene	1573	-	woody	0.36±0.14	1.1±0.26	0.36±0.3	0.22±0.06	0.2±0.2	0.1±0.08
Caryophyllene oxide	1606	Woody	sweet fresh dry woody spicy	4.2±2.06	1.9±0.02	1.44±1.48	0.9±1.58	1.2±0.34	1.68±1.46
Humulenol-II	1651	-	-	1.46±0.42	5.88±2.26	2.56±2.28	2±0.72	2.12±0.82	3.16±1.2
T-Muurolol	1669	Herbal	herbal spicy honey	1.04±0.8	1.82±0.38	1±0.94	0.3±0.1	0.9±0.4	0.1±0.08
Cadalene	1690	-	-	1.58±0.52	4.98±0.22	2.16±2.04	1.46±0.52	1.36±0.5	2.8±0
Totals	**30**			**39.8±20.76**	**62.6±28.16**	**36.78±37.84**	**36.28±26.24**	**30.4±11.38**	**49.66±25.42**

[z] Relative peak area percent compounds were identified by comparison of mass spectra with NIST14 (National Institute of Standards and Technology, Gaithersburg, MD, USA), Flavors and Fragrances of Natural and Synthetic Compounds (FFNSC3, John Wiley & Sons, Inc., Hoboken, NJ, USA), and Adams Essential Oils (Adams 2007) mass spectral libraries and comparison of calculated Kovats retention indices (Kováts 1958) with previously reported values.

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Table 3. Principal components[z,y] analysis of volatile aroma compounds in fresh-market muscadines grown and evaluated at the University of Arkansas System Division of Agriculture, Clarksville, AR (2021).

		Principal component 1 (52.56%) AM-148 → AM 70	**Principal component 2 (27.37%)** AM-154 → Lactones
Positive loadings	*Compound classifications*	Lactones	Alcohols
		Alcohols	Ketones
		Monoterpenes	Lactones
		Aldehydes	
		Ketones	
		Sesquiterpenes	
		Epoxides	
	Genotype	AM-135	AM-148
		AM-26	AM-26
		AM-154	AM-77
		AM-70	AM-135
			AM-70
Negative loadings	*Compound classifications*	Esters	Aromatic hydrocarbons
		Aromatic hydrocarbons	Sesquiterpenes
			Epoxides
			Esters
			Monoterpenes
			Aldehydes
	Genotype	AM-77	AM-154
		AM-148	

[z]Percent of variation in data explained by each component, total 79.93%.
[y]Compound class variables represent the sum of the total ion chromatogram (TIC) relative peak areas (%) of positively identified compounds within each compound class (Table 2)

AM-26

AM-70

AM-77

AM-135

AM-148

AM-154

Fig. 1. Photo at harvest of clamshells of muscadine grapes grown and evaluated at the University of Arkansas System Division of Agriculture, Clarksville, AR (2021).

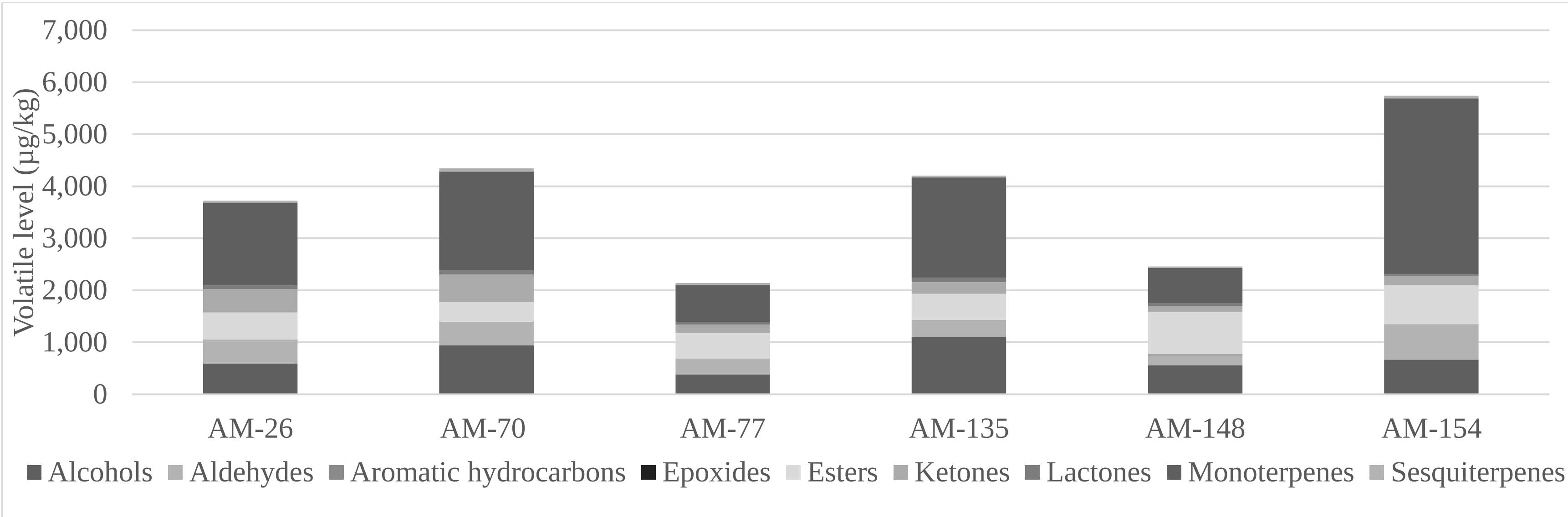

Fig 2. Total concentrations of volatile aroma compounds identified in muscadine grapes grown and evaluated at the University of Arkansas System Division of Agriculture, Clarksville, AR (2021)

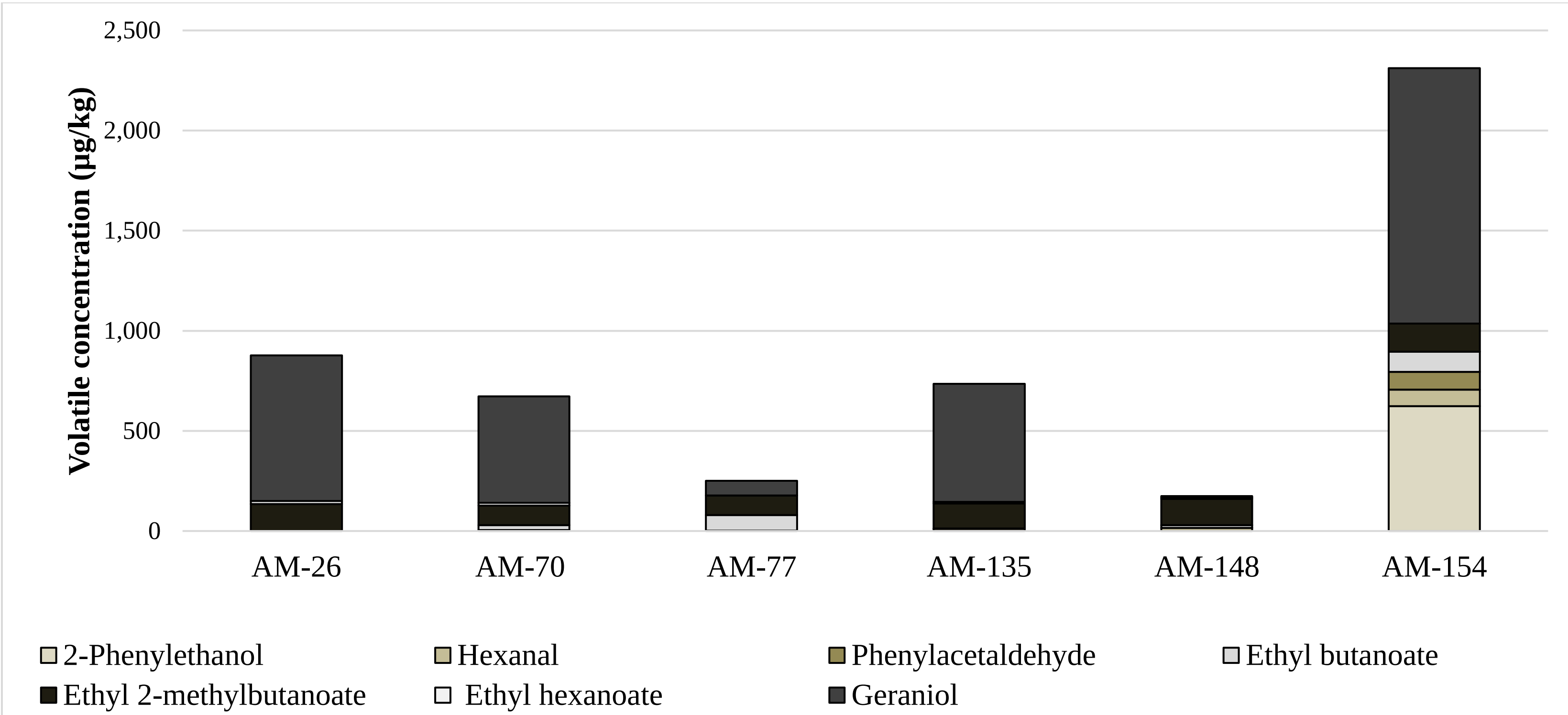

Fig 3. Total concentrations of impactful volatile aroma compounds identified (µg/kg) in muscadine grapes grown and evaluated at the University of Arkansas System Division of Agriculture, Clarksville, AR (2021).