Investigating the Winemaking Potential of Enchantment, a New *Vitis* Hybrid Teinturier Cultivar

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Abstract: Enchantment is a *Vitis* hybrid released from the University of Arkansas System Division of Agriculture winegrape breeding program in 2016. This new teinturier cultivar has potential for producing high-quality wines. The effects of oak addition (no oak, American oak, or French oak) and aging on Enchantment wine attributes were evaluated in 2017 and 2018. Enchantment grapes were harvested in August of both years for wine production. The 2017 and 2018 wines were analyzed initially (0 months) for basic chemistry, anthocyanin, color, and aroma attributes, and 2017 wines were analyzed during storage (0, 6, and 12 months at 15°C) for basic chemistry, anthocyanin, and color attributes. Regardless of oak additions, the initial chemistry of wines in both years was typical for dry wines and remained stable during storage. In both years, malvidin-3-glucoside was the predominant anthocyanin in Enchantment wine, and malvidin-3-glucoside, petunidin-3-glucoside, and delphinidin-3-glucoside comprised >80% of total anthocyanin content. Although anthocyanins decreased during storage, the deep red color of the wine remained stable. In 2018, wines had a deeper, darker red color than in 2017; this corresponded with higher anthocyanin levels in 2018. About 50 volatile aroma compounds were identified in Enchantment wines. There was minimal impact of oak treatment on basic chemistry and anthocyanins, but some impact on color attributes. Oak addition greatly impacted aroma attributes, resulting in wines with oaky, roasted, and caramelized aroma compounds in both years. These results demonstrated the potential of Enchantment winegrapes for producing deeply red-colored, single-varietal wines and blends with oaking and storage potential.

Key words: anthocyanins, color, oak, teinturier, volatile aroma compounds

Vitis vinifera grapevines are highly vulnerable to pests, diseases, and extreme temperatures and are difficult to grow in much of the United States. Hybrids (crosses of two or more *Vitis* species) are generally better adapted to surviving stresses that devastate *V. vinifera* grapes (Reisch et al. 2012). The University of Arkansas System Division of Agriculture (UA System) has a fruit-breeding program that was established in 1964. This program began breeding winegrapes over 40 years ago, with a goal of developing new hybrid winegrape cultivars that grow well in Arkansas and similar regions, have unique and desirable attributes, and are suitable for winemaking. In 2016, the first hybrid winegrape cultivars, Opportunity (a white wine cultivar) and Enchantment (a red wine cultivar) were released from the UA System.

The Enchantment grapevine produces teinturier berries with a dark purple color in the skin, flesh, and juice of the grape and shows potential for regions with limited productivity of red wine cultivars. The breeding background and plant, grape, and wine attributes of Enchantment have been determined (Clark et al. 2018). The female parent of Enchantment, Ark. 1628, was a cross between *V. vinifera* cultivars Petite Sirah and Alicante Bouschet. The male parent, Ark. 1481, was a cross between *V. vinifera*-derived cultivars Bouschet Petite and Salvador. Alicante Bouschet, Bouschet Petite, and Salvador are also teinturier cultivars. In evaluations from 1998 to 2015, Enchantment grapevines displayed hardiness for growth in the Arkansas climate, the potential to withstand disease pressures in the region, acceptable fruit yield for commercial production, and berries with good composition for winemaking. Wines have been produced from Enchantment grapes at the UA System Department of Food Science since 1998 using small-scale winemaking techniques. In these preliminary trials, wines showed a deep red color and acceptable composition for a red table wine.

The primary anthocyanin in Enchantment grapes and wine was malvidin-3-glucoside, which is also the primary anthocyanin in *V. vinifera* cultivars (Clark et al. 2018). Malvidin-3-glucoside and other monoglucoside anthocyanins

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are more stable than the diglucoside anthocyanins typically found in hybrid grapes and wine (Cheynier et al. 2006, He et al. 2012, Zhu et al. 2012). Although the color of young red wine is due to monomeric flavylium anthocyanins and their associated copigment complexes, the color contribution from monomeric anthocyanins decreases over time (de Freitas et al. 2017). During aging, anthocyanins participate in three major reactions that can influence wine color: direct polymerization between anthocyanins and tannins, indirect polymerization between anthocyanins and tannins via acetaldehyde, and formation of pyranoanthocyanins (Li and Duan 2019). These reactions create compounds/adducts that are more resistant to hydration and bisulfite bleaching and less sensitive to degradation. Therefore, such "polymeric pigments" are important for color in aged red wines (Escribano-Bailón and Santos-Buelga 2012, de Freitas et al. 2017). Unlike monoglucoside anthocyanins, diglucoside anthocyanins are unable to form such polymeric pigments and thus tend to produce wines with less-stable color (Cheynier et al. 2006, He et al. 2012, Zhu et al. 2012). Because of its intense color and *vinifera*-like anthocyanin composition, Enchantment shows potential to be used in blending to improve wine color quality. Other teinturier cultivars, including Alicante Bouschet, a parent of Enchantment, are commonly used in blending to increase color of wine produced from lighter-colored cultivars (Revilla et al. 2016).

In sensory evaluations, Enchantment wines were described as having a fruity aroma similar to that of Syrah and some vegetal characteristics (Clark et al. 2018). It was proposed that Enchantment wines could benefit from addition of oak during wine production. Aging wine in contact with oak can increase complexity through extraction of woody, smoky, spicy, and vanilla aromas (Singleton 1995, Alencar et al. 2019). Oak staves and chips can be used as alternatives to oak barrels, as they are less expensive and more suitable for production of smaller volumes. These "barrel alternatives" can give wines similar complexity and aromatic character as barrel aging (Eiriz et al. 2007). The impact of barrel alternatives (oak powder, shavings, or cubes) on sensory attributes of red wines aged in stainless steel tanks has been evaluated (Cano-López et al. 2008). In general, oak aging improved wine quality and increased fruity, vanilla, woody, spicy, and smoky aromas. Panelists could distinguish between control wines and wines with oak shavings or cubes, and wines aged with oak shavings had the best overall aroma quality. American oak (*Quercus alba*) and French oak (*Quercus robur* and *Quercus petraea*) are the species most commonly used for wine production (Singleton 1995). American oak typically has higher concentrations of oak lactones and possesses more noticeable woody character than French oak (Masson et al. 1995). The impact of American and French oak chips on Syrah wine sensory attributes has been evaluated (Alencar et al. 2019). Wines produced with American oak had more woody characteristics, while wines produced with French oak had more vanilla characteristics.

While the most noticeable effect of maturing wine in contact with oak is the extraction of aroma compounds, oak contact can also impact wine pigments and color (Li and Duan 2019). The primary non-volatile components extracted into wine from oak are ellagitannins. Oak ellagitannins interact with wine anthocyanins to produce purple-colored ellagitannin-anthocyanin complexes, which were proposed to cause a red-to-purple shift during oak aging (Chassaing et al. 2010). Ellagitannins can be degraded and hydrolyzed to ellagic acid, which can enhance wine copigmentation and protect phenolic compounds from oxidation (Cadahía et al. 2001, Jordão et al. 2006, Zhang et al. 2017). In addition, certain volatile compounds extracted into wine from oak can react with wine phenolics to produce pigment complexes that alter wine color. This could include the brick-red oaklin pigments from oak cinnamic aldehydes and wine flavanols (de Freitas et al. 2004, Sousa et al. 2012) and the orange-red pyranoanthocyanins from oak 4-vinylguaiacol and wine anthocyanins (Fulcrand et al. 1996, Schwarz et al. 2003). Multiple studies evaluated the impact of oak barrel aging and barrel alternatives on wine color, measured through spectrophotometric techniques. Red wines aged with barrel alternatives had greater yellow-to-red color ratios than wines aged in traditional oak barrels, while wines aged with French oak had more yellow color than American-oaked wines (del Álamo Sanza et al. 2004). In general, relative to unoaked wines, wine lost color, particularly the red color component, due to oak aging, while the yellow color component increased. Similarly, there was a decrease in red color and an increase in yellow color of red wines with increasing barrel aging times (del Alamo et al. 2000). Although these studies showed a loss in color quality of red wines due to oak aging, sensory studies showed that these color differences were not perceivable (Cano-López et al. 2008, Alencar et al. 2019).

Although Enchantment grapes and wine have been preliminarily evaluated in viticultural and winemaking trials for >20 years, there is no published research on the impact of winemaking techniques, such as oak additions, on wine attributes. Since Enchantment grows well in Arkansas and similar regions, the objective of this study was to investigate the winemaking potential of Enchantment, a *Vitis* hybrid teinturier cultivar.

Materials and Methods

Grape harvest. Enchantment grapes were grown in an experimental vineyard at the UA System Fruit Research Station in Clarksville, AR (USDA hardiness zone 7b) in the Ozark Mountain American Viticultural Area. The soil type was Linker fine sandy loam (fine-loamy, siliceous, semi-active, thermic Typic Hapludult). The grapes were grown on a high-wire bilateral cordon system on own-rooted, variable-aged vines. Average daily temperature and rainfall from January to August in 2017 and 2018 were recorded in Clarksville, AR. About 50 kg of Enchantment winegrapes were hand-harvested from 10 vines in August 2017 and 2018 for small-scale (~23 L) wine production. Harvest date was determined based on ideal composition attributes for Arkansas red wine grapes, past harvest data, weather, and fruit quality. The grapes were taken to the UA System Food Science Department

in Fayetteville, AR and stored at 4°C overnight for wine production the following day.

Wine production. In 2017 and 2018, Enchantment wines were produced in a traditional red wine style prior to oak addition and bottling. A single batch of wine was produced each year and was split later for oak treatments in duplicate. Winemaking procedures were kept as similar as possible for both years. Grapes were crushed/destemmed and 30 mg/L sulfur dioxide (SO_2) as potassium metabisulfite was added at crush. In 2017, grapes were harvested on 17 Aug and had 14.6% soluble solids (SS), pH 3.14, and 0.84% w/v (g tartaric acid/100 mL juice) titratable acidity (TA). In 2018, grapes were harvested on 8 Aug and had 17.3% SS, pH 3.81, and 0.70% TA. The SS (expressed as %) of the must was determined using a Bausch & Lomb Abbe Mark II refractometer (Scientific Instruments) and the pH and TA of musts were measured using a Metrohm 862 Compact Titrosampler (Metrohm AG) fitted with a pH meter. Adjustments were made to the musts to ensure complete fermentation. Must SS was adjusted to 21% using table sugar (sucrose) in both years, and in 2018, must TA was adjusted through tartaric acid additions to 0.9% to reduce the pH below 3.6 for fermentation.

Musts were inoculated with Lalvin ICV D254 wine yeast (Lallemand, Inc.) at a rate of 0.26 g/L and fermented on the skins for four days at 15°C. At the onset of fermentation, 20 g/hL Fermaid O yeast nutrient (Lallemand, Inc.) was added to musts. Four days of skin contact time was used for this study based on previous winemaking experience with Enchantment. This allowed extraction of compounds from skins without over-extracting tannins and phenolics. After four days, musts were pressed with a 70-L Enoagricola Rossi Hydropress using three 10-min press cycles and a pressure of 207 kPa. The wine was collected in a 22.7-L glass carboy fitted with a fermentation lock. Fermentation continued at 15°C for approximately six months. Wines were racked several times during fermentation. After fermentation was complete, the free SO_2 content of wines was determined using the aeration-oxidation method (Iland et al. 1993) and adjusted to 60 mg/L. No further additions of tartaric acid were needed since the pH of the wine was below 3.6.

The wine was split into six 3.8-L glass jars for oak treatment, with two replications for each treatment. The oak additions included a control (no oak), French oak, and American oak. Medium-toast French oak and American oak staves (38.3 × 1.5 × 1.5 cm; Innerstave, LLC) were placed in the wines and wines were aged on oak for two months at 15°C. Prior to bottling, free SO_2 levels were again measured and adjusted to 60 mg/L. Wines were bottled into 125-mL glass bottles, sealed with plastisol-lined lug caps, and stored at 15°C until analysis. Wines were stored at 15°C for one week prior to the initial (month 0) analysis to account for any bottle shock effects.

In 2017 and 2018, wines were analyzed at 0 months storage for basic chemistry, anthocyanin, color, and aroma attributes. The 2017 wines were analyzed for basic chemistry, anthocyanin, and color attributes after 0, 6, and 12 months storage at 15°C. Basic chemistry attributes of wines included pH, TA, glycerol, ethanol, individual and total residual sugars, and individual and total organic acids. Anthocyanin attributes included individual and total anthocyanins. Color attributes included L*, a*, b*, red color (abs 520 nm), yellow/brown color (abs 420 nm), and color density (abs 520 nm + abs 420 nm). Basic chemistry, anthocyanin, and color attributes for each sample were analyzed in duplicate. Aroma attributes included identification of volatile compounds and determination of relative peak areas. Aroma attributes for each sample were analyzed in triplicate. The composition, anthocyanin, and color attributes were evaluated at the UA System Food Science Department (Fayetteville, AR), and the aroma attributes were evaluated at the Graz Technical University Institute of Analytical Chemistry and Food Chemistry (Graz, Austria).

Composition attributes analysis. *pH and TA.* The pH and TA of Enchantment wines were measured using a Metrohm 862 Compact Titrosampler fitted with a pH meter. The probe was left in samples for 2 min to equilibrate before recording the pH value. The TA was expressed as % w/v (g/100 mL) tartaric acid. Six grams of sample was weighed, then 50 mL degassed, deionized water was added to the sample, and the sample was titrated with 0.1 N sodium hydroxide to an endpoint of pH 8.2. Wine was degassed prior to analysis.

Glycerol, ethanol, residual sugars, and organic acids. The glycerol, ethanol, residual sugars, and organic acids in Enchantment wines were identified and quantified by high-performance liquid chromatography (HPLC) as described (Walker et al. 2003). Samples were passed through a 0.45 µm polytetrafluoroethylene (PTFE) syringe filter (Varian, Inc.) before injection onto an HPLC system consisting of a Waters 515 HPLC pump, a Waters 717 plus autosampler, and a Waters 410 differential refractometer detector connected in series with a Waters 996 photodiode array (PDA) detector (Water Corporation). Analytes were separated with a Bio-Rad HPLC Organic Acids Analysis Aminex HPX-87H ion exclusion column (300 × 7.8 mm) connected in series with a Bio-Rad HPLC column for fermentation monitoring (150 × 7.8 mm; Bio-Rad Laboratories). A Bio-Rad Micro-Guard Cation-H refill cartridge (30 × 4.5 mm) was used as a guard column. Columns were maintained at a temperature of 65 ± 0.1°C by a temperature control unit. The isocratic mobile phase consisted of aqueous sulfuric acid at pH 2.28 at a flow rate of 0.45 mL/min. Injection volumes of both 10 µL (for analysis of organic acids and sugars) and 5 µL (for ethanol and glycerol) were used to avoid overloading the detector. The total run time per sample was 60 min. Citric, tartaric, malic, lactic, and succinic acids were detected at 210 nm using the PDA detector, and glucose, fructose, ethanol, and glycerol were detected at 410 nm using the differential refractometer detector.

Analytes in samples were identified and quantified using external calibration curves based on peak area estimation with baseline integration. Results were expressed as mg analyte/100 mL wine for organic acids and sugars, g/L wine for glycerol, and % v/v for ethanol. Total residual sugars was calculated as the sum of glucose and fructose, and total organic acids was calculated as the sum of tartaric, malic, lactic, citric, and succinic acids.

Anthocyanin attributes analysis. *Anthocyanin quantification.* Anthocyanins in Enchantment wines were quantified using the HPLC-PDA as described (Cho et al. 2004). Samples were passed through a 0.45 µm PTFE syringe filter before injection onto a Waters Alliance HPLC system equipped with a Waters model 996 PDA detector and Millennium version 3.2 software. A 4.6 × 250 mm Symmetry C_{18} column (Waters Corporation) preceded by a 3.9 mm × 20 mm Symmetry C_{18} guard column was used to separate analytes. The mobile phase consisted of a binary gradient with 5% (v/v) formic acid in water (solvent A) and methanol (solvent B) at a flow rate of 1.0 mL/min. A gradient was used with 2 to 60% B from 0 to 60 min, 60 to 2% B from 60 to 65 min, then holding at 2% B from 65 to 80 min. A 50 µL injection volume was used and total run time per sample was 80 min. Anthocyanins were detected at 510 nm.

Anthocyanins were quantified as anthocyanidin-3-glucoside equivalents of their major aglycone (cyanidin, delphinidin, peonidin, petunidin, or malvidin) using external calibration curves based on peak area estimation with baseline integration. Results were expressed as mg/100 mL wine. Total anthocyanins were determined by summing concentrations of individual anthocyanin compounds.

Anthocyanin identification. Anthocyanins in Enchantment wines were identified by HPLC-electrospray ionization (ESI)-mass spectrometry (MS) as described (Cho et al. 2004). An HPLC-ESI-MS system equipped with an analytical Hewlett Packard 1100 series HPLC instrument (Hewlett-Packard Enterprise Company), an autosampler, a binary HPLC pump, and a UV-vis detector interfaced to a Bruker Esquire LC/MS ion trap mass spectrometer (Bruker Corporation) was used to identify anthocyanins. Reverse-phase separation of anthocyanins was conducted using the same HPLC conditions previously described for anthocyanin quantification, and absorption was recorded at 510 nm. Mass spectral analysis was operated in positive ion electrospray mode with a capillary voltage of 4000 V, a nebulizing pressure of 30.0 psi, a drying gas flow of 9.0 mL/min, and a temperature of 300°C. Data was collected with Bruker software in full scan mode over a range of *m/z* 50 to 1000 at 1.0 sec per cycle. Characteristic ions were used for peak assignment.

Color attribute analysis. *L*, a*, and b*.* Enchantment wine L*, a*, and b* color analysis was conducted using a ColorFlex system (HunterLab). This system has a ring and disk set (to control liquid levels and light interactions) for measuring translucent liquids in a 63.5-mm glass sample cup with an opaque cover to determine CIE Lab transmission values of L*, a*, and b* (Commission Internationale de l'Eclairage 1986). The vertical axis L* measured lightness from completely opaque (0) to completely transparent (100), while the hue-circle measured +a* red, -a* green, +b* yellow, and -b* blue.

Red color, yellow/brown color, and color density. Red color of Enchantment wines was measured spectrophotometrically as absorbance at 520 nm, and yellow/brown color was measured as absorbance at 420 nm. Color density was calculated as red color + yellow/brown color (Iland et al. 1993). Absorbance values were measured using a Hewlett-Packard 8452A Diode Array spectrophotometer equipped with UV-Visible ChemStation software (Agilent Technologies, Inc.). Samples were diluted 10 times with deionized water prior to analysis and were measured against a blank sample of deionized water. A 1-cm cell was used for all spectrophotometer measurements.

Aroma attribute analysis. Volatile aroma profiles of the wines were determined using headspace (HS)-solid-phase microextraction (SPME)-gas chromatography (GC)-MS as described (Kraujalyté et al. 2012). Volatile compounds were extracted from 1 mL wine in a 20-mL glass vial using SPME with a 2-cm stable flex divinylbenzene/carboxen/polydimethylsiloxane (DVB/CAR/PDMS) fiber for 30 min at 40°C. The samples were thermostated at 40°C for 10 min before exposing the fiber to enrich the volatiles. A GC-MS system equipped with a Shimadzu GC 2010 (Shimadzu Corporation), Shimadzu QP 2010 MS, and PAL HTX autosampler (CTC Analytics AG) was used to separate and identify volatile compounds. Samples were extracted/injected in triplicate. Volatiles were separated on a nonpolar Restek Rxi 5MS column (30 m × 0.25 mm × 1 µm; Restek) with a temperature gradient program: 30°C (hold 1 min) to 230°C at 5°C/min, then to 280°C (hold 1 min) at 20°C/min in constant flow mode with a linear velocity of 35 cm/min. Data was recorded in the scan mode (*m/z* 35 to 350) with a 9.8 min solvent cut time and a detector voltage relative to the tuning result.

Data was analyzed using the Shimadzu GCMS Solution Analysis software (Version 4.45). Compounds were identified using comparison with three mass spectra libraries: National Institute of Standards and Technology (NIST14), Flavors and Fragrances of Natural and Synthetic Compounds (FFNSC3; Mondello 2015), and Adam's Essential Oils (Adams 2007). A series of n-alkanes from C8 to C20 were measured under identical conditions to calculate Kovats retention indices (Kováts 1958) of volatile compounds in wine samples. The identities of compounds were confirmed by comparison of calculated retention indices with values reported in the Flavornet (Acree and Arn 2004) and Pherobase (El-Sayed 2003) databases. A matching library result and a retention index within ±20 of previously reported values was considered a positive identification. Total ion chromatogram (TIC) peak areas were used to determine the relative peak areas (%) for each compound.

Experimental design and statistical analysis. In both years, a single batch of wine was fermented, then split into three oak treatments (no oak, American oak, or French oak) in two replications. Replications were limited in this study because there was not enough fruit to produce more wines while maintaining reasonable fermentation volumes. There were six samples (3 oak treatments × 2 replications) when wines were analyzed at 0 months storage, and there were 18 samples (3 oak treatments × 3 storage times × 2 replications) in 2017 when wines were analyzed during storage. At each storage time, samples for basic chemistry, anthocyanin, color, and aroma attributes were taken from one 125-mL bottle. Statistical analyses were conducted using JMP Pro statistical software (version 15.0.0, SAS Institute, Inc.).

Basic chemistry, anthocyanin, and color attributes. For 2017 and 2018 wines at 0-months storage, a univariate analysis of variance (ANOVA) was used to determine the significance of the main factors, year and oak treatment, and their interaction. Tukey's honest significant difference (HSD) was used to detect differences among means ($p < 0.05$). For the 2017 wines during storage, a univariate mixed-model with a first-order autoregressive (AR1) covariance structure was used to conduct a repeated measures in time analysis, with individual experimental units (wines) as the subjects in a repeated structure for storage time. For the fixed effects (storage and oak), an ANOVA was used to determine the significance of the main factors and their interaction. All factors were treated as categorical. Tukey's HSD was used to detect differences among means ($p < 0.05$) for the fixed effects.

Aroma attributes. Relative peak areas (%) for each positively identified compound in 2017 and 2018 Enchantment wines at 0-months storage were used for principal components analysis (PCA). Each compound was assigned a chemical compound class and a general aroma category based on aroma descriptors reported in the Flavornet (Acree and Arn 2004) and Pherobase (El-Sayed 2003) databases. The relative peak areas of compounds within each compound class and aroma category were summed to create general variables. This was done so that the model did not overfit to noise, which occurs when the number of parameters is greater than the number of variables. PCAs were conducted based on the compound class and aroma category variables and were used to explore the relationship between oak treatments and volatile aroma profiles.

Results and Discussion

The 2017 and 2018 winegrape production seasons in Clarksville, AR, were relatively mild in temperature and rainfall. The high and low temperatures were similar from January to August in both years, with more rainfall from April (budbreak on grapevines) to July prior to harvest in 2017 than in 2018. In August of 2017 and 2018, the average daily high temperatures were 28.6°C and 30.0°C, respectively. In August, there was less cumulative monthly rainfall in 2017 (198.5 mm) than in 2018 (281.7 mm).

The grapes were harvested in August of both years for wine production. After about eight months fermentation and two months aging on oak, the wines were bottled in May and stored at 15°C. In 2017 and 2018 Enchantment wines, the impacts of year and oak addition on all attributes (basic chemistry, anthocyanin, color, and aroma) were evaluated at 0-months storage. In 2017 Enchantment wines, the basic chemistry, anthocyanin, and color attributes were evaluated after 0, 6, and 12 months storage at 15°C.

Basic chemistry, anthocyanin, color, and aroma attributes at 0-months storage (2017 and 2018). The impact of oak treatment on basic chemistry, anthocyanin, color, and aroma attributes was mostly consistent between the two years in which the study was replicated. The year had a major impact on most attributes, while oak addition mainly affected color and aroma attributes.

Basic chemistry attributes. Enchantment wines were analyzed for pH, TA, glycerol, ethanol, glucose, fructose, total residual sugars, tartaric acid, malic acid, citric acid, succinic acid, lactic acid, and total organic acids (Table 1). Of the basic chemistry attributes, the year × oak interaction was only significant for citric acid. The year impacted all basic chemistry attributes except glycerol and ethanol. The 2018 wines had a lower pH and higher TA than 2017 wines. Oak treatment was also significant for pH, although there was very little variation in pH values among oak treatments. Glycerol and ethanol contents of Enchantment wines fell within the ranges of 7 to 10 g/L glycerol and 11 to 14% ethanol reported for dry table wines (Liu and Davis 1994, Alston et al. 2011).

There was no impact of oak treatment on residual sugar concentrations in Enchantment wines. Wines from 2017 had more glucose, fructose, and total residual sugar levels than 2018 wines. The residual sugar levels in all wines were <1% and were similar to concentrations of 50 to 100 mg/100 mL glucose and 20 to 400 mg/100 mL fructose reported for dry table wines (Liu and Davis 1994).

Wine from 2017 had higher concentrations of each individual acid and total organic acids than 2018 wines. In the year × oak interaction, there was no difference among oak treatments for citric acid levels in 2018 wines. In 2017, French-oaked wines had more citric acid than unoaked or American-oaked wines, and 2017 wines had more citric acid than all 2018 wines. In general, concentrations of tartaric, malic, and lactic acids in Enchantment wines were within reported ranges of 200 to 600 mg/100 mL tartaric acid, 200 to 700 mg/100 mL malic acid, and 0 to 300 mg/100 mL lactic acid for dry table wines (Fowles 1992, Sowalsky and Noble 1998, Da Conceicao Neta et al. 2007). However, concentrations of citric and succinic acids were higher than reported ranges of 10 to 70 mg/100 mL citric acid and 50 to 100 mg/100 mL succinic acid for dry table wines (Fowles 1992, Sowalsky and Noble 1998, Da Conceicao Neta et al. 2007).

Anthocyanin attributes. Enchantment wines were analyzed for individual and total anthocyanins, including the monoglucosides and their acetyl and coumaryl derivatives (Table 2). Of note, only anthocyanin monoglucosides, not their diglucoside counterparts, were detected in Enchantment wines. The native and hybrid wines that typically grow well in Arkansas and the mid-south United States contain significant amounts of diglucoside anthocyanins (Pastrana-Bonilla et al. 2003, Zhu et al. 2012). Unlike monoglucosides, diglucosides do not form copigment and acylated complexes and are therefore more susceptible to bisulfite bleaching or hydration (Cheynier et al. 2006, He et al. 2012, Zhu et al. 2012). In both years, malvidin-3-glucoside was the predominant anthocyanin in Enchantment wines, followed by petunidin-3-glucoside and delphinidin-3-glucoside. While malvidin-3-glucoside was the predominant anthocyanin in young red wines from the teinturier grape Alicante Bouschet, peonidin-3-glucoside was the second-most prevalent, followed by petunidin-3-glucoside (García-Beneytez et al. 2003, Revilla et al. 2016). Alicante Bouschet is a parent of Enchantment, which also had malvidin-3-glucoside as the predominant anthocyanin.

The concentrations of anthocyanin compounds in Enchantment wines are shown in Supplemental Table 1 and Figure 1. Total anthocyanin levels were similar to the levels of 44 to 164 mg/100 mL reported for young Alicante Bouschet wines (Revilla et al. 2016). Multiple studies have evaluated the anthocyanin profile of Syrah wines. Syrah is a parent of Petite Sirah (Syrah × Peloursin), and Petite Sirah is a parent of Enchantment (Meredith et al. 1999). Young Spanish Syrah wines had 53 mg/100 mL, 65 mg/100 mL, or 22 mg/100 mL total anthocyanins, respectively, in three studies (Gómez-Míguez and Heredia 2004, Gutiérrez et al. 2005, or Gómez-Míguez et al. 2007). The lower anthocyanin levels in Syrah wines than in the Enchantment wines in the present study are logical, as Enchantment is a teinturier grape

Table 1 Effect of year (2017 or 2018) and oak treatment (no oak, American oak, or French oak staves) on basic chemistry attributes after 0-months storage of wines produced from Enchantment grapes grown at the University of Arkansas System Division of Agriculture Fruit Research Station, Clarksville, AR.

Effects	pH	Titratable acidity[a] (%)	Glycerol (g/L)	Ethanol (% v/v)	Glucose (mg/100 mL)	Fructose (mg/100 mL)	Total residual sugars (mg/100 mL)	Tartaric acid (mg/100 mL)	Malic acid (mg/100 mL)	Citric acid (mg/100 mL)	Succinic acid (mg/100 mL)	Lactic acid (mg/100 mL)	Total organic acids (mg/100 mL)
Year													
2017	3.44 a[b]	0.62 b	7.85	11.15	53.46 a	184.93 a	238.39 a	580.50 a	458.96 a	233.37 a	715.46 a	303.41 a	2291.71 a
2018	3.25 b	0.70 a	7.82	11.17	39.03 b	100.67 b	139.70 b	412.92 b	218.39 b	172.37 b	361.74 b	95.50 b	1260.92 b
p value	***<0.0001***[c]	***<0.0001***	*0.7732*	*0.8314*	***0.0019***	***<0.0001***	***<0.0001***	***<0.0001***	***<0.0001***	***<0.0001***	***0.0002***	***0.0107***	***<0.0001***
Oak													
No oak	3.34 b	0.66	7.76	11.03	41.78	124.50	166.28	478.56	351.78	192.94 b	573.51	245.71	1842.50
American oak	3.35 a	0.66	7.82	11.17	49.44	140.40	189.83	519.58	363.16	196.30 b	602.90	232.29	1914.23
French oak	3.34 ab	0.66	7.92	11.29	47.51	163.51	211.02	492.00	301.10	219.38 a	439.38	120.35	1572.22
p value	***0.0030***	*0.6703*	*0.2557*	*0.1212*	*0.2860*	*0.1469*	*0.1864*	*0.4786*	*0.0995*	***0.0056***	*0.1962*	*0.3287*	*0.3056*
Year x Oak													
2017													
No oak	3.44	0.62	7.78	11.01	46.84	149.80	196.64	548.89	492.52	215.51 b	782.62	391.34	2430.87
American oak	3.44	0.62	7.83	11.12	55.44	173.53	228.97	624.08	504.26	219.48 b	842.57	366.67	2557.06
French oak	3.44	0.62	7.94	11.33	58.10	231.47	289.57	568.54	380.12	265.13 a	521.18	152.23	1887.19
2018													
No oak	3.24	0.70	7.75	11.05	36.73	99.20	135.92	408.22	211.04	170.38 c	364.41	100.09	1254.13
American oak	3.25	0.70	7.82	11.22	43.43	107.27	150.70	415.08	222.05	173.11 c	363.23	97.92	1271.39
French oak	3.25	0.70	7.91	11.26	36.92	95.55	132.47	415.46	222.08	173.63 c	357.59	88.48	1257.25
p value	*0.0751*	*0.8734*	*0.9902*	*0.7842*	*0.4897*	*0.0832*	*0.1164*	*0.5691*	*0.0708*	***0.0106***	*0.2203*	*0.3937*	*0.3234*

[a]Expressed as % w/v (g/100 mL) tartaric acid.
[b]Connecting letters are only shown for attributes with significant differences among treatments. Means with different letters for each attribute within effects are significantly different ($p < 0.05$) according to Tukey's honest significant difference test.
[c]*p* values denoted with bold text are significant ($p < 0.05$).

Table 2 Anthocyanins identified in Enchantment wines after 0-months storage produced from Enchantment grapes grown at the University of Arkansas System Division of Agriculture Fruit Research Station, Clarksville, AR (2017 and 2018).

Compound	Molecular ion (*m/z*)	Characteristic fragment peak (*m/z*)	Relative composition[a] (%)	
			2017	2018
Malvidin-3-O-glucoside	493	331	45.7	37.2
Petunidin-3-O-glucoside	479	317	20.4	14.8
Delphinidin-3-O-glucoside	465	303	14.7	11.7
Peonidin-3-O-glucoside	463	301	11.9	7.1
Cyanidin-3-O-glucoside	449	287	1.8	0.5
Malvidin-3-O-(6-O-acetyl)-glucoside	535	331	0.9	8.7
Petunidin-3-O-(6-O-acetyl)-glucoside	521	317	0.6	3.9
Delphinidin-3-O-(6-O-acetyl)-glucoside	507	303	0.8	1.7
Peonidin-3-O-(6-O-acetyl)-glucoside	505	301	0.2	2.1
Cyanidin-3-O-(6-O-acetyl)-glucoside	491	287	0.1	0.4
Malvidin-3-O-(6-O-*p*-coumaryl)-glucoside	639	331	1.8	6.3
Petunidin-3-O-(6-O-*p*-coumaryl)-glucoside	625	317	0.8	1.7
Delphinidin-3-O-(6-O-*p*-coumaryl)-glucoside	611	303	0.8	1.7
Cyanidin-3-O-(6-O-*p*-coumaryl)-glucoside	595	287	0.2	0.3

[a]Average relative composition (%) across oak treatments (no oak, American oak, or French oak staves).

and thus produces wines with more anthocyanins and deeper color (Santiago et al. 2008).

The year × oak interaction was not significant for anthocyanin attributes, but year was significant for all anthocyanin attributes except peonidin-3-glucoside (Figure 1). Enchantment wines from 2018 had higher concentrations of malvidin-3-glucoside, petunidin-3-glucoside, delphinidin-3-glucoside, total anthocyanins, total acylated anthocyanins, and total coumaryl anthocyanins, while 2017 wines had higher concentrations of cyanidin-3-glucoside, though levels were low. The generally higher anthocyanin levels in 2018 wines could have been due to the 2018 grapes being riper at harvest, as evidenced by higher SS and pH values. In addition, environmental factors such as temperature, pests, or rain could have caused the difference in anthocyanin levels between the two years (Kliewer 1977, Spayd et al. 2002).

Oak treatment did not impact anthocyanin levels of Enchantment wines, which contrasted with previous studies. Spanish red wines aged in oak barrels or with oak chips and staves lost monomeric anthocyanins faster in the wines aged with oak alternatives than in wines aged in barrels, and French-oaked wines had slightly more anthocyanins at the end of oak aging than American-oaked wines (del Alamo-Sanza and Domíngues 2006). Similarly, another study reported lower anthocyanin concentrations in Spanish red wines aged with oak alternatives than in those aged in oak barrels, but found no difference among oak species (del Álamo Sanza et al. 2004).

Color attributes. Enchantment wines were evaluated for L*, a*, b*, red color (abs 520 nm), brown/yellow color (abs 420 nm), and color density (red color + yellow/brown color) (Supplemental Table 2 and Figure 2). The year × oak interaction was significant for L* (Figure 2A). All 2018 wines had lower L* (darker color) than 2017 wines. In 2018, French-oaked wine had a darker color than American-oaked or unoaked wines. There was no difference in L* among oak treatments in 2017. The year and oak treatment impacted a* and b*. Enchantment wines from 2018 had higher a* (more red color) and higher b* (more yellow color) than 2017 wines, indicating a greater overall color intensity. French-oaked wines had higher a* and b* than unoaked wines, while unoaked wines had higher values than American-oaked wines. This was consistent with results of Alencar et al. (2019), who found that wines aged with French oak chips displayed an 18% increase in a* over wines with American oak chips and unoaked wines, and a 25 to 29% increase in b*. The year × oak interaction was also significant for red color (Figure 2B). All 2018 wines had more red color than 2017 wines, but there were no differences among oak treatments within either year. The year main effect was significant for brown/yellow color and color density, and 2018 wines had less brown/yellow color and greater color density than 2017 wines. The increased red color and color density and reduced brown/yellow color of 2018 wines could indicate that these wines had a more desirable color, consistent with their greater anthocyanin levels. The color density values for both 2017 and 2018 Enchantment wines in this study were greater than the average color density of 19.1 reported for young Alicante Bouschet wines (Revilla et al. 2016).

There were only slight differences among oak treatments for color attributes of Enchantment wines. Previous studies

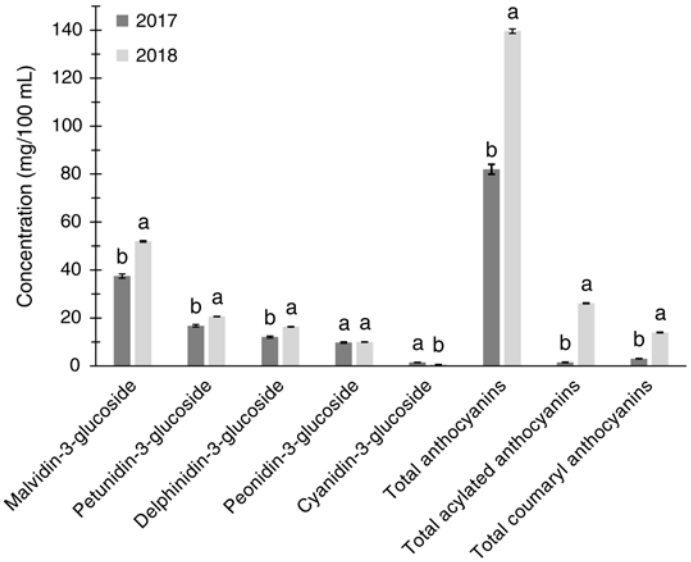

Figure 1 Effect of year (2017 or 2018) on anthocyanin attributes at 0-months storage of wines produced from Enchantment grapes grown at the University of Arkansas System Division of Agriculture Fruit Research Station, Clarksville, AR. Error bars represent standard error. Means with different letters for each attribute are significantly different ($p < 0.05$) according to student's *t*-test.

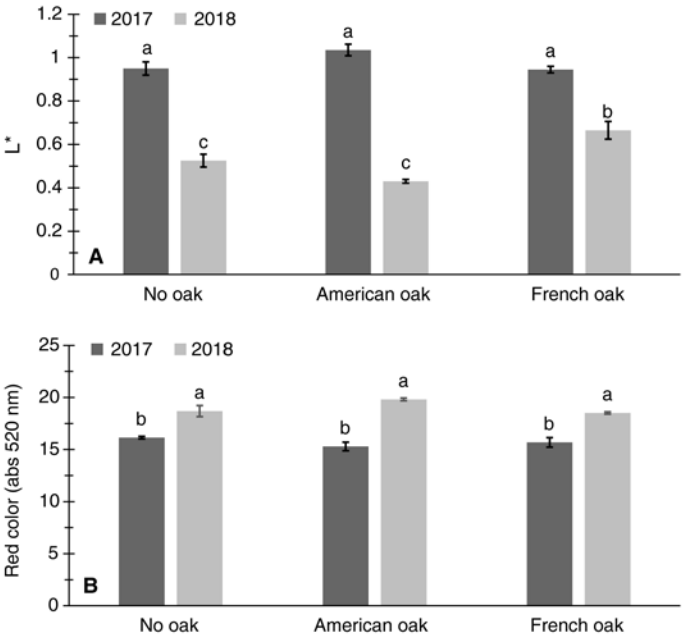

Figure 2 Effect of year (2017 or 2018) and oak treatment (no oak, American oak, or French oak staves) on L* (**A**) and red color (**B**) at 0-months storage of wines produced from Enchantment grapes grown at the University of Arkansas System Division of Agriculture Fruit Research Station, Clarksville, AR. Error bars represent standard error. Means with different letters for each attribute are significantly different ($p < 0.05$) according to Tukey's honest significant difference test.

reported an impact of oak exposure on red wine color. French-oaked wines had more yellow color than American-oaked wines (del Álamo Sanza et al. 2004). This is consistent with higher b* values of French-oaked Enchantment wine in the present study. The impact of oak contact on wine color can depend on species of oak (Jindra and Gallander 1987, Revilla and González-SanJosé 2001). There was an increased yellow-to-red color ratio in wines aged with barrel alternatives, relative to wines aged in traditional oak barrels, thus, barrel alternatives may alter chromatic characteristics of red wine more rapidly than barrels (del Álamo Sanza et al. 2004). However, sensory panelists could not detect a difference in color among red wines aged with barrel alternatives and those aged in oak barrels (Cano-López et al. 2008). Similarly, there was no effect of oak chip addition on perceived color of Syrah wines, despite slight impacts of oak addition on spectrophotometric measurements (Alencar et al. 2019).

Teinturier wines such as Alicante Bouschet are often used in wine blends to increase the color of wines made from lighter-colored cultivars (Revilla et al. 2016). The effects of blending wines with less-desirable color with varieties with more ideal color attributes have been studied (Li et al. 2020). All blended wines had greater color intensity and red color than control wines. As anthocyanin content and color of Enchantment wines were similar to those reported for Alicante Bouschet (Revilla et al. 2016), Enchantment could potentially be used in wine blends to improve color. This would be especially significant for wines produced from grapes grown in the mid-south United States, where Enchantment grapevines have been shown to grow well (Clark et al. 2018). The grape varieties typically produced in this region have less stable anthocyanins than *V. vinifera* grapes and therefore struggle with color loss during aging (Cheynier et al. 2006, He et al. 2012, Zhu et al. 2012).

Multiple studies evaluated the impact of wine blending on wine sensory attributes. García-Carpintero et al. (2010) produced blends from three Spanish red varieties and performed descriptive analysis. All blends were rated higher for desirable sensory attributes and complexity than single-varietal wines. Similarly, in a study on the effect of blending on perceived complexity of 34 blends of two similar wines, all blends were rated higher than the lower-scoring wine of each pair on its own, and higher ratings were attributed to the increased complexity of blended wines (Singleton and Ough 1962). Adding 10% of either Graciano or Cabernet Sauvignon to Tempranillo wines made a visually detectable color difference, and blends had higher overall ratings than single-varietal Graciano, Cabernet Sauvignon, or Tempranillo wines (Monagas et al. 2006a, 2006b). Therefore, using Enchantment wine in blends with less-intensely-colored varieties may increase the overall complexity of wines and improve color.

Aroma attributes. Fifty-two volatile aroma compounds were identified in 2017 Enchantment wines, and 50 compounds were identified in 2018 wines (Table 3). Compounds included chemical, floral, fruity, green/fat, roasted/caramelized, and vegetal alcohols; floral, green/fat, and roasted/caramelized aldehydes; vegetal alkyl sulfides; chemical benzothiazoles; fruity, green/fat, and unpleasant carboxylic acids; floral and fruity esters; chemical ethers; roasted/caramelized furans; fruity glycols; green/fat and vegetal ketones; floral, fruity, and herbal/spicy terpenes; and oaked lactones.

The esters were the largest class of compounds in all wines. Esters are characteristic by-products of alcoholic fermentation and are central aroma compounds in most wines. While some esters, such as ethyl esters, are relatively stable in wines during storage, acetate esters in particular decrease with time (Ramey and Ough 1980, Waterhouse et al. 2016). When Enchantment wines were analyzed for aroma attributes at 0-months storage, esters were predominant. Oak lactone, an aliphatic γ-lactone extracted into wine during contact with oak, was only identified in 2017 American-oaked wines, and not in 2017 French-oaked wines or 2018 wines.

PCA was used to reduce the dimensionality of the data and to elucidate relationships among compound classes, aroma categories, and oak treatments. The relative TIC peak areas (%) were summed for compounds within each compound class and aroma category. The PCAs showed differences in compound classes and aroma categories among oak treatments in 2017 and 2018.

In a PCA of compound class variables (Figure 3A), two components explained 83% of the variation in the data. PC1 (69.6%) had positive loadings for benzothiazoles, alkyl sulfides, glycols, alcohols, terpenes, lactones, aldehydes, furans, and all 2017 wines, regardless of oak treatment. Ethers, esters, ketones, carboxylic acids, and all 2018 wines loaded negatively on PC1. This indicated that there was a difference between 2017 and 2018 wines based on relative abundance of different classes of compounds. It was likely that 2018 wines had more esters. PC2 (13.5%) had positive loadings for carboxylic acids, terpenes, alcohols, and 2017 and 2018 unoaked wines. Aldehydes, lactones, and 2017 and 2018 American- and French-oaked wines loaded negatively on PC2. Therefore, there was a clear separation between oaked and unoaked wines based on compound class variables.

In a PCA of aroma category variables (Figure 3B), two components explained 89% of the variation in the data. PC1 (66.3%) had positive loadings for vegetal, chemical, floral, herbal/spicy, roasted/caramelized, unpleasant, and oaked aroma categories, and for all 2017 wines, regardless of oak treatment. Fruity and green/fat aroma categories and all 2018 wines loaded negatively on PC1. This indicated that there was a clear distinction between 2017 and 2018 wines based on the distribution of volatile compounds among different aroma categories. The association of 2018 wines with fruity aromas was consistent with their association with esters in the compound class PCA. Esters are characteristic by-products of yeast during alcoholic fermentation; their production is influenced by factors such as must composition, oxygen availability, and temperature (Waterhouse et al. 2016). Although must composition and fermentation conditions were consistent among years, slight variations in such factors could explain the difference in relative ester content between 2017 and 2018 Enchantment wines.

Table 3 Volatile aroma compounds identified in unoaked, American-oaked, or French-oaked wines after 0-months storage produced from Enchantment grapes grown at the University of Arkansas System Division of Agriculture Fruit Research Station, Clarksville, AR (2017 and 2018).

Compound[b]	Compound class	Measured retention index[c]	Previously reported retention index[d]	Aroma category[e]	Aroma description[f]	Relative peak area (%)[a]					
						2017-no oak	2017-American oak	2017-French oak	2018-no oak	2018-American oak	2018-French oak
1-Pentanol	Alcohol	768	766	Fruity	Balsamic, fruit	1.05 ± 0.04	1.01 ± 0.05	0.98 ± 0.02	0.30 ± 0.03	0.28 ± 0.01	0.30 ± 0.01
4-Methyl-2-pentanol	Alcohol	835	807	Green/fat	Oil, green, wine	0.52 ± 0.06	0.48 ± 0.05	0.45 ± 0.07	0.24 ± 0.03	0.21 ± 0.02	0.23 ± 0.03
3-Methyl-1-pentanol	Alcohol	844	854	Fruity	Wine, cognac	12.72 ± 0.51	12.31 ± 0.64	11.90 ± 0.42	8.88 ± 0.28	8.29 ± 0.16	8.75 ± 0.19
Furfuryl alcohol	Alcohol	855	851; 866	Roasted/caramelized	Caramel	0.41 ± 0.03	0.41 ± 0.01	0.39 ± 0.02	0.07 ± 0.00	0.07 ± 0.01	0.07 ± 0.00
cis-3-Hexen-1-ol	Alcohol	856	857; 858	Green/fat	Grass, leaf	0.03 ± 0.01	0.03 ± 0.00	–	0.01 ± 0.01	0.00 ± 0.01	0.01 ± 0.01
1-Hexanol	Alcohol	867	851; 867	Green/fat	Green, herbal	0.03 ± 0.01	0.02 ± 0.02	0.03 ± 0.01	–	–	–
1-Heptanol	Alcohol	868	851; 867	Green/fat	Chemical, green, fresh	0.42 ± 0.01	0.31 ± 0.08	0.39 ± 0.02	0.54 ± 0.09	0.53 ± 0.02	0.57 ± 0.02
2-Heptanol	Alcohol	898	898; 925	Vegetal	Mushroom, herbal	0.15 ± 0.02	0.14 ± 0.01	0.12 ± 0.01	–	–	–
2-Ethylhexanol	Alcohol	1028	1032; 1037	Floral	Rose, citrus	0.07 ± 0.03	0.06 ± 0.01	0.06 ± 0.02	0.03 ± 0.01	0.03 ± 0.01	0.03 ± 0.01
Benzyl alcohol	Alcohol	1039	1039; 1043	Floral	Floral, fruit	–	–	–	1.43 ± 0.49	1.02 ± 0.14	0.99 ± 0.13
Octanol	Alcohol	1069	1070; 1072	Chemical	Chemical, metal	6.03 ± 0.13	5.83 ± 0.22	5.76 ± 0.11	6.08 ± 0.21	5.68 ± 0.14	6.06 ± 0.10
2-Phenylethanol	Alcohol	1122	1118; 1122	Floral	Honey, rose	0.09 ± 0.02	0.09 ± 0.01	0.02 ± 0.03	–	–	–
1-Nonanol	Alcohol	1171	1154; 1171	Green/fat	Fat, green	0.14 ± 0.04	–	–	0.11 ± 0.03	–	–
1-Decanol	Alcohol	1272	1263; 1272	Green/fat	Fat	0.02 ± 0.02	–	0.05 ± 0.02	0.07 ± 0.01	0.06 ± 0.01	0.07 ± 0.01
1-Undecanol	Alcohol	1374	1371; 1372	Fruity	Mandarin	–	0.22 ± 0.03	–	–	–	–
1-Dodecanol	Alcohol	1476	1473	Green/fat	Fat, wax	0.14 ± 0.01	0.13 ± 0.02	0.14 ± 0.00	–	–	–
Furfural	Aldehyde	834	829; 830	Roasted/caramelized	Almond, caramel	–	0.01 ± 0.02	–	–	–	–
5-Methylfurfural	Aldehyde	966	962; 978	Roasted/caramelized	Bread, almond	0.23 ± 0.02	0.22 ± 0.03	0.19 ± 0.03	0.13 ± 0.01	0.13 ± 0.02	0.11 ± 0.01
Benzaldehyde	Aldehyde	967	960; 961	Roasted/caramelized	Almond, caramel	0.29 ± 0.01	0.24 ± 0.03	0.26 ± 0.03	0.22 ± 0.04	0.21 ± 0.06	0.20 ± 0.04
Octanal	Aldehyde	1003	1004; 1006	Green/fat	Fat, soap, green	0.04 ± 0.01	0.04 ± 0.00	0.05 ± 0.01	–	0.06 ± 0.02	0.06 ± 0.01
Phenylacetaldehyde	Aldehyde	1052	1049	Floral	Floral, honey, rose	–	–	–	–	0.25 ± 0.02	0.34 ± 0.05
4-Methylbenzaldehyde	Aldehyde	1092	1079	Roasted/caramelized	Almond, caramel	–	–	–	–	0.77 ± 0.32	–
Nonanal	Aldehyde	1106	1104	Green/fat	Fat, citrus, green	2.32 ± 0.57	2.90 ± 0.55	2.84 ± 0.52	–	–	–
Decanal	Aldehyde	1208	1209	Green/fat	Soap, orange peel	–	1.77 ± 0.22	3.26 ± 0.27	–	3.65 ± 1.15	3.05 ± 0.23
Methionol	Alkyl sulfide	980	978	Vegetal	Cooked potato	0.60 ± 0.08	0.58 ± 0.05	0.57 ± 0.07	0.39 ± 0.04	0.39 ± 0.04	0.37 ± 0.07
Benzothiazole	Benzothiazole	1247	1240; 1243	Chemical	Gasoline, rubber	0.05 ± 0.01	0.06 ± 0.01	0.05 ± 0.01	–	–	–
Isovaleric acid	Carboxylic acid	832	834	Unpleasant	Sweat, cheese	0.11 ± 0.01	0.11 ± 0.00	0.11 ± 0.00	–	–	–
Octanoic acid	Carboxylic acid	1164	1179	Unpleasant	Sweat, cheese, fat	0.19 ± 0.10	0.26 ± 0.06	0.24 ± 0.08	0.69 ± 0.11	0.66 ± 0.07	0.80 ± 0.04
Decanoic acid	Carboxylic acid	1357	1373	Green/fat	Fat, soap	0.24 ± 0.03	0.23 ± 0.06	0.20 ± 0.04	–	–	–
Octanoic acid, 3-methylbutyl ester	Carboxylic acid	1447	1450	Fruity	Fruit, pineapple	0.50 ± 0.29	0.15 ± 0.17	0.30 ± 0.16	0.12 ± 0.01	0.13 ± 0.01	–
Ethyl isobutyrate	Ester	760	756; 762	Fruity	Strawberry	1.37 ± 0.12	1.36 ± 0.06	1.39 ± 0.14	1.34 ± 0.11	1.35 ± 0.21	1.28 ± 0.08
Isobutyl acetate	Ester	774	767; 776	Fruity	Apple, banana	0.28 ± 0.11	–	–	0.23 ± 0.05	–	–
Ethyl butanoate	Ester	800	800; 804	Fruity	Apple, strawberry, bubblegum	3.38 ± 0.45	3.60 ± 0.28	3.73 ± 0.33	3.92 ± 0.13	3.86 ± 0.35	3.94 ± 0.15
Ethyl 2-methylbutyrate	Ester	850	846	Fruity	Apple, strawberry	–	–	–	0.50 ± 0.02	0.45 ± 0.02	0.46 ± 0.01

Ethyl isovalerate	Ester	853	849; 854	Fruity	Anise, apple, black currant	1.12 ± 0.08	1.09 ± 0.04	1.07 ± 0.04	1.26 ± 0.04	1.16 ± 0.02	1.20 ± 0.04
Isoamyl acetate	Ester	876	876	Fruity	Banana, pear	2.20 ± 0.16	2.12 ± 0.15	2.08 ± 0.13	3.08 ± 0.10	2.95 ± 0.07	3.03 ± 0.07
2-Methylbutyl acetate	Ester	878	880	Fruity	Fermented fruit, banana, rum	–	–	–	0.11 ± 0.00	0.11 ± 0.00	0.11 ± 0.00
Ethyl pentanoate	Ester	899	898; 900	Fruity	Fruit, yeast	0.08 ± 0.01	0.08 ± 0.00	0.08 ± 0.00	0.13 ± 0.01	0.12 ± 0.00	0.13 ± 0.00
Methyl hexanoate	Ester	924	934	Fruity	Fruit, fresh, paint thinner	0.18 ± 0.01	0.17 ± 0.01	0.18 ± 0.01	0.28 ± 0.01	0.26 ± 0.01	0.28 ± 0.01
Ethyl 3-hydroxybutyrate	Ester	934	935; 945	Fruity	Grape, coconut, marshmallow	0.08 ± 0.01	0.08 ± 0.01	0.08 ± 0.01	0.04 ± 0.00	0.04 ± 0.00	0.04 ± 0.00
Ethyl hexanoate	Ester	997	997; 1002	Fruity	Apple peel, strawberry, anise	5.87 ± 0.18	5.76 ± 0.26	5.95 ± 0.14	2.32 ± 0.10	2.23 ± 0.07	2.30 ± 0.06
Hexyl acetate	Ester	1011	1008; 1014	Fruity	Fruit, herb, wine	5.34 ± 0.85	5.47 ± 0.67	5.35 ± 0.67	9.51 ± 0.46	9.73 ± 0.53	9.60 ± 0.31
Ethyl 2-hexenoate	Ester	1043	1025	Fruity	Fruit	0.05 ± 0.01	0.05 ± 0.01	0.06 ± 0.01	0.50 ± 0.03	0.56 ± 0.07	0.48 ± 0.06
Ethyl 2-furoate	Ester	1054	1056	Fruity	Fruit, floral	0.10 ± 0.01	0.11 ± 0.01	0.10 ± 0.01	0.16 ± 0.02	0.17 ± 0.01	0.15 ± 0.01
Ethyl heptanoate	Ester	1096	1097	Fruity	Fruit	14.34 ± 0.62	13.67 ± 0.12	13.41 ± 0.27	16.36 ± 0.36	15.51 ± 0.18	15.72 ± 0.21
Diethyl succinate	Ester	1176	1167; 1179	Fruity	Wine, fruit, watermelon	0.42 ± 0.03	0.41 ± 0.04	0.43 ± 0.03	0.76 ± 0.05	0.69 ± 0.04	0.76 ± 0.04
Ethyl octanoate	Ester	1196	1195; 1198	Fruity	Fruit, floral	0.46 ± 0.02	0.45 ± 0.03	0.46 ± 0.01	0.60 ± 0.01	0.56 ± 0.02	0.60 ± 0.02
Isopentyl hexanoate	Ester	1250	1254	Fruity	Fruit	0.17 ± 0.05	0.16 ± 0.03	0.14 ± 0.01	0.15 ± 0.01	0.18 ± 0.01	0.15 ± 0.02
2-Phenylethyl acetate	Ester	1265	1260; 1265	Floral	Honey, floral, rose	25.45 ± 1.35	24.78 ± 0.53	25.13 ± 1.04	23.79 ± 0.40	23.35 ± 0.71	22.86 ± 0.32
Ethyl nonanoate	Ester	1294	1297	Fruity	Tropical fruit, rose	–	–	–	0.06 ± 0.01	0.05 ± 0.00	0.06 ± 0.00
Methyl decanoate	Ester	1324	1324; 1326	Fruity	Wine, fruit	0.10 ± 0.01	0.11 ± 0.00	0.10 ± 0.00	1.12 ± 0.03	1.03 ± 0.01	1.05 ± 0.02
Ethyl decanoate	Ester	1394	1394; 1398	Fruity	Grape	9.60 ± 0.38	9.44 ± 0.24	9.16 ± 0.32	12.27 ± 0.17	11.29 ± 0.25	11.85 ± 0.07
Isopentyl octanoate	Ester	1448	1444	Fruity	Fruit, pineapple	0.32 ± 0.02	0.32 ± 0.02	0.32 ± 0.02	0.28 ± 0.03	0.26 ± 0.01	0.28 ± 0.02
Ethyl dodecanoate	Ester	1594	1595	Fruity	Mango, leaf	–	–	–	0.28 ± 0.01	0.28 ± 0.01	0.27 ± 0.01
2,5-Diethyltetrahydrofuran	Furan	901	884	Roasted/caramel-ized	Caramel	–	–	–	0.13 ± 0.01	0.13 ± 0.01	0.12 ± 0.01
2,3-Butanediol	Glycol	781	769	Fruity	Fruit, onion	–	–	–	0.01 ± 0.01	0.03 ± 0.00	0.01 ± 0.01
2,3-Hexanedione	Ketone	784	786	Green/fat	Butter, cream, caramel	0.05 ± 0.00	0.05 ± 0.00	0.05 ± 0.01	0.05 ± 0.01	0.05 ± 0.00	0.05 ± 0.00
6-Methyl-5-hepten-2-one	Ketone	987	985	Vegetal	Mushroom, earthy	–	–	–	0.05 ± 0.00	0.05 ± 0.00	0.05 ± 0.00
Oak lactone	Lactone	1336	1321	Oaked	Coconut, floral	–	–	0.05 ± 0.01	–	–	–
p-Cymene	Terpene	1032	1026; 1027	Herbal/spicy	Herbal, spicy	2.26 ± 0.73	2.33 ± 0.49	2.05 ± 0.62	1.17 ± 0.26	0.90 ± 0.07	0.99 ± 0.08
Linalool	Terpene	1102	1100; 1103	Floral	Floral, lavender, Earl Grey tea	–	–	–	0.02 ± 0.02	0.03 ± 0.00	0.03 ± 0.01
alpha-Terpineol	Terpene	1204	1195; 1207	Herbal/spicy	Anise, mint, toothpaste	0.02 ± 0.00	–	–	–	–	–
Citronellol	Terpene	1230	1228; 1233	Floral	Rose, citrus, clove	–	0.51 ± 0.03	–	–	–	–
β-damascenone	Terpene	1402	1386; 1391	Fruity	Apple, rose, honey	0.14 ± 0.02	0.13 ± 0.02	0.13 ± 0.02	0.03 ± 0.00	0.03 ± 0.00	–

[a]Peak areas were obtained from the total ion chromatogram. Error term represents standard deviation.
[b]Compounds were identified by comparison of three mass spectra libraries: National Institute of Standards and Technology (NIST14), Flavors and Fragrances of Natural and Synthetic Compounds (FFNSC3; Mondello 2015), and Adam's Essential Oils (Adams 2007).
[c]Retention indices were calculated as Kovats retention indices (Kováts 1958).
[d]Reported retention indices were obtained from the Flavornet (Acree and Arn 2004) and Pherobase (El-Sayed 2003) databases.
[e]Compounds were grouped into aroma categories based on aroma descriptors reported in the Flavornet (Acree and Arn 2004) and Pherobase (El-Sayed 2003) databases.
[f]Aroma descriptors were obtained from the Flavornet (Acree and Arn 2004) and Pherobase (El-Sayed 2003) databases.

In Figure 3B, PC2 (22.5%) had positive loadings for unpleasant and herbal/spicy aroma categories and 2017 and 2018 unoaked wines. Roasted/caramelized and oaked aroma categories and 2017 and 2018 American- and French-oaked wines loaded negatively on PC2. The association of unoaked wines with unpleasant and herbal/spicy aromas was consistent with their association with carboxylic acids and terpenes, respectively, in the compound class PCA. The association of oaked wines with roasted/caramelized and oaked aromas was expected, as oak addition imparts such aromas to wines. In 2017, American-oaked wines had a very strong association with roasted/caramelized and oaked aromas, while French-oaked wines had only a weak association with these aroma categories. This correlation of American-oaked wines with traditional woody characteristics is supported by a study of the impact of American and French oak chip addition on sensory attributes of Syrah wines (Alencar et al. 2019). Oak-aged wines had greater overall aromatic intensity than control wines, and wines produced with American oak chips had more coffee, woody, and sweet/caramelized aromas than French-oaked wines. In a consumer test, wines produced with American oak chips were associated with "woody" characteristics, while wines produced with French oak chips were associated with "vanilla" characteristics. 2018 American- and French-oaked Enchantment wines showed no visible differences in the PCA plot for aroma categories. Overall, these results suggested that oak addition could give Enchantment wines more complex, roasted, and "oaky" aromas than unoaked wines.

Basic chemistry, anthocyanin, and color attributes during storage (2017). Storage had a major impact on basic chemistry, anthocyanins, and color attributes, while oak was not very influential. In most cases, the impact of storage did not depend on the oak treatment.

Basic chemistry attributes. The storage × oak interaction was not significant for any basic chemistry attribute but malic acid, and the oak main effect did not impact any attributes (Supplemental Table 3). Storage impacted pH and TA of Enchantment wine, with pH increasing from 0 to 12 months storage and TA decreasing from 6 to 12 months storage. However, all pH and TA values remained within the ranges of pH 3.3 to 3.7 and 0.5 to 0.65% TA for dry red table wines (Waterhouse et al. 2016). Storage time affected tartaric and citric acids. Tartaric acid concentration decreased from 0 to 6 months storage, consistent with the increased pH. There was no difference among storage times for citric acid concentration.

Anthocyanin attributes. The storage × oak interaction and oak main effect were not significant for any anthocyanin attributes (Supplemental Table 4). Storage affected all anthocyanin attributes (Figure 4). Individual and total anthocyanin concentrations decreased from 0 to 12 months storage, with the exception of total acylated and total coumaryl anthocyanins, which increased from 0 to 6 months storage and then decreased from 6 to 12 months storage. The malvidin-3-glucoside concentration decreased 64% and total anthocyanins decreased 61% over 12 months storage. This was likely due to formation of compounds/adducts from monomeric

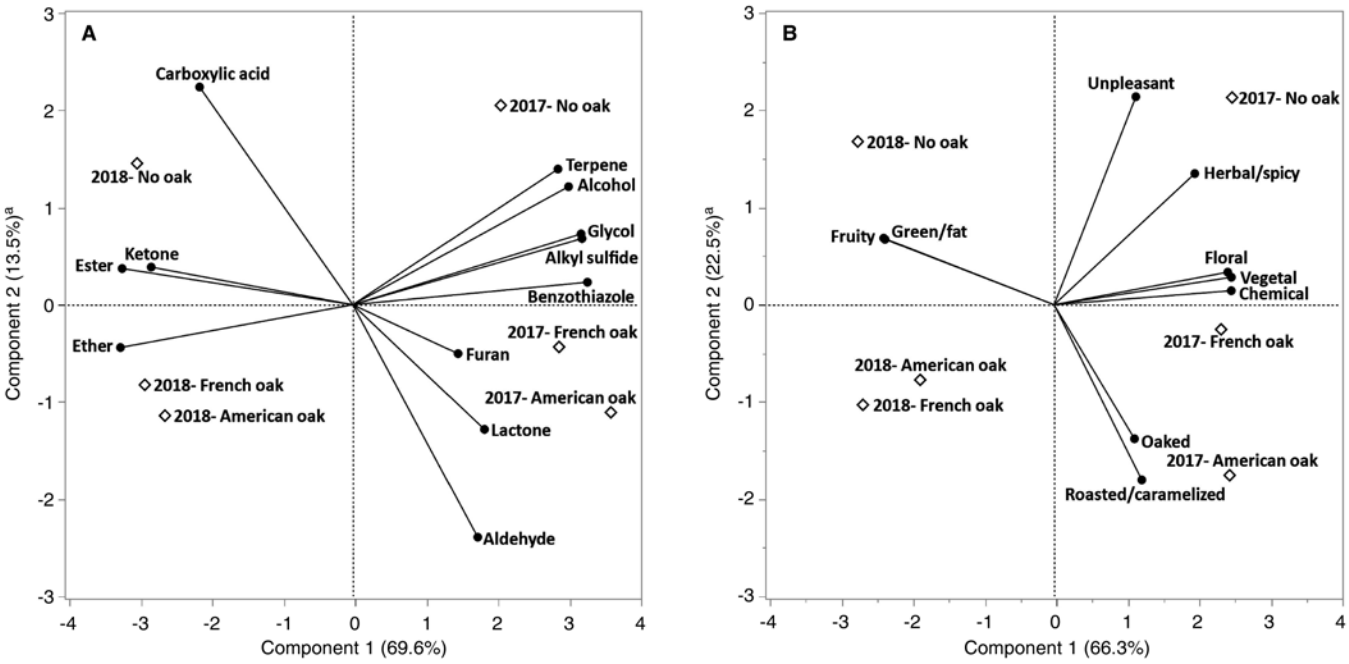

Figure 3 Biplots of principal components analysis on volatile aroma compound classes (**A**) and aroma categories (**B**) in wines at 0-months storage at 15°C produced from Enchantment grapes grown at the University of Arkansas System Division of Agriculture Fruit Research Station, Clarksville, AR (2017 and 2018). Compound class variables represent the sum of the total ion chromatogram (TIC) relative peak areas (%) of positively identified compounds within each compound class (Table 3). Aroma category variables represent the sum of the TIC relative peak areas (%) of positively identified compounds within each aroma category. [a]Percent of variation in data explained by each component.

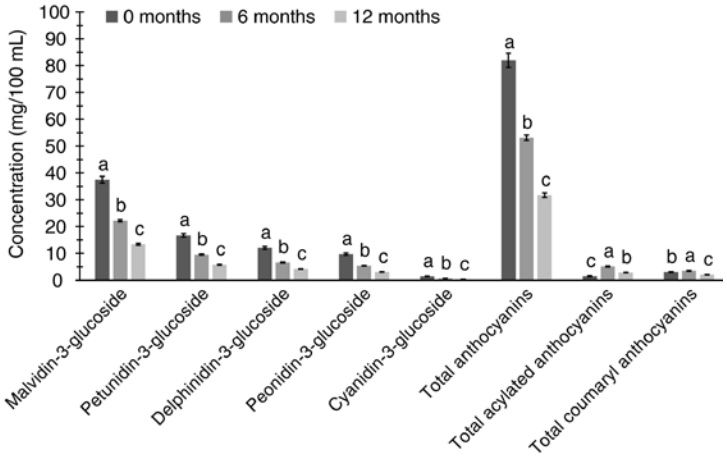

Figure 4 Effect of storage (0, 6, or 12 months at 15°C) on anthocyanin attributes of wines produced from Enchantment grapes grown at the University of Arkansas System Division of Agriculture Fruit Research Station, Clarksville, AR (2017). Error bars represent standard error. Means with different letters for each attribute are significantly different ($p < 0.05$) according to Tukey's honest significant difference test.

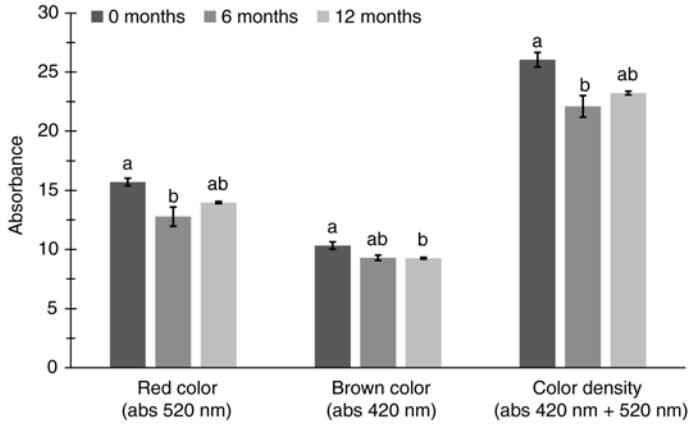

Figure 6 Effect of storage (0, 6, or 12 months at 15°C) on red color, brown/yellow color, and color density of wines produced from Enchantment grapes grown at the University of Arkansas System Division of Agriculture Fruit Research Station, Clarksville, AR. Error bars represent standard error. Means with different letters for each attribute are significantly different ($p < 0.05$) according to Tukey's honest significant difference test.

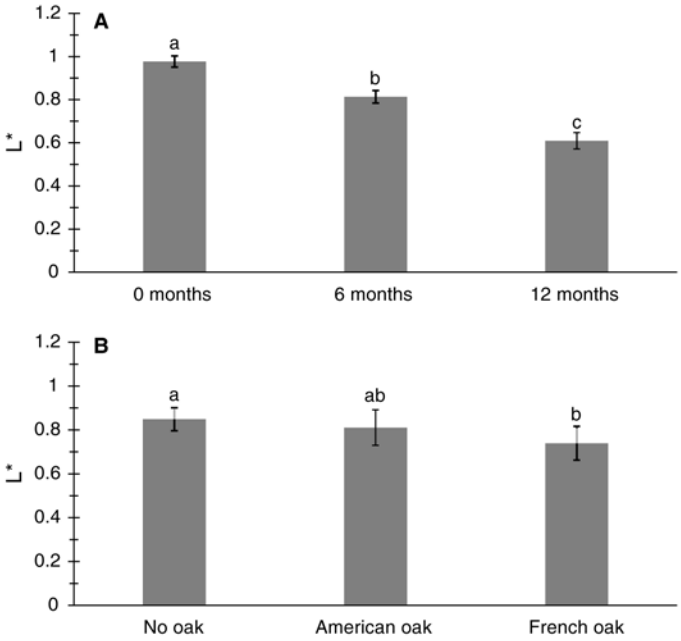

Figure 5 Effect of storage (0, 6, or 12 months at 15°C) (**A**) and oak treatment (no oak, American oak, or French oak staves) (**B**) on L* of wines produced from Enchantment grapes grown at the University of Arkansas System Division of Agriculture Fruit Research Station, Clarksville, AR. Error bars represent standard error. Means with different letters within each effect are significantly different ($p < 0.05$) according to Tukey's honest significant difference test.

anthocyanins that can influence and stabilize wine color during storage (Escribano-Bailón and Santos-Buelga 2012, de Freitas et al. 2017, Li and Duan 2019).

Color attributes. The storage × oak interaction was not significant for any color attributes except b*, but there were no differences among treatments (Supplemental Table 5). Storage affected all color attributes except b*. There was no effect of oak treatment on any color attribute except L*. Enchantment wines became darker during storage (decreasing L*) and French-oaked wines had darker color than unoaked wines (Figure 5). Storage time was significant for a*: the red color of wines increased (increasing a*) from 0 to 12 months storage. The red color and color density of Enchantment wines decreased from 0 to 6 months storage, but had a slight (although insignificant) increase from 6 to 12 months storage (Figure 6). This was in contrast to the a* measurements, which showed red color increasing during storage. Brown/yellow color decreased from 0 to 12 months storage.

Conclusions

In both 2017 and 2018, Enchantment wines had basic chemistry within acceptable ranges for a dry red table wine, remaining mostly stable during one year of storage at 15°C. Anthocyanin-3-glucosides, but not their diglucoside counterparts, were identified in Enchantment wines, with malvidin-3-glucoside as the predominant anthocyanin. Although red color and color density decreased slightly during 12 months storage, Enchantment wines maintained a deep red/purple color. There was minimal impact of oak treatment on basic chemistry and anthocyanins, but some impact on color attributes. The volatile aroma profiles of Enchantment wines were clearly distinguished by year and oak treatment: oaked wines in both years were associated with more oaky, roasted, and caramelized aroma compounds. Enchantment can be used to produce high-quality, deeply red-colored wines that benefit from oak additions and retain quality during storage. Enchantment shows potential as a teinturier winegrape for the mid-south United States, as a single varietal or to enhance wine blends.

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