

Southern Region Small Fruit Consortium

Final Report Research

Title: Identifying Flavor and Aroma Attributes of Arkansas Fresh-Market Blackberries that Impact Marketability

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Public Abstract

Fresh-market blackberries (*Rubus* subgenus *Rubus*) have unique aromas and flavors that appeal to consumers. Although the basic tastes (sweetness, sourness, and bitterness) impact the flavor perception of blackberries, volatile aroma compounds (substances which vaporize easily at ambient temperature) are also responsible for typical aromas and flavors. The berry attributes, composition attributes, and volatile aroma attributes of Arkansas fresh-market blackberries were measured. Blackberries were harvested from the University of Arkansas System Division of Agriculture Fruit Research Station, Clarksville, AR in June 2020. Nineteen genotypes were evaluated including nine cultivars (Caddo, Natchez, Osage, Ouachita, Ponca, Prime-Ark® 45, Prime-Ark® Horizon, Prime-Ark® Traveler, and Tupy) and ten breeding selections (A-2526T, A-2528T, A-2547T, A-2587T, A-2610T, A-2620T, A-2625T, A-2658T, A-2701T, and APF-409T). Blackberry genotypes significantly impacted berry, composition, and volatile aroma attributes. Berry weight ranged from 6.27 g (Osage) to 15.15 g (A-2620T). A-2620T also had the lowest firmness (1.78 N), while A-2701T had the highest (13.13 N). Soluble solids ranged from 9.80% (A-2587T) to 14.60% (Ponca). Osage (0.64%) had lowest titratable acidity, and Ouachita (1.37%) had the highest. The genotypes with soluble solids/titratable acidity ratio of 10-13 included Caddo, Prime-Ark® 45, Prime-Ark® Horizon, Prime-Ark® Traveler, Tupy, A-2526T, A-2528T, and A-2587T. Ponca had the highest total sugars (14.61 g/100 mL), while A-2587T had the lowest (7.26 g/100 mL). Ouachita (1.34 g/100 mL) had the highest total organic acids, while A-2658T (0.49 g/100 mL) had the lowest. There were 155 volatile aroma compounds

identified and quantified in the blackberry genotypes harvested in 2020 including monoterpenes (43), esters (31), aldehydes (29), alcohols (21), sesquiterpenes (18), ketones (6), aromatic hydrocarbons (3), norisoprenoids (3), and lactones (1). In terms of total volatile compounds, Ouachita (1,401 µg/kg) had the lowest, and Caddo (18,121 µg/kg) had the highest. Caddo, Tupy, and A-2620T had the three highest levels of total volatile compounds mainly consisting of ethyl acetate an ester in the fruity aroma category with an aroma of fruity, pineapple, and anise. Other volatile aroma compounds at high levels in these blackberries were D-limonene (monoterpene in the fruity aroma category with a citrus and mint aroma), hexanal (aldehyde in the green/fat aroma category with a green and herbal aroma), and octanoic acid (aldehyde in the green/fat aroma category with a cheese and grass aroma). Data generated from this project provided information on berry, composition, and volatile aroma attributes that can be used for marketing these genotypes and supporting blackberry breeding efforts.

Introduction

Blackberry (*Rubus* subgenus *Rubus*) is one of the best examples of a wild-harvested specialty crop that moved to commercial use through increased consumer demand, new cultivars, advanced production methods, and year-round availability. There have been many improvements to fresh-market blackberry quality from the University of Arkansas System Division of Agriculture (UA System) Blackberry Breeding Program (Clark 2005; Clark and Perkins-Veazie 2011; Finn and Clark 2012; Finn and Clark 2017; Segantini et al. 2017). The development of new blackberry cultivars with unique aroma and flavor attributes can improve consumer perceptions of the crop and support further industry expansion.

Although the basic tastes (sweetness, sourness, and bitterness) impact the flavor of blackberries, volatile aroma compounds (substances in fruit which vaporize easily at ambient temperature) are also responsible for typical aromas and aromatic flavors of blackberries. Volatiles in blackberries include acids, esters, alcohols, aldehydes, ketones, lactones, phenols, or terpenoids but vary by variety, ripeness, and harvest and storage conditions (Du et al. 2010; El Had et al. 2013; Qian and Wang 2005). Although some published research on blackberry volatile composition has been done in the United States (Du et al. 2010; Qian and Wang 2005), Poland (Wajs-Bonikowska et al. 2017), Italy and Spain (D'Agostino et al. 2015), and Brazil (Jacques et al. 2014), no research has been published on volatile aroma attributes of Arkansas blackberries.

A preliminary analysis at the UA System Food Science Department, Fayetteville using Gas Chromatography-Mass Spectrometry (GC-MS) identified major classes of volatile aroma compounds in Prime-Ark® Traveler and Osage including alcohols (39-45%), aldehydes (23-25%), and monoterpenes (15-22%). Other research on Oregon-grown blackberries showed that Marion and Black Diamond (Du et al. 2010) and Marion and Thornless Evergreen (Qian and Wang 2005) had volatiles including alcohols (32%), acids (32%), and monoterpenes (24%). Du et al. (2010) and Qian and Wang (2005) showed hexanoic acid, 2-heptanol, linalool, butanoic acid, octanol, hexanol, benzyl alcohol, α -pinene, acetic acid, α -terpineol and p-cymen-8-ol to be the 10 major volatile compounds. Research is also in progress at the UA System Food Science Department to identify volatile aroma compounds in Arkansas genotypes (cultivars and advanced selections) and to also determine the impact of volatiles on in vitro anti-inflammatory properties.

Threlfall et al (2020) gathered information on consumer perceptions and purchase intent of blackberries through an online study. The 879 survey participants responded that they consumed fresh blackberries once per month (41.6%), mostly purchased from grocery stores (33.6%). In a

consumer study by Threlfall et al. (2021), Ponca, Osage, Caddo, and Natchez were rated highly for sweetness, sourness, overall flavor, and overall impression, while Ponca had the most ideal composition of the cultivars evaluated according to the criteria established by Threlfall et al. (2016) that included blackberries with a soluble solids of 9-11%, titratable acidity of 0.9-1.0%, and a soluble solids/titratable acidity ratio of 10-13..

Consumer overall impression and flavor of Arkansas blackberries were negatively correlated to the descriptive attributes for sourness, bitterness, and green/unripe aromatic (Threlfall et al. 2016). The aromatic attributes (volatiles perceived by the olfactory system while chewing a sample in the mouth) of the blackberries identified in this study included overall aromatic impact, blackberry, earthy/dirty, green/ unripe, overripe/fermented, chemical, mold/ mildew, and metallic with Natchez having the highest overall aromatic intensity. Segantini et al. (2017) also investigated postharvest and descriptive sensory of Arkansas genotypes and found that after seven days of storage at 2 °C Natchez was associated with sweet taste and overall aromatic impact.

These consumer and descriptive studies provided unique data to characterize consumer perception and purchasing of fresh-market blackberries, but there is a critical need to determine the key aroma and flavor attributes that impact consumer preference and can be used to steer breeding decisions and help southern U.S. growers better market blackberries. The original objective of this research was to **identify physicochemical and descriptive sensory attributes of fresh-market blackberry genotypes from the UA System blackberry breeding program.**

Objectives

1. Evaluate physicochemical attributes of fresh-market blackberries

Measure berry attributes, composition attributes, and aroma and flavor attributes of Arkansas fresh-market blackberries

2. Identify descriptive sensory attributes of fresh-market blackberries

Conduct descriptive analysis to determine key aroma and flavor characteristics of Arkansas fresh-market blackberries

Pandemic Impact on the Project: The Covid-19 pandemic impacted the objectives for this project. Originally, the project included the physicochemical (Objective 1) and descriptive sensory (Objective 2) attribute evaluation of 4-8 fresh-market blackberry genotypes. A descriptive sensory analysis of fresh blackberries was scheduled for June 2020 (Objective 2). However, the UA System Sensory Service Center was closed from March to September due to the pandemic with limited capacity to implement descriptive sensory analysis upon reopening. In addition, the Sensory Service Center raised the costs of services due to changes in protocols related to implement UA System Covid-19 safety guidelines. Prior to harvest in June 2020, the research team decided to increase the number of genotypes from 8 to 19 for physicochemical attribute analysis (Objective 1). Extra blackberries of each of the genotypes were harvested and frozen with plans to determine a method to evaluate the descriptive sensory attributes of the frozen blackberries using other funds in Spring 2021.

Material and Methods

Objective 1: Identify Physicochemical Attributes of Fresh-market Blackberries

Measure berry attributes, composition attributes, and volatile aroma attributes of Arkansas fresh-market blackberries

Blackberries were hand-harvested from the UA System Fruit Research Station, Clarksville, AR in June 2020 from 7:00-10:00 _{AM} at the shiny-black stage of ripeness. The blackberries were randomly picked from different plants and locations on the plants. Nineteen

genotypes were evaluated including nine cultivars (Caddo, Natchez, Osage, Ouachita, Ponca, Prime-Ark® 45, Prime-Ark® Horizon, Prime-Ark® Traveler, and Tupy) and ten breeding selections (A-2526T, A-2528T, A-2547T, A-2587T, A-2610T, A-2620T, A-2625T, A-2658T, A-2701T, and APF-409T). The “T” on the selection names indicates that the plant is thornless. Prime-Ark® Horizon (formerly APF-268) is a thorny cultivar recently released from the UA System. Tupy was included because it is one of the most widely-grown blackberry cultivars for fresh-markets. The blackberries were harvested and placed directly into 312 g (11 oz) pint vented clamshells in triplicate. After harvest, the clamshells were placed in chilled coolers and transported to the UA System Department of Food Science, Fayetteville. These genotypes were evaluated for berry attributes at harvest, then the berries were frozen (-10 °C) for composition attributes and volatile aroma attributes.

Berry attribute analysis

The day of harvest, five berries per genotype and replication were measured for berry weight, length, and width, and berry firmness.

Berry weight. Each berry was weighed (g) using a precision digital scale (PA224 Analytic Balance, Ohaus Corporation, Parsippany, NJ).

Berry length and width. The length and width (mm) of each berry were measured using digital calipers.

Berry firmness. Firmness of each berry was measured by a Stable Micro Systems TA.TX.XT plus Texture Analyzer (Texture Technologies Corporation, Hamilton, MA). Firmness was tested by placing an individual berry horizontally on a flat surface using a cylindrical probe. The force needed to compress the berry was measured and recorded in Newtons (N).

Composition attribute analysis

Composition of the juice from five berries per genotype and replication were measured for soluble solids, pH, titratable acidity, sugars, and organic acids. The five berries were thawed at room temperature (21 °C) and squeezed through cheesecloth to extract the juice for analysis.

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

pH. The pH of juice was measured using a Metrohm 862 Compact Titrosampler fitted with a pH meter. The probe was left in the samples for two minutes to equilibrate before recording the pH value.

Titratable acidity. The titratable acidity of juice was expressed as % w/v (g/100 mL) citric acid and measured using a Metrohm 862 Compact Titrosampler. Three grams of sample was added to 50 mL degassed, deionized water and titrated with 0.1 N sodium hydroxide to an endpoint of pH 8.2.

Sugars and organic acids.

Individual and total sugars and organic acids of the juice were evaluated by High Performance Liquid Chromatography (HPLC) using previously established procedures (Walker et al., 2003; Segatini et al., 2018). Glucose, fructose, citric acid, and malic acid levels of the juice were measured. The HPLC was equipped with a Bio-Rad HPLC Organic Acid Analysis Aminex HPX-87H ion exclusion column (300 x 7.8 mm) and a Bio-Rad HPLC column (150 x 7.8 mm) in series. A Bio-Rad Micro-Guard Cation-H refill cartridge (30 x 4.5 mm) was used as guard column. The peaks were quantified using external standard calibration based on peak

height estimation with baseline integration. Individual and total sugars (glucose + fructose) and organic acids (citric + malic) of the juice were expressed as g/100 mL.

Volatile aroma attribute analysis

Ten berries per genotype and replication were frozen (-10 °C) after harvest and used for volatile aroma attribute 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 included identification and quantitation of odor-active compounds. For the analysis of blackberry volatiles, the 10 blackberries were weighed and deionized water and NaCl were mixed using a ratio of 1:2:0.1 (w/v/w), respectfully. To further reduce column saturation, two mL of berry/deionized water/NaCl solution were added to 2 mL of deionized water (4 mL total) and placed in vials with one for GC and the other for FID analysis.

Solid phase micro-extraction (SPME): The SPME fiber used in this analysis was the 85 µm CAR/PDMS Stableflex Manual Holder, 24 Ga, Supelco (Bellefonte, PA). Vials containing 4 ml of samples were placed on a stir plate with heating capability at 65° C with the SPME fiber inserted into the headspace above the sample. Adsorption was timed for 30 min.

GC-FID and GC-MS Analysis: Samples were analyzed on both GC-FID and GC-MS. 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 (Agilent Technologies, Santa Clara, CA). 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 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 National Institute of Standards and Technology NIST17 spectral library, literature data, and retention indices. Tentatively identified compounds were quantified using calibration curves of authentic standards. The retention indices were performed after running alkane standards of 5 to 20 carbons and online searches of similar work with HP5 or DB5 columns. Volatile concentrations were expressed as µg/kg. The cumulative concentration of each class of volatile compound for each variety was expressed as total volatile compounds (µg/kg).

Statistical analysis

Nineteen genotypes (Caddo, Natchez, Osage, Ouachita, Ponca, Prime-Ark® 45, Prime-Ark® Horizon, Prime-Ark® Traveler, Tupy, A-2526T, A-2528T, A-2547T, A-2587T, A-2610T, A-2620T, A-2625T, A-2658T, A-2701T, and APF-409T) were evaluated in triplicate. The data was analyzed by analysis of variance (ANOVA) using JMP® (version 15.2.0; SAS Institute Inc., Cary, NC). Tukey's Honest Significant Difference was used for mean separations ($p = 0.05$).

Results and Discussion

Berry attribute analysis

The berry weight, length, and width, and berry firmness were evaluated at harvest (Table 1). Blackberry genotypes significantly impacted the berry attributes. A-2620T had the highest berry weight (15.15 g) and berry length (43.75 mm) but had the lowest firmness (1.78 N). Ponca had the lowest berry length (25.90 mm). Osage had the lowest berry weight (6.27 g). A-2658T had the highest berry width (25.94 mm) and APF-409T had the lowest (20.99 mm). A-2701T had the highest firmness (13.13N). Tupy, the commercial standard, had a berry weight of 10.02 g, berry length of 36.13 mm, berry width of 24.18 mm, and berry firmness of 4.88 N.

Composition attribute analysis

The soluble solids, pH, titratable acidity, sugars, and organic acids of the juice from the blackberries were evaluated (Table 1). Blackberry genotypes significantly impacted the composition attributes. Ponca had the highest soluble solids (14.60%), and A-2587T had the lowest soluble solids (9.80%). Osage had the highest pH (3.91) and lowest titratable acidity (0.64%), conversely, Ouachita had the lowest pH (3.01) and highest titratable acidity (1.37%). A-2658T (20.82) had the highest soluble solids/titratable acidity ratio, while APR-409T (8.20) had the lowest. Tupy, the commercial standard, had a soluble solids level of 12.10%, pH level of 3.58, titratable acidity level of 0.93%, and a soluble solids/titratable ratio of 13.13

In a consumer study, Threlfall et al. (2016) found that fresh-market blackberries should have soluble solids of 9-11%, titratable acidity of 0.9-1.0%, and a soluble solids/titratable acidity ratio of 10-13. The genotypes in this study that had a soluble solids level of 9-11% included Natchez, Prime-Ark® 45, Prime-Ark® Horizon, Prime-Ark® Traveler, Ponca, A-2528T, A-2587T, A-2620T, and APF-409T). The genotypes that had a titratable acidity of 0.9-1% included Caddo, Prime-Ark® 45, Prime-Ark® Horizon, Prime-Ark® Traveler, Tupy, A-2526T, A-2547T, and A-2610T. The genotypes that had the soluble solids/titratable acidity ratio of 10-13 included Caddo, Prime-Ark® 45, Prime-Ark® Horizon, Prime-Ark® Traveler, Tupy, A-2526T, A-2528T, and A-2587T.

The individual and total sugars and organic acids of the juice from the blackberries were evaluated (Table 2). Ponca had the highest glucose (7.33 g/100 mL), fructose (7.28 g/100 mL), and total sugars (14.61 g/100 mL), while A-2587T had the lowest glucose (3.57 g/100 mL), fructose (3.99 g/100 mL), and total sugars (7.26 g/100 mL). Natchez (0.96 g/100 mL), APF-409T (0.45 g/100 mL), and Ouachita (1.34 g/100 mL) had the highest citric acid, malic acid, and total organic acids, respectively. A-2620T (0.34 g/100 mL), A-2701T (0.11 g/100 mL), and A-2658T (0.49 g/100 mL) had the lowest citric acid, malic acid, and total organic acids, respectively.

Volatile aroma attribute analysis

There were 155 volatile aroma compounds identified and quantified in the blackberry genotypes harvested in 2020 (Table 3). The compounds identified included monoterpenes (43), esters (31), aldehydes (29), alcohols (21), sesquiterpenes (18), ketones (6), aromatic hydrocarbons (3), norisoprenoids (3), and lactones (1). Compounds included fruity, green/fat, roasted/caramelized, and vegetal alcohols, roasted/caramelized, green/fat, floral, vegetal, and fruity aldehydes, fruity and vegetal aromatic hydrocarbons, fruity and floral esters, green/fat, vegetal, floral, and fruity ketones, fruity lactones, vegetal, floral, green/fat monoterpenes, floral norisoprenoids, and green/fat, floral and fruity sesquiterpenes. Monoterpenes are a class of terpenes that contain two isoprene molecules and are predominantly the product of secondary metabolism of plants known for their biological activities such as antimicrobial, anti-

inflammatory, and anti-plasmodial properties and have been used in flavorings and fragrances (Tchimene et al., 2013).

In Figure 1, the cumulative concentration of each class of volatile compounds for each genotype was shown. In terms of total volatile compounds, Ouachita (1,401.44 $\mu\text{g}/\text{kg}$) had the lowest and Caddo (18,121.17 $\mu\text{g}/\text{kg}$) had the highest. Caddo, Tupy, and A-2620T had the three highest levels of total volatile compounds. Genotypes with less than 5,000 $\mu\text{g}/\text{kg}$ total volatile compounds included Ouachita, Prime-Ark® Traveler, A-2528T, APF-409T, Natchez, A2526T, Prime-Ark® 45, A-2701T, and A2658T.

The highest amounts of aroma compounds in the blackberries were mostly ethyl acetate in the aroma category fruity with an aroma descriptor of fruity, pineapple, and anise. Caddo (14,967.91 $\mu\text{g}/\text{kg}$), Tupy (12,989.67 $\mu\text{g}/\text{kg}$), and A-2620T (9,062.21 $\mu\text{g}/\text{kg}$) had high ethyl acetate levels. There were blackberries with high levels of D-limonene, a monoterpene in the fruity aroma category with a citrus and mint aroma descriptor. A-2625T (2,210.29 $\mu\text{g}/\text{kg}$) and A-2620T (1,504.03 $\mu\text{g}/\text{kg}$) had the highest levels of D-limonene. There were blackberries with high levels of hexanal, an aldehyde in the green/fat aroma category with a green and herbal aroma descriptor. Caddo (1,587.48 $\mu\text{g}/\text{kg}$) had the highest levels of hexanal. There were blackberries with high levels of octanoic acid, an aldehyde in the green/fat aroma category with a cheese and grass aroma descriptor. Osage (863.14 $\mu\text{g}/\text{kg}$), Natchez (704.14 $\mu\text{g}/\text{kg}$), and Ponca (558.61 $\mu\text{g}/\text{kg}$) had the highest levels of octanoic acid.

Conclusions

The berry, composition, and volatile aroma attributes of 19 fresh-market blackberries harvested from the UA System Fruit Research Station in Clarksville, AR in 2020 were evaluated. Nine cultivars (Caddo, Natchez, Osage, Ouachita, Ponca, Prime-Ark® 45, Prime-Ark® Horizon, Prime-Ark® Traveler, and Tupy) and ten breeding selections were evaluated. Blackberry genotypes significantly impacted the berry, composition, and volatile aroma attributes. Although the berry and composition attributes had a wide range of values, the values were typical of previously reported values from other research done on these cultivars and selections. There were 155 volatile aroma compounds identified and quantified in these blackberry genotypes including monoterpenes, esters, aldehydes, alcohols, sesquiterpenes, ketones, aromatic hydrocarbons, norisoprenoids, and lactones. Caddo, Tupy, and A-2620T had the three highest levels of total volatile compounds mainly consisting of ethyl acetate (fruity, pineapple, and anise aromas). Other volatile compounds at high levels in these blackberries were D-limonene (monoterpene with mint aroma), hexanal (aldehyde with green and herbal aroma), and octanoic acid (aldehyde with cheese and grass aroma). Data generated from this project provided information on berry, composition, and volatile aroma attributes that can be used for marketing these genotypes and supporting blackberry breeding efforts.

Impact Statement

This project on 19 fresh-market blackberry cultivars and breeding selections from the University of Arkansas System Division of Agriculture provided the first year of data in a two-year study on berry, composition, and volatile aroma attributes. In the blackberries, 155 volatile aroma attributes were identified and quantified. The berry, composition, and volatile aroma attribute data on fresh-market blackberries from this study will be used for presentations at regional and national conferences in 2021, a Food Science Department Master's student thesis, and a journal publication.

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Table 1. Berry and composition attributes of fresh-market blackberry genotypes, Clarksville, AR (2020)

Genotype ^z	Berry weight (g)	Berry length (mm)	Berry width (mm)	Firmness (N)	Soluble solids (%)	pH	Titrateable acidity (%) ^y	Soluble solids/titrateable acidity ratio
A-2526T	7.78 e-h	30.98 f-i	22.56 cd	5.10 ef	12.07 a-d	3.27 b-e	1.00 a-d	12.06 a-c
A-2528T	8.47 d-h	31.62 e-h	22.11 cd	5.75 ef	11.47 b-d	3.55 a-d	0.75 d	13.32 a-c
A-2547T	7.82 e-h	30.22 g-j	22.56 cd	6.23 ef	12.43 a-d	3.49 a-e	0.87 b-d	14.73 a-c
A-2587T	13.50 ab	41.56 ab	25.01 a-c	4.88 fg	<u>9.80 d</u>	3.58 a-c	0.84 c-d	11.83 a-c
A-2610T	8.88 d-h	32.11 e-g	22.60 cd	5.93 ef	13.20 ab	3.39 b-e	0.96 b-d	14.07 a-c
A-2620T	15.15 a	43.75 a	25.58 ab	<u>1.78 g</u>	11.90 b-d	3.55 a-d	0.75 d	15.94 a-c
A-2625T	8.86 d-h	32.95 d-g	23.82 a-d	8.10 bf	12.27 a-d	3.77 ab	0.79 d	15.95 a-c
A-2658T	13.01 a-c	38.78 a-c	25.94 a	5.84 ef	13.10 a-c	3.61 a-c	0.68 d	20.82 a
A-2701T	10.46 c-e	40.20 a-c	22.32 cd	13.13 a	13.17 ab	3.74 ab	0.73 d	18.36 ab
APF-409T	7.31 gh	30.61 f-j	<u>20.99 d</u>	11.22 ab	9.83 d	3.17 c-e	1.20 a-c	<u>8.20 c</u>
Caddo	10.98 b-d	35.63 ef	24.01 a-c	8.18 b-e	12.03 a-d	3.49 a-e	0.90 b-d	13.64 a-c
Natchez	10.07 d-f	37.76 b-d	22.07 cd	7.63 c-f	10.50 cd	3.05 de	1.24 a-b	8.55 c
Osage	<u>6.27 h</u>	26.01 ij	22.71 b-d	6.71 ef	12.87 a-c	3.91 a	<u>0.64 d</u>	20.06 a
Ouachita	7.04 h	26.73 h-j	22.18 cd	5.46 ef	12.50 a-c	<u>3.01 e</u>	1.37 a	9.33 bc
Ponca	6.87 h	<u>25.90 j</u>	23.33 a-d	7.11 d-f	14.60 a	3.68 a-c	0.76 d	19.95 a
Prime-Ark® 45	7.66 f-h	32.76 d-g	21.04 d	7.68 c-f	10.63 b-d	3.37 b-e	0.87 b-d	12.43 a-c
Prime-Ark® Horizon	9.99 d-g	39.72 a-c	22.23 cd	10.07 a-d	11.70 b-d	3.21 c-e	0.87 b-d	13.52 a-c
Prime-Ark® Traveler	7.42 f-h	31.12 e-h	21.00 d	10.71 a-c	11.13 b-d	3.38 b-e	0.91 b-d	12.30 a-c
Tupy	10.02 d-g	36.13 c-e	24.18 a-c	4.88 fg	12.10 a-d	3.58 a-c	0.93 b-d	13.13 a-c
<i>P-value</i>	<i><0.0001</i>	<i><0.0001</i>	<i><0.0001</i>	<i><0.0001</i>	<i><0.0001</i>	<i><0.0001</i>	<i><0.0001</i>	<i><0.0001</i>

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

^y Titrateable acidity expressed as % citric acid.

Table 2. Individual and total sugars and organic acid attributes of fresh-market blackberry genotypes, Clarksville, AR (2020)

Genotype ^z	Glucose (g/100 mL)	Fructose (g/100 mL)	Total sugars (g/100 mL)	Citric acid (g/100 mL)	Malic acid (g/100 mL)	Total organic acids (g/100 mL)
A-2526T	5.33 b	4.17 b-d	9.49 b-f	0.56 b-d	0.29 b-d	0.84 c
A-2528T	4.95 b-e	4.87 b-d	9.81 b-e	0.43 cd	0.18 ef	0.60 c-e
A-2547T	5.06 b-d	4.99 b-d	10.05 b-d	0.48 cd	0.20 c-f	0.68 c-e
A-2587T	<u>3.57</u> f	<u>3.69</u> d	<u>7.26</u> f	0.35 cd	0.30 bc	0.65 c-e
A-2610T	5.54 b	5.43 bc	10.97 bc	0.59 bc	0.27 b-e	0.86 bc
A-2620T	4.55 b-f	4.55 b-d	9.10 b-f	<u>0.34</u> d	0.17 ef	0.50 de
A-2625T	5.00 b-d	4.83 b-d	9.83 b-e	0.49 cd	0.13 f	0.62 c-e
A-2658T	5.27 bc	5.15 b-d	10.42 bc	0.35 cd	0.14 f	<u>0.49</u> e
A-2701T	5.66 b	5.65 b	11.31 b	0.55 cd	<u>0.11</u> f	0.66 c-e
APF-409T	3.62 ef	3.93 cd	7.55 ef	0.80 ab	0.45 a	1.25 a
Caddo	4.37 b-f	4.44 b-d	8.81 c-f	0.47 cd	0.21 c-f	0.67 c-e
Natchez	3.94 c-f	4.01 cd	7.95 d-f	0.96 a	0.19 c-f	1.16 ab
Osage	5.03 b-d	5.01 b-d	10.04 b-d	0.38 cd	0.19 c-f	0.57 c-e
Ouachita	4.71 b-f	4.80 b-d	9.52 b-f	0.93 a	0.41 a	1.34 a
Ponca	7.33 a	7.28 a	14.61 a	0.56 b-d	0.17 ef	0.74 c-e
Prime-Ark® 45	4.41 b-f	4.43 b-d	8.84 c-f	0.40 cd	0.18 d-f	0.58 c-e
Prime-Ark® Horizon	4.69 b-f	4.73 b-d	9.42 b-f	0.53 cd	0.13 f	0.65 c-e
Prime-Ark® Traveler	4.58 b-f	4.71 b-d	9.28 b-f	0.52 cd	0.35 ab	0.86 bc
Tupy	3.83 d-f	3.98 cd	7.81 d-f	0.56 b-d	0.25 b-e	0.81 cd
<i>P-value</i>	<i><0.0001</i>	<i><0.0001</i>	<i><0.0001</i>	<i><0.0001</i>	<i><0.0001</i>	<i><0.0001</i>

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

Table 3. Volatile aroma compounds ($\mu\text{g}/\text{kg}$) of fresh-market blackberry genotypes, Clarksville, AR (2020)

Compound	Compound class	Measured retention index	Aroma category	Aroma description	A-2526T	A-2528T	A-2547T	A-2528T	A-2610T	A-2620T	A-2625T	A-2658T	A-2701T	Prime-Ark® Horizon	APF-409T	Cuddo	Natchez	Onachita	Osage	Prime-Ark® 45	Prime-Ark® Traveler	Ponca	Tupy
1-Butanol	alcohol	642	Fruity	Banana, alcohol, sweet	0.0	0.0	0.0	0.0	0.0	0.0	0.0	19.4	0.0	0.0	0.0	20.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1-Penten-3-ol	alcohol	665	Green/fat	Butter, fish, green	11.5	4.4	2.5	0.0	0.0	29.7	1.9	1.4	4.6	2.1	3.1	0.0	28.04	5.4	2.9	4.1	2.3	4.1	23.3
3-Buten-1-ol, 3-methyl	alcohol	717	Fruity	Cherry, herbal, spices	0.00	0.00	0.00	0.00	0.00	0.00	9.89	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8.19	0.00
1-Butanol, 3-methyl	alcohol	720	Roasted/caramelized	Burnt, cocoa, floral, malt	5.80	0.00	19.54	0.00	0.00	0.00	7.06	5.33	11.21	11.99	9.07	24.27	0.00	4.97	13.89	11.93	0.00	18.69	25.32
1-Butanol, 2-methyl	alcohol	723	Green/fat	Fish oil, green, malt, onion, wine	3.95	0.00	6.14	0.00	0.00	0.00	5.03	6.55	5.91	6.75	3.30	9.21	0.00	5.78	5.83	11.76	0.00	6.27	5.82
2-Penten-1-ol	alcohol	769	-	-	3.90	0.00	0.00	0.00	0.00	0.00	9.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	10.41	0.00	0.00	3.36	0.00
3-Hexen-1-ol	alcohol	851	Vegetal	Burdock	43.82	0.00	0.00	48.19	0.00	0.00	72.38	0.00	0.00	13.77	36.96	30.56	41.85	34.01	0.00	20.99	0.00	0.00	19.71
2-Hexen-1-ol	alcohol	861	Green/fat	Blue cheese, vegetable	5.22	15.40	5.25	3.00	19.30	3.33	9.36	13.70	0.00	2.38	40.02	1.77	13.38	6.22	56.12	5.14	24.53	15.72	4.45
1-Hexanol	alcohol	863	Green/fat	Grass, herbal, banana	141.61	78.96	95.47	26.77	74.66	28.18	156.09	102.47	70.86	14.13	82.80	21.76	126.86	64.61	212.95	21.56	54.34	174.43	38.97
2-Heptanol	alcohol	895	Vegetal	Mushroom, herbal	391.78	30.66	26.69	26.69	13.64	54.53	203.95	652.39	159.30	29.00	69.63	175.19	593.08	49.26	51.88	59.46	2.30	75.36	83.01
1-Heptanol	alcohol	968	Green/fat	Chemical, green, fresh	6.66	5.78	2.32	4.03	6.50	3.67	19.48	0.00	5.10	5.68	5.24	7.25	7.48	6.39	6.99	5.79	4.73	8.70	6.47
1-Octen-3-ol	alcohol	978	Green/fat	Fat, floral, mushroom	2.28	2.71	8.26	2.57	1.90	0.00	12.24	2.21	2.88	0.00	4.00	2.12	4.76	4.17	2.96	1.52	2.54	5.61	3.75
1-Pentanol, 3-ethyl-4-methyl	alcohol	1019	-	-	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.77	0.00	0.00	0.00	0.00	8.11	0.00	0.00	0.00	0.00
1-Hexanol, 2-ethyl	alcohol	1028	Green/fat	Green, rose	53.34	102.32	72.88	58.91	49.14	69.02	15.76	54.41	80.91	47.17	63.91	9.47	100.03	37.00	10.35	55.95	48.63	44.95	29.69
1-Octanol	alcohol	1069	Chemical	Chemical, metal	9.22	10.46	8.67	6.73	8.43	4.20	21.79	16.68	30.39	6.39	6.66	8.64	19.83	8.27	28.32	9.28	3.93	23.76	14.56
Dihydro myrcenol	alcohol	1072	-	-	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.79
1-Nonanol	alcohol	1169	Green/fat	Fat, green	4.98	3.41	1.73	3.27	3.04	3.45	7.19	2.06	4.50	2.59	3.99	2.46	3.31	3.24	7.81	4.26	2.55	6.63	5.07
Camphenol, 6	alcohol	1177	-	-	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	19.28	0.00	43.53	0.00	24.92	17.40	0.00	24.15	6.79	0.00	0.00
1-Decanol	alcohol	1271	Green/fat	Fat	2.83	3.06	1.44	4.47	3.84	0.92	12.10	8.05	6.57	1.47	1.28	2.31	0.65	1.08	6.71	2.04	0.48	2.69	2.62
1-Undecanol	alcohol	1374	Fruity	Mandarin	2.70	5.77	0.00	0.00	0.00	0.00	0.00	3.93	1.31	0.00	0.00	0.00	0.00	0.00	2.65	0.00	4.56	1.41	0.00
Dodecanol	alcohol	1474	Green/fat	Fat	0.85	0.56	0.38	0.87	0.00	3.15	1.36	0.64	1.29	0.19	0.00	0.00	1.51	2.36	3.09	0.57	0.29	2.74	0.00

Compound	Compound class	Measured retention index	Aroma category	Aroma description	A-2526T	A-2528T	A-2547T	A-2528T	A-2610T	A-2620T	A-2625T	A-268T	A-270T	Prime-Ark® Horizon	APF-409T	Cuddo	Natchez	Onachita	Ossage	Prime-Ark® 45	Prime-Ark® Traveler	Ponca	Tupuy
Butanal, 3-methyl	aldehyde	622	Roasted/caramelized	Malt, chocolate	46.79	16.83	30.68	27.99	86.02	29.62	59.25	0.00	40.95	27.02	28.60	23.75	35.94	15.99	87.68	72.18	45.30	64.35	15.80
2-Butenal	aldehyde	629	-	-	0.0	0.0	0.0	0.0	0.0	39.1	7.0	15.5	1.7	0.0	0.0	23.6	4.5	8.1	10.1	11.3	6.5	5.5	7.1
Butanal, 2-methyl	aldehyde	636	Roasted/caramelized	Almond, cocoa	27.39	14.15	24.65	15.45	34.03	31.45	47.23	0.00	38.07	20.58	29.68	76.20	0.00	17.41	80.20	53.13	33.55	23.10	28.56
Pentanal	aldehyde	677	Roasted/caramelized	Almond, bitter, malt, oil	0.00	7.32	0.00	0.00	0.00	0.00	18.30	0.00	17.75	37.71	0.00	28.75	0.00	77.81	0.00	12.49	31.98	34.03	0.00
2-Butenal, 2-methyl	aldehyde	741	-	-	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.33	0.00	0.00	0.00	0.00
2-Pentenal	aldehyde	744	-	-	3.56	1.60	0.00	0.00	0.00	5.25	0.00	2.67	1.59	3.44	6.14	4.33	10.49	8.75	4.96	3.55	4.64	5.27	3.35
Hexanal	aldehyde	792	Green/fat	Green, herbal	125.09	52.97	279.56	21.73	455.34	120.34	300.23	146.05	111.85	0.00	130.62	1587.48	300.49	175.17	293.85	0.00	156.41	253.73	703.73
2-Hexenal	aldehyde	845	Floral	Herbal tea, spearmint, wheat	0.00	0.00	0.00	0.00	0.00	0.00	11.20	8.50	5.58	0.00	2.79	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2-Hexenal	aldehyde	850	Floral	Herbal tea, spearmint, wheat	323.29	190.82	116.58	10.40	282.20	90.51	437.24	604.27	313.59	44.44	147.15	89.11	151.55	141.50	1212.70	76.45	270.08	592.83	79.43
Styrene	aldehyde	893	Green/fat	Gasoline	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.41	0.00	0.00	2.97	1.95	0.00	0.00	0.00	0.00	0.00	2.08	3.50
Heptanal	aldehyde	902	Green/fat	Chemical, green, fresh	0.00	0.00	0.00	0.00	1.53	0.00	0.00	0.00	0.94	2.01	0.16	0.00	0.00	3.66	2.32	3.38	1.38	1.36	0.17
2,4-Hexadienal, (E,E)	aldehyde	909	Green/fat	Olive, peanuts, caviar	10.46	9.56	2.11	2953.87	9.64	0.00	18.09	16.67	4.48	0.00	5.92	0.96	5.30	6.45	44.98	0.00	4.83	16.47	1.93
2-Heptenal	aldehyde	-	Green/fat	Almond	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.89	0.00	0.00	0.00	0.00
3-Hepten-1-ol	aldehyde	912.0	Green/fat	Green, herbal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Benzaldehyde	aldehyde	965	Roasted/caramelized	Almond, caramel	9.44	14.32	17.94	7.91	13.46	11.12	17.72	8.90	8.81	5.64	7.37	18.23	17.01	10.11	21.89	11.76	12.61	16.76	15.38
Octanal	aldehyde	1003	Green/fat	Fat, soap, green, Berry, geranium, honey, nut	6.71	4.28	53.44	3.28	5.27	6.30	13.96	3.32	3.47	4.30	4.21	3.78	13.65	5.17	9.53	4.01	5.37	29.55	5.26
Phenylacetaldehyde	aldehyde	1050	Green/fat	Dandelion, fat, fruit, spice	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.83	0.00	0.00	0.00	0.00	5.19	4.36	0.00	0.00
2-Octenal	aldehyde	1059	Green/fat	Fat, citrus, green	2.12	0.00	0.00	2.17	4.60	5.54	2.85	0.00	2.35	0.00	4.53	21.62	0.76	1.77	3.40	4.22	1.15	2.13	1.45
Nonanal	aldehyde	1104	Green/fat	Melon, mushroom	11.86	10.10	5.12	6.24	9.28	9.22	41.72	6.47	4.53	5.35	6.38	74.97	17.09	0.00	20.16	0.00	6.67	18.24	4.34
3-Nonen-1-ol	aldehyde	1156	Green/fat		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.39	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.00
Octanoic acid	aldehyde	1161	Green/fat	Cheese, grass	54.47	348.39	121.94	344.63	0.00	114.12	865.12	217.20	118.39	97.87	197.68	152.21	704.14	76.87	863.14	178.80	0.00	558.61	0.00
2-Nonenal	aldehyde	1165	Green/fat	Paper	0.70	1.97	0.67	0.00	0.00	1.02	0.00	0.00	0.91	0.00	0.00	0.00	0.00	1.08	0.00	0.94	0.64	0.42	0.00
Decanal	aldehyde	1206	Green/fat	Soap, orange peel	7.37	12.00	5.16	42.14	5.09	5.23	25.15	2.31	10.83	2.15	4.88	0.00	10.48	3.25	14.80	4.01	5.37	13.18	0.00
2,4-Decadienal	aldehyde	1215	Green/fat	Coriander, fat	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.43	25.27	0.00	0.00	0.00	1.59	15.36
2-Decenal	aldehyde	1265	Green/fat	Fat, fish, orange	1.91	0.00	0.79	1.31	2.05	3.42	12.25	1.52	1.91	1.98	2.11	1.30	5.43	1.86	7.04	1.43	2.01	5.29	2.53
Undecanal	aldehyde	1308	Vegetal	Basil, corn, celery	1.12	3.28	0.69	0.00	0.69	1.29	3.24	0.00	0.93	0.56	1.03	0.00	3.72	1.29	1.45	0.00	0.80	3.54	1.25
2-Undecenal	aldehyde	1367	Fruit	Orange, tea	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.06	0.00	0.00	0.00	0.00
trans-2-Hexenyl hexanoate	aldehyde	1384	Green/fat	Cognac, herbal, wax	0.00	0.00	0.00	0.00	0.00	0.00	1.88	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.28	0.00	0.00	0.00	0.00
Dodecanal	aldehyde	1411	Green/fat	Citrus, fat, lily	1.19	0.00	0.00	0.56	0.00	0.67	1.16	0.00	0.00	0.00	0.00	0.31	1.64	0.00	0.88	0.00	0.00	1.51	0.30

Compound	Compound class	Measured retention index	Aroma category	Aroma description	A-2526T	A-2528T	A-2547T	A-2528T	A-2610T	A-2630T	A-2625T	A-2658T	A-2701T	Prime-Ark® Horizon	APF-409T	Caddo	Natchez	Quachita	Osage	Prime-Ark® 45	Prime-Ark® Traveler	Ponca	Tupay
Toluene	aromatic hydrocarbon	759	Fruity	Apple, spearmint, dill	11.03	61.14	94.00	56.66	89.03	58.06	9.08	73.80	41.85	36.58	22.99	13.27	40.10	35.97	6.12	87.32	174.55	165.25	128.12
Xylene	aromatic hydrocarbon	886	Vegetal	Parsley, cherry, corn, bell pepper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.91	0.00	0.00	0.00	0.00	0.00	0.00	0.42
alpha,Para-dimethylstyrene	aromatic hydrocarbon	1095	Vegetal	Spicy, balsamic, musty	6.02	52.09	17.78	70.63	60.64	91.49	155.61	43.94	19.80	0.91	8.81	11.22	25.95	6.50	14.05	3.43	2.72	34.73	9.91
Ethyl Acetate	ester	593	Fruity	Fruity, pineapple, anise	1446.52	303.14	4489.56	313.45	7174.16	9062.21	1101.04	209.18	1473.81	6015.05	1413.14	14967.91	82.85	220.60	3733.83	2039.94	846.38	1122.45	12989.67
Ethyl propanoate	ester	699	Fruity	Apple, pineapple, strawberry	2.80	5.52	9.01	2.52	16.38	2.97	3.11	0.43	0.75	13.73	1.79	41.46	0.00	0.00	22.26	6.77	3.90	5.22	18.12
Methyl butanoate	ester	711	Fruity	Apple, banana, cheese, floral	0.62	11.35	6.44	6.75	9.19	0.00	0.00	0.48	0.00	13.46	0.00	28.98	0.00	0.00	11.30	4.66	4.59	4.87	9.17
Ethyl isobutanoate	ester	758	Fruity	Apple, pineapple	0.00	0.00	2.09	0.00	0.00	0.00	0.00	0.00	0.00	2.57	0.00	10.23	0.00	0.00	9.42	0.63	0.00	0.00	8.61
Methyl 2-methylbutanoate	ester	770	-	-	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	9.13	0.00	0.00	2.29	0.00	0.00	0.00	0.00	0.00
2-Butenoic acid, ethyl ester	ester	784	-	-	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.98	0.00	0.00	0.00	0.00
Ethyl butanoate	ester	-	Fruity	Apple, butter, cheese, pineapple	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.45	1.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Butyl acetate	ester	815	Fruity	Apple, banana, glue	21.90	93.68	18.64	46.27	0.00	0.00	0.00	0.00	0.00	518.27	0.00	0.00	0.00	0.00	1331.40	0.00	28.97	85.36	0.00
2-Butenoic acid, ethyl ester	ester	841	-	-	3.28	0.00	25.75	0.00	39.04	0.00	1.62	0.00	0.00	10.98	0.00	68.07	0.00	0.00	173.60	5.53	17.97	0.53	23.70
Ethyl 2-methylbutanoate	ester	851	Fruity	Apple, kiwi	0.00	0.00	8.54	0.00	0.00	0.00	0.00	0.00	0.00	13.88	0.00	21.60	0.00	0.00	84.64	3.36	4.80	7.83	22.35
Methyl hexanoate	ester	921	Fruity	Fruit, fresh, paint thinner	1.12	5.52	0.72	1.40	6.72	1.22	3.26	1.80	0.35	1.87	0.00	74.17	1.12	0.00	17.15	1.42	1.13	2.18	4.26
Ethyl 3-hydroxybutyrate	ester	939	Fruity	Grape, coconut, marshmallow	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.20	0.00	5.05	0.00	0.00	16.51	0.00	0.00	0.82	3.04
Ethyl 2-methyl-2-butenolate	ester	939	-	-	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.35	0.00	72.74	0.00	0.00	173.95	0.00	0.00	0.00	0.00
Ethyl hexanoate	ester	998	Fruity	Apple peel, strawberry, anise	9.60	17.37	17.49	12.25	48.64	9.67	45.29	5.11	5.74	100.41	3.62	166.48	5.55	2.99	770.98	17.50	3.89	15.41	205.81
Hexyl acetate	ester	1010	Fruity	Apple, banana	0.72	0.32	0.19	0.00	0.00	0.00	0.00	0.58	0.25	0.06	0.15	0.00	0.51	0.14	0.56	0.09	0.18	0.28	0.00
2-Hexenyl acetate	ester	1013	Fruity	Apple, peach	0.51	0.00	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.00	0.00	0.00	0.00	0.86	0.00	0.35	0.00	0.00
Methyl octanoate	ester	1122	Fruity	Fruit, orange, wax, wine	0.00	1.84	0.00	1.41	0.00	0.00	1.21	0.00	0.00	0.00	0.00	0.00	1.60	0.00	8.00	0.00	0.00	0.42	0.52
Ethyl 3-hydroxyhexanoate	ester	1128	Fruity	Pear, red wine	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.63	0.00	0.00	0.00	0.00
Ethyl 2-hexenoate	ester	-	-	-	0.00	0.00	1.94	0.00	1.61	0.00	0.00	0.00	0.00	1.37	0.00	5.96	0.00	0.00	19.85	1.79	0.65	1.11	2.36
Neo-allo-ocimene	ester	1146	Fruity	Celery	10.22	0.00	0.00	0.00	0.00	0.00	2.51	25.86	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	35.16	0.00
Ethyl benzoate	ester	1179	Fruity	Chamomile, celery, flower	0.88	5.22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.72	0.00	0.00	4.41	0.00	0.00	1.22	4.12
Hexyl butanoate	ester	1189	Fruity	Apple, citrus	4.88	0.00	0.00	0.00	0.00	0.00	0.00	30.20	0.00	0.63	0.00	0.00	0.00	0.00	11.12	0.00	0.00	0.00	0.00
2-Hexenyl butanoate	ester	1192	Fruity	Blueberry, blackberry	4.33	9.03	5.43	0.00	0.00	0.00	8.80	13.15	0.00	0.52	0.00	0.00	9.10	0.00	0.00	1.49	2.30	7.43	0.00
Ethyl octoate	ester	1194	Fruity	Apricot, Brandy	2.91	18.24	6.47	0.00	9.25	0.00	38.30	0.00	0.00	5.54	2.56	11.23	3.80	2.15	354.54	2.29	1.36	10.48	38.15
Methyl salicylate	ester	1206	Floral	Wintergreen	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.92	0.00	0.00	0.00	0.00	0.00	0.00	1.03
Ethyl 2-octenoate	ester	1245	Fruity	Fruity, tropical	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.61	0.00	0.00	0.00	0.00
Methyl decanoate	ester	1322	Fruity	Pear, blackberry	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.36	0.00	0.00	1.96	0.00
Hexyl hexanoate	ester	1385	Fruity	Apple, peach, plum	3.09	11.14	0.00	0.00	0.00	0.00	3.10	6.42	2.19	0.00	0.00	0.00	0.00	0.00	1.07	0.00	0.00	7.65	0.00
Ethyl decanoate	ester	1392	Fruity	Grape	2.06	0.00	3.49	0.00	3.65	1.44	6.00	0.65	0.34	1.33	0.00	2.68	0.95	0.00	46.25	0.54	0.00	8.95	5.50
Methyl dodecanoate	ester	1519	-	-	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.70	0.00	0.00	0.00	0.00
Ethyl dodecanoate	ester	1591	Fruity	Mango, leaf	0.51	0.00	0.00	0.00	1.73	0.63	3.56	0.00	0.00	0.00	0.00	0.68	0.00	0.46	10.64	0.00	0.00	3.56	1.64

Compound class	Measured retention index	Aroma category	Aroma description	A-2526T	A-2528T	A-2547T	A-2528T	A-2610T	A-2620T	A-2625T	A-2658T	A-2701T	Prime-Ark® Horizon	APF-409T	Caddo	Natchez	Quachita	Osage	Prime-Ark® 45	Prime-Ark® Traveler	Ponca	Tupay	
1-Penten-3-one	ketone	-	Fish, mustard	0.00	0.00	0.00	0.00	0.00	0.00	12.26	0.00	0.00	0.00	0.00	0.00	167.27	0.00	10.78	0.00	0.00	9.45	0.00	
2-Heptanone	ketone	890	Vegetal	Blue cheese, fruit, green, nut	11.83	2.85	2.93	0.49	0.00	4.36	10.19	34.46	12.92	0.00	3.12	5.55	17.36	2.81	3.03	2.25	0.00	2.61	5.06
5-Hepten-2-one, 6-methyl	ketone	987	Vegetal	Mushroom, earthy	2.79	5.23	0.89	0.00	0.00	0.00	0.00	0.00	1.63	0.00	1.80	0.00	3.04	1.36	5.47	1.90	1.93	1.15	0.00
Camphenone, 6	ketone	1130	-	-	6.07	0.00	0.00	2.81	0.00	0.00	14.66	0.00	0.00	5.34	0.00	5.41	0.00	0.00	0.00	0.00	0.00	0.00	
Camphor	ketone	1160	Floral	Mint	8.25	0.00	0.00	0.00	0.00	0.00	11.96	0.00	0.00	4.23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	133.71
2-Undecanone	ketone	1294	Fruity	Orange, Rose	1.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.34	0.00	0.72	0.00	0.00	2.30	0.42	
gamma.-Undecanolactone	lactone	1480	Fruity	Apricot	0.00	3.68	0.00	0.00	0.00	0.00	19.89	0.00	0.00	0.00	0.00	86.93	0.00	28.75	0.00	0.00	0.00	14.47	
3-Carene	monoterpene	928	Green/fat	Nutmeg	0.00	0.00	0.00	0.00	1.15	0.97	0.65	0.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.21	0.00	
alpha.-Thujene	monoterpene	934	Vegetal	Herb, woody, green	0.00	12.15	38.33	33.34	29.26	47.42	79.50	29.23	12.42	0.00	0.00	0.00	0.00	0.00	0.00	8.20	0.00	4.18	10.23
alpha.-Pinene	monoterpene	939	Floral	Cedar, pine																			
Dehydrosabinene	monoterpene	960	-	-	0.00	144.87	268.54	451.24	100.59	24.36	153.47	148.96	63.32	0.00	51.82	18.99	0.00	12.31	0.00	28.17	9.96	92.19	0.00
Camphene	monoterpene	955	Green/fat	Camphor, mothball, oil	1.90	10.90	17.74	41.38	32.37	61.17	57.34	35.81	19.05	0.00	11.77	8.25	0.00	8.68	0.00	9.15	5.02	13.21	17.24
beta.-Pinene	monoterpene	985	Floral	Pine, wood	0.00	0.00	0.00	143.47	138.18	358.96	226.71	89.53	33.53	0.00	0.00	0.00	0.00	0.00	15.11	0.00	0.00	44.62	101.15
beta.-Myrcene	monoterpene	992	Fruity	Balsamic, fruit, herb	34.39	35.64	9.99	59.06	64.59	143.69	298.75	94.39	20.69	10.94	24.12	31.49	28.92	15.32	133.56	14.38	0.00	138.32	36.66
alpha.-Phellandrene	monoterpene	1009	Fruity	Citrus, fresh, mint, pepper, spice	0.00	0.00	0.00	0.00	28.69	38.81	102.70	0.00	0.00	0.00	9.28	0.00	0.00	0.00	0.00	0.00	0.00	18.33	0.00
alpha.-Terpinene	monoterpene	1022	Fruity	Lemon	2.94	58.51	11.43	60.01	28.92	25.71	64.81	29.03	14.61	0.00	20.88	10.41	15.41	7.31	0.00	18.24	5.31	12.19	6.74
Cymene	monoterpene	1031	Fruity	Citrus, fresh, solvent	1.04	5.81	3.17	18.91	10.55	13.67	23.42	9.98	3.51	0.35	2.61	1.38	3.76	0.67	2.29	1.84	0.56	5.29	1.91
D-Limonene	monoterpene	1036	Fruity	Citrus, mint	57.89	165.23	160.30	846.62	742.64	1504.03	2210.29	758.81	254.73	9.85	94.11	135.20	99.54	67.85	223.14	109.19	30.94	371.78	235.72
Eucalyptol	monoterpene	1040	Fruity	Camphor	0.00	0.00	545.82	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1155.54
m-Cymene	monoterpene		Fruity	Sweet basil, blackcurrant, fruit	0.00	0.00	0.00	0.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Terpinolene	monoterpene	-	Fruity	Mint	0.00	0.00	0.00	0.00	0.00	0.00	2.83	0.00	0.00	0.00	0.00	0.00	11.60	0.00	14.63	0.00	3.36	0.00	
beta.-cis-Ocimene	monoterpene	1049	Fruity	Tea, celery	41.90	0.00	8.13	0.00	4.51	0.00	0.00	94.03	0.00	1.09	0.00	7.94	0.00	0.88	13.99	0.00	0.00	109.15	4.78
beta.-Ocimene	monoterpene	1050	Green/fat	Floral	14.48	3.71	0.00	23.94	0.00	16.12	35.74	0.00	0.00	1.34	0.00	5.51	0.00	0.00	0.00	0.00	79.96	0.00	
gamma.-Terpinene	monoterpene	1063	Fruity	Bitter, citrus	8.49	23.80	5.71	44.10	17.37	19.65	47.42	16.95	10.97	0.00	7.88	4.16	11.41	17.12	7.92	3.55	9.00	7.36	16.96
Linalool oxide	monoterpene	1078	-	-	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.97	

Compound	Compound class	Measured retention index	Aroma category	Aroma description	A-2526T	A-2528T	A-2547T	A-2528T	A-2610T	A-2620T	A-2625T	A-2658T	A-2701T	Prime-Ark® Horizon	APF-409T	Caddo	Natchez	Onachita	Osage	Prime-Ark®-45	Prime-Ark® Traveler	Ponca	Tupuy
Linalool	monoterpene	1100	Floral	Floral, lavender, Earl Grey tea	46.29	16.34	95.03	6.57	8.53	110.58	230.31	53.08	8.55	9.67	9.62	46.22	11.56	6.17	28.50	10.20	4.20	244.96	36.47
Allocimene	monoterpene	1131	-	-	12.70	0.00	0.00	4.94	0.00	0.00	7.49	14.31	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	19.61	0.00
L-Pinocarveol	monoterpene	1153	-	-	0.00	0.00	0.00	0.00	0.00	0.00	31.31	23.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Verbenol	monoterpene	1158	Green/fat	Green	0.00	0.00	0.00	0.00	5.94	0.00	0.00	0.00	1.35	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Verbenol	monoterpene	1158	Green/fat	Green	0.00	0.00	0.00	0.00	0.00	0.00	13.52	9.66	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
alpha-Phellandrene-8-ol	monoterpene	1175	-	-	0.00	0.00	0.00	43.96	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Menthol	monoterpene	1182	Floral	Mint	0.79	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.23	0.00
endo-Borneol	monoterpene	1187	Green/fat	Camphor, fragrant, green, polish	1.54	10.53	5.22	10.68	6.42	17.99	16.30	12.50	9.24	0.00	10.48	2.00	4.53	6.84	1.97	4.81	3.52	3.49	6.98
erpinen-4-ol	monoterpene	1188	Green/fat	Earth, must, nutmeg, wood	0.00	23.11	17.55	91.03	23.93	38.47	76.02	0.00	13.51	0.00	9.26	5.01	18.60	4.16	0.00	7.33	3.43	19.98	12.07
p-Cymene-8-ol	monoterpene	1191	-	-	0.00	0.00	0.00	16.81	0.00	18.41	0.00	0.00	7.23	0.00	0.00	0.00	0.00	2.38	0.00	0.00	0.00	0.00	0.00
alpha-Terpineol	monoterpene	1200	Green/fat	Anise, fresh, mint, oil	15.03	21.85	26.05	32.82	17.73	67.45	68.01	24.78	15.12	4.71	13.23	16.45	18.65	15.05	12.52	7.45	9.28	56.16	16.74
Myrtenol	monoterpene	1208	Green/fat	Mint, cool	1.49	4.72	0.00	7.61	0.00	0.00	7.89	11.96	2.83	0.00	4.03	3.43	5.10	2.02	8.29	4.73	0.00	3.27	0.00
Pinocamphone	monoterpene	1223	Floral	Spearmint	0.00	0.00	0.00	79.88	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nerol	monoterpene	1224	Fruity	floral/fruit	1.28	0.00	0.00	0.00	0.00	0.00	0.00	10.64	0.00	0.00	0.00	12.96	14.69	0.00	4.61	2.28	0.00	8.09	0.00
Verbenone	monoterpene	1228	-	-	0.00	0.00	0.00	0.00	8.20	8.73	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Citronellol	monoterpene	1233	Floral	Rose, citrus, clove	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.79	0.00	0.00	0.00	0.00	0.00	0.00	0.78	0.00	0.00	0.00
methyl carvacrol	monoterpene	1250	Floral	Camphor, spice, wood	0.00	10.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.66	0.00
D-Carvone	monoterpene	1256	-	-	0.00	13.02	10.78	36.53	11.67	21.28	59.59	20.16	18.58	0.00	26.50	0.00	0.00	12.66	0.00	21.25	6.77	0.00	19.22

Compound	Compound class	Measured retention index	Aroma category	Aroma description	A-2526T	A-2528T	A-2547T	A-2528T	A-2610T	A-2620T	A-2625T	A-2688T	A-2701T	Prime-Ark@Horizon	APF-409T	Caldlo	Natchez	Onachita	Osage	Prime-Ark@45	Prime-Ark@Traveler	Ponca	Tupy	
Geraniol	monoterpene	1258	Floral	Geranium, lemon peel, passion fruit, peach, rose	11.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.26	0.00	0.00	19.85	0.00	16.19	0.00	0.00	35.26	0.00	
Geranial	monoterpene	1274	-	-	1.02	1.92	0.00	3.08	0.00	0.00	4.96	2.53	1.75	0.00	0.00	1.69	0.00	0.00	2.88	0.88	0.00	3.42	0.00	
Carvacrol	monoterpene	1285	Vegetal	Caraway, spice, thyme	0.00	0.00	0.00	5.61	0.00	0.00	0.00	4.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Perillic alcohol	monoterpene	1299	Green/fat	Fat, green, pungent	0.00	11.65	0.00	0.00	0.00	0.00	12.25	13.43	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.15	0.00	0.00	0.00	
Thymol or Carvacrol	monoterpene	1304	-	-	0.00	0.00	0.00	9.80	0.00	0.00	9.46	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Perillic alcohol	monoterpene	1299	Green/fat	Fat, green, pungent	0.00	0.00	0.00	28.71	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Geranylacetone	monoterpene	1458	Fruity	Fruit	1.52	4.71	1.45	2.06	1.10	2.87	2.23	1.00	0.53	0.49	1.14	0.00	2.16	0.88	2.18	1.35	1.08	2.71	0.95	
Theaspirane	Norisoprenoids	1335	Floral	Honey	4.62	3.85	2.24	1.17	2.63	3.78	0.00	0.00	0.00	12.58	1.35	0.00	4.21	3.27	8.73	11.58	5.83	0.00	8.82	
Theaspirane	Norisoprenoids	1335	-	-	3.91	5.64	1.34	1.61	1.84	4.82	0.00	2.18	0.00	11.05	0.72	0.49	2.61	2.19	7.85	8.53	5.85	0.00	7.31	
beta.-Ionone	Norisoprenoids	1502	Floral	Floral, violet	1.15	0.54	0.00	0.00	0.00	0.78	0.00	0.71	0.83	0.64	0.00	0.00	1.73	0.00	0.59	0.00	0.00	0.71	0.89	
delta.-Elemene	Sesquiterpenes	1351	-	-	0.43	0.00	0.00	0.00	0.00	0.00	0.66	0.00	0.00	0.00	0.00	0.00	0.41	0.00	0.00	0.00	0.00	2.56	0.41	
alpha.-Cubebene	Sesquiterpenes	1367	Green/fat	Herbal, wax	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.18	0.00	
delta.-Elemene	Sesquiterpenes	1381	-	-	0.00	0.00	0.00	0.00	0.00	0.00	0.90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.84	0.00	
Ylangene	Sesquiterpenes	1393	-	-	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.08	0.00	0.00	0.00	0.00	0.00	
Copaene	Sesquiterpenes	1398	Floral	Spice, wood	1.44	0.46	0.59	0.95	1.02	1.74	2.82	0.82	0.00	0.55	0.00	0.48	1.34	1.78	0.63	0.00	0.00	4.78	1.01	
.beta.-Panasinsene	Sesquiterpenes	1428	Floral	Tea	1.21	0.00	0.59	0.74	0.95	1.17	2.73	0.82	0.30	0.50	0.00	0.40	0.92	1.21	0.76	0.00	0.00	6.11	1.24	
Cadinene	Sesquiterpenes	1448	-	-	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.96	0.00	
.alpha.-Himachalene	Sesquiterpenes	1482	Fruity	Apple, oregano, anise	0.00	0.00	0.00	0.00	0.00	0.00	0.22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.43	0.00	
alpha.-Caryophyllene	Sesquiterpenes	1491	Floral	Wood	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.00	0.52	0.00	0.00	0.00	0.00	
germacrene D	Sesquiterpenes	1499	Floral	Spice, wood	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.41	0.00	
delta.-Cadinene	Sesquiterpenes	1542	Floral	Thyme, wood	0.59	0.00	0.35	0.64	1.18	4.11	2.70	1.22	0.20	0.35	0.00	0.46	0.53	0.57	0.80	0.00	0.00	1.76	0.36	
trans-Calamenene	Sesquiterpenes	1545	-	-	0.88	0.00	0.26	2.14	0.44	0.00	1.74	0.50	0.18	0.29	0.00	1.22	0.63	3.09	0.68	0.00	0.00	2.50	0.49	
alpha.-Calacorene	Sesquiterpenes	1572	-	-	0.49	0.00	0.00	0.40	0.00	0.65	0.50	0.32	0.00	0.00	0.00	0.19	0.00	0.00	0.00	0.00	0.00	0.80	0.13	
Cubebene	Sesquiterpenes	1558	Fruity	Lemon, orange, mint	0.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.17	0.00
alpha.-Cubebene	Sesquiterpenes	1660	Green/fat	Herbal, wax	1.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.64	
Di-epi-1,10-cubanol	Sesquiterpenes	1661	-	-	0.00	0.00	0.00	0.00	0.00	0.00	27.64	6.37	0.00	0.00	0.00	10.61	0.00	8.70	0.00	0.00	25.05	0.00	0.00	
alpha.-Cadinol	Sesquiterpenes	1669	-	-	5.60	0.00	0.00	3.29	0.00	0.00	13.49	1.71	0.00	0.00	0.00	6.85	0.00	0.00	0.00	0.00	29.56	0.00	0.00	
Cadalene	Sesquiterpenes	1707	Fruity	Anise, rosemary, cloves, fig	0.69	0.00	0.84	0.69	0.00	0.00	0.37	0.29	0.17	0.18	0.00	0.61	0.95	1.57	0.84	0.00	0.00	1.68	0.38	

*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
Volatile aroma compounds highlighted are top four highest levels.

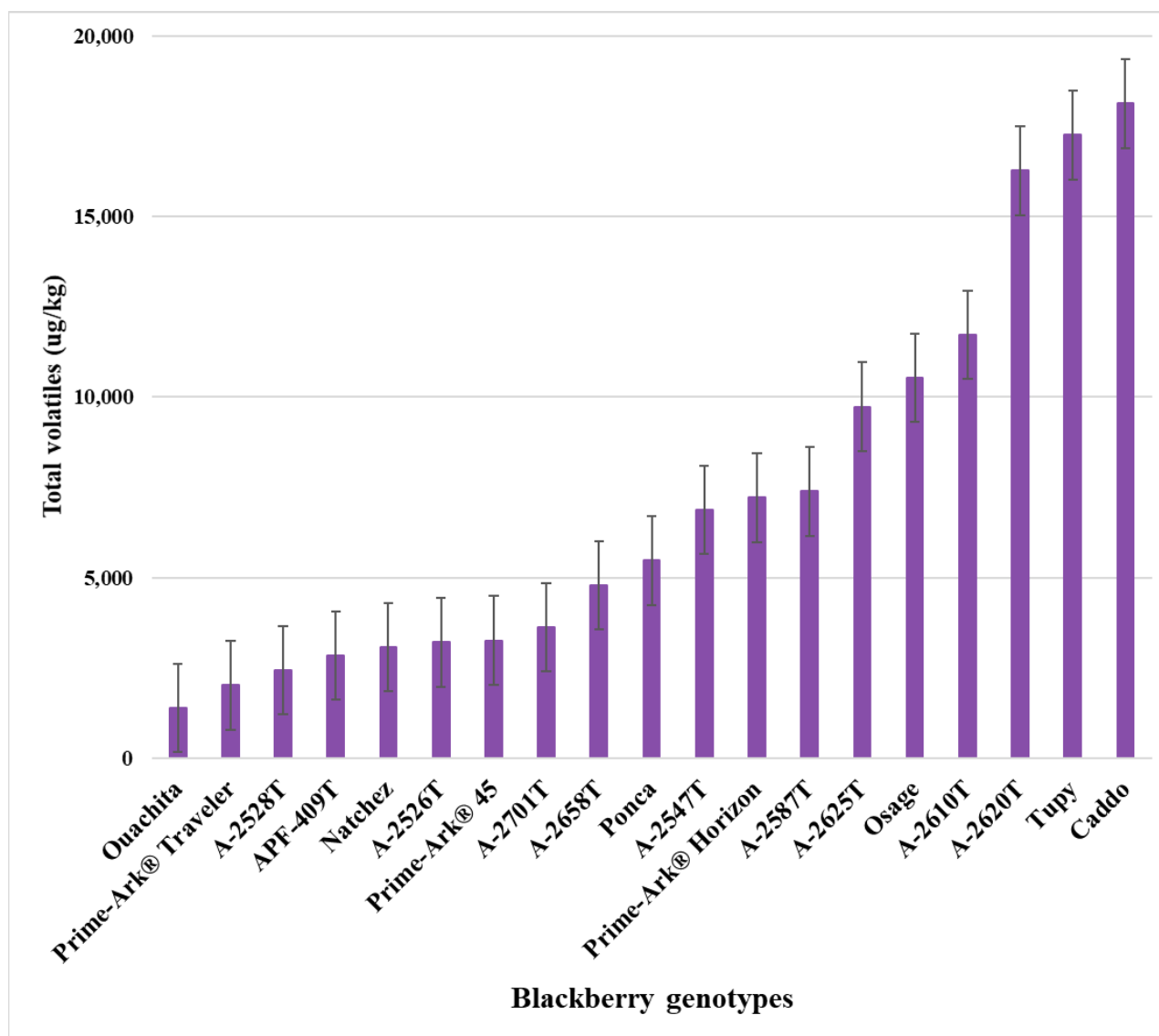


Figure 1. Total volatile aroma compounds of fresh-market blackberry genotypes, Clarksville, AR (2020)
Total volatile aroma compounds is the cumulative concentration of each class of volatile aroma compounds for each genotype.