Physiochemical and Sensory Attributes of Fresh Blackberries Grown in the Southeastern United States

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Abstract. Blackberries (*Rubus* subgenus *Rubus* Watson) are grown worldwide for commercial fresh markets. Physiochemical and sensory attributes were evaluated on fresh fruit of five blackberry cultivars (Natchez, Osage, Ouachita, Prime-Ark® 45, and Prime-Ark® Traveler) and six advanced breeding selections from the University of Arkansas Fruit Breeding Program. The physiochemical attributes of blackberries were within a commercially acceptable range (soluble solids = 8% to 11%, pH = 3.0–3.6, titratable acidity = 0.7% to 1.4%, berry weight = 6 to 14 g, drupelets/berry = 50 to 150, and pyrenes/berry = 51 to 115). ‘Natchez’ had the highest berry weight, berry length, drupelets/berry, and pyrenes/berry, whereas A-2453 was the lowest for these attributes. The highest nutraceutical levels were found in ‘Osage’ (total flavonols and total anthocyanins), A-2434 (total ellagitannins) and A-2453 (total phenolics). A trained descriptive sensory panel (n = 9) evaluated fresh blackberry attributes for appearance, basic tastes, feeling factors, aromatics, and texture using a 15-point scale (0 = less of the attribute; 15 = more of the attribute in terms of intensity). The descriptive panel identified ‘Natchez’ as having the largest descriptive size of berry with the highest overall aromatics and A-2453 as the smallest, glossiest, and firmest. Although A-2491 had the highest soluble solids, the descriptive panelists could not differentiate sweetness among the genotypes, but found A-2491 the least sour. A consumer sensory panel (n = 74) evaluated appearance, flavor, and texture attributes of blackberries on a 9-point verbal hedonic liking scale (1 = extremely dislike; 9 = like extremely) and 5-point just about right (JAR) scale (1 = not nearly enough; 3 = JAR; 5 = much too much). In terms of overall impression and overall flavor, A-2491 and ‘Prime-Ark® Traveler’ had the highest liking; average attributes for these blackberries were a berry weight of 9.1 g, soluble solids of 10.0%, titratable acidity of 0.95%, and a soluble solids/titratable acid ratio of 11.9. ‘Prime-Ark® Traveler’ also had the highest liking for appearance and berry size. A-2453, the glossiest berry, had the highest liking for berry color. Consumer panelists liked the firmness of the blackberries including those that were very firm, such as A-2453, but did not indicate differences in liking among genotypes. Consumers found the size of ‘Ouachita’, ‘Prime-Ark® Traveler’, and ‘Prime-Ark® 45’ (berry weight ≈ 8.3 g) JAR, but ‘Natchez’ (14.3 g) too large. Consumers found the sweetness and sourness of A-2491 JAR. Consumer overall impression and flavor of blackberries were positively correlated to consumer liking of berry shape and color and negatively correlated to the descriptive attributes for sourness, bitterness, green/unripe aromatic, and amount of seeds. Consumer liking of appearance was positively correlated with consumer liking of berry size, shape, color, and descriptive uniformity of color and glossiness. To produce a commercially marketed fresh-market blackberry, there are many characteristics that are important, but our data for these genotypes suggest that a desired blackberry should have a berry weight of 8–10 g, soluble solids of 9% to 11%, titratable acidity of 0.9% to 1%, and a soluble solids/titratable acid ratio of 10 to 13. However, optimum sugar and acidity levels require more investigation including other factors in flavor and aromatics. Evaluating the physiochemical and sensory attributes of fresh fruit is an important tool that can be used to determine commercial potential for selections and cultivars.

Blackberries (*Rubus* subgenus *Rubus* Watson) are a high-value specialty crop grown worldwide for fresh market and processing. Fresh blackberry fruit has potential for an increased role in commercial markets due to the increase of production and consumer demand for this flavorful, nutraceutical-rich fruit. In 2005, world blackberry production area was 20,036 ha and was projected to increase to over 27,000 ha by 2015 (Strik et al., 2007). The increase in production can be contributed in part to blackberry breeding programs that have enhanced desirable traits and reduced undesirable traits in plants and fruit. Since 1985, over 60 blackberry cultivars have been released from breeding programs in the United States (Clark, 1999; Clark and Finn, 2008). In 2014, 2469 ha of blackberries were harvested in the United States including ≈ 1400 t of fresh-market blackberries (USDA, 2014).

In the southeastern United States, the University of Arkansas System Division of Agriculture has been the primary blackberry breeding program providing cultivars with unique and improved traits incorporated into adapted genotypes (cultivars and advanced, nonreleased selections). Breeding traits of interest in fresh-market blackberries include enhanced fruit quality, flavors, and shipping capabilities and plant thornlessness, productivity, adaptation/habit, and disease/pest resistance (Clark, 2005, 2008; Clark and Finn, 2008; Clark and Perkins-Veazie, 2011; Finn and Clark, 2012; Lewers et al., 2010). The breeding program released the first primocane-fruited cultivars, plants that produce fruit on first-year canes in addition to second-year floricanes. ‘Prime-Jim®’, ‘Prime-Jan®’, ‘Prime-Ark® 45’, and more recently ‘Prime-Ark® Traveler’ are primocane-fruited releases from the University of Arkansas (Clark and Finn, 2008).

Blackberry is an aggregate fruit comprised of drupelets surrounding a soft tissue receptacle or torus. The size of a blackberry is determined by the combination of torus size, drupelet number, and size of drupelets (Clark et al., 2007). Each drupelet has a thin exocarp, a fleshy mesocarp, and a hard, lignified endocarp (or pyrene) that encloses a single seed (Tomlik-Wyremblewska et al., 2010). Pyrene characteristics are distinctive to each blackberry genotype and based on the shape of the raphe, have been classified into three groups: straight, concave, or convex (Wada and Reed, 2010; Wada et al., 2010). Slight variation of pyrene shape can occur in the same genotype, and the outer layer of the endocarp will have characteristic patterns of reticulation (Tomlik-Wyremblewska et al., 2010; Wada et al., 2010). Pyrene shape and endocarp thickness influence perceived seediness when consumed (Takeda, 1993). Pyrene weight and pyrene number were positively correlated with blackberry fruit weight (Moore et al., 1974). Moore et al. (1975) found that pyrene size in blackberries is highly heritable with partial dominance for small pyrene size.

Like other dark-pigmented fruits, blackberries are a source of nutraceutical-rich

components that can positively impact human health (Clark et al., 2002; Conner et al., 2005; de Souza et al., 2014; Howard and Hager, 2007; Manganaris et al., 2014; Moyer et al., 2002; Radočaj et al., 2014; Reyes-Carmona, et al., 2005; Sariburun et al., 2010; Seeram, 2008; Sellappan, et al., 2002; Siriwoharn et al., 2004; Wang et al., 2009). High levels of anthocyanins, a polyphenolic antioxidant, naturally occur in blackberries and account for the dark red pigmentation of the fruit (Wang et al., 2009). Polyphenols, including anthocyanins, proanthocyanidins, flavonones, and flavonols, also have properties that could positively impact human health (Ness and Poulens, 1997; Prior et al., 1998; Reyes-Carmona et al., 2005; Steinmetz and Potter, 1996). Radočaj et al. (2014) investigated the nutraceutical content of seed oil extracted from dried blackberry press pomace. Despite their healthy properties, these potential nutraceutical components can impact fruit quality and sensory perception. Phenolic compounds are also relevant as they play a role in the bitterness, sweetness, or astringency of products and contribute to aroma (Tomás-Barberán and Espín, 2001).

Fruit attributes such as sweetness, tartness, flavor, and astringency along with color, firmness, and seediness are important to consumers (Clark et al., 2007; Clark and Finn, 2008; Hall et al., 2002). In general, consumers prefer fresh blackberries that are perceived as less “seedy” (fewer, smaller, and/or softer pyrenes). The structure, size, and number of pyrenes in the blackberry may influence mouthfeel of the blackberries when consumed (Clark et al., 2007). Small pyrene size (<3.0 mg) is preferred in both fresh-market and processed blackberry products, and large pyrenes can be objectionable (Moore et al., 1975). Large pyrene size, based on weight, length or volume, and seediness is also undesirable in processed blackberry products (Takeda, 1993). Fresh-market blackberries can feel “seedy” when consumed, depending on pyrene attributes.

Harrison et al. (1999) established sensory descriptors for the flavor of raspberries and suggested the potential use of sensory characteristics for breeding selections. Some sensory research has been done to profile processing blackberries grown in the northwestern United States. Kurnianta et al. (2005) evaluated 10 thornless blackberry selections in comparison with the standard ‘Marion’ and developed a lexicon of 21 aroma descriptors for floral, fresh fruit, cooked fruit, vegetal, grainy, vinyl,

wet cardboard, and basic tastes/mouth feel. Du et al. (2010b) found the 11 thornless blackberries genotypes from the Pacific Northwest had diverse descriptive sensory aroma profiles. Du et al. (2010a) also profiled the flavor of ‘Marion’ blackberries using instrumental and sensory analysis. de Souza et al. (2014) profiled sensory attributes of blackberries that had been frozen/thawed using different methods as compared with a fresh control. Cavender et al. (2014) investigated the sensory profiles and antioxidant properties of blackberries grown using different weed management strategies.

More research is needed to determine attributes of the fresh-market blackberries that consumers want for blackberries that are or will be commercially available. Therefore, the objective of this work was to evaluate the physiochemical and sensory attributes of fresh-market blackberries developed from southeastern U.S. germplasm and grown in the southeastern United States.

Materials and Methods

Fruit

Blackberries were harvested from the University of Arkansas Fruit Research Station, Clarksville. The blackberries were harvested at the shiny-black stage of ripeness and were free of major blemishes, flaws, or damage. Fruit were hand-harvested from the plants in June 2014. About 4 kg of fruit was harvested from each of the 11 genotypes, five cultivars (Natchez, Osage, Ouachita, Prime-Ark® 45, and Prime-Ark® Traveler), and six selections (A-2416, A-2418, A-2434, A-2450, A-2453, and A-2491). Six genotypes were harvested on 23 June and five genotypes were harvested on 1 July. Air temperatures were the same for both harvests. On the first harvest date, there was a light rain early in the morning, but the harvest was delayed until the fruit was dry. On both dates, the fruit was harvested by 11:00 AM. Fruit was harvested directly into 240-g (pint), low-profile vented clamshells, placed in chilled coolers and transported to the Department of Food Science, Fayetteville. A random sample of fruit was collected from the harvest clamshells and used for the sensory and physiochemical analysis. A 100 g sample of each genotype was frozen (−20 °C) in triplicate for physiochemical analysis, and the remainder was stored overnight in clamshells at 2 °C for sensory analysis.

Physiochemical analysis

Evaluations for physiochemical attributes of blackberries were done at the Department of Food Science, University of Arkansas, Fayetteville. Three samples of ≈100 g of berries from each genotype were stored at −20 °C until analyzed.

Berry and pyrene attributes. From the frozen berries, three randomly selected berries per genotype and replication were used to determine berry attributes (individual weight, length, width, and drupelets/berry) and pyrene attributes (number/berry and weight/berry). The three-berry samples were weighed on

a digital scale (Explorer, Ohaus Corporation, Parsippany, NJ), and the width and height (at the widest or longest sections of the berry) of each blackberry was measured with a digital caliper.

To determine pyrene attributes, a 0.1 mL of Pec5L enzyme (Scott Laboratories, Petaluma, CA) was added to each bag containing the three-berry frozen sample to break down the skin and pulp. Once the berries thawed, they were hand mashed in the bags. After 1.5 h at 21 °C, distilled water was added to each bag. The samples were then poured into a strainer. Under running water, the pulp was mashed against the strainer until only pyrenes remained. The pyrenes were placed onto paper towels and dried at ambient temperature (21 °C) for 1.5 h. The pyrenes for each three-berry sample were counted and weighed. The pyrenes were further dried in a laboratory oven (Isotemp®, Model 655F; Fischer Scientific, Pittsburg, PA) at 55 °C for ≈24 h, then removed and weighed.

Composition analysis. Three-berry samples of each genotype were used in triplicate to determine the soluble solids, pH, and titratable acidity. Samples were thawed, placed in cheesecloth, and squeezed to extract the juice from the berries. Titratable acidity and pH were measured by an 877 Titrino Plus (Metrohm AG, Herisau, Switzerland) standardized to pH 2.0, 4.0, 7.0, and 10.0 buffers. Titratable acidity was determined using 6 g of juice diluted with 50 mL of deionized, degassed water by titration with 0.1 N sodium hydroxide to an endpoint of pH 8.2; results were expressed as percent citric acid. Total soluble solids (expressed as percent) were measured with a Bausch & Lomb Abbe Mark II refractometer (Scientific Instrument, Keene, NH).

Nutraceutical analysis. Nutraceutical analysis was done on each genotype in triplicate. To obtain sample extracts, samples (25 g) were homogenized with 20 mL of acetone/water/acetic (70:29.5:0.5 v/v/v) with a Euro Turrax T18 Tissuemizer (Tekmar-Dohrman Corp., Mason, OH). The samples were filtered through Miracloth (Calbiochem, La Jolla, CA), the filter cakes were isolated and the extraction was repeated. This extraction process was repeated with methanol/water/formic acid (60:37:3 v/v/v). The filtrates were adjusted to a final volume of 250 mL with extraction solvent to assure complete extraction of the nutraceutical compounds.

Ellagitannins and flavonols. Sample extracts (3 mL) were dried using a Speed Vac concentrator (ThermoSavant, Holbrook, NY) and resuspended in 0.5 mL of extraction solvent. The reconstituted samples were passed through 0.45 µm polytetrafluoroethylene syringe filters (Varian, Inc., Palo Alto, CA) before high-performance liquid chromatography (HPLC) analysis. The ellagitannins were analyzed on a Waters Alliance HPLC system (Milford, MA) equipped with a Waters model 996 photodiode array detector and Millennium version 3.2 software (Waters Corp., Milford, MA). Separation was performed using a Phenomenex Aqua 5 µm C₁₈ (250 ×

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4.6 mm) column (Torrance, CA) with a binary gradient of 2% acetic acid for mobile phase A and 0.5% acetic acid in water/acetonitrile (1:1 v/v) for mobile phase B at a flow rate of 1.0 mL·min⁻¹. A linear gradient was run from 10% to 55% B (0–50 min), from 55% to 100% B (50–60 min), and from 100% to 10% B (60–65 min). The ellagitannins and flavonols were identified on the basis of comparison of HPLC retention times to our previous HPLC results obtained using the identical HPLC conditions and liquid chromatography–mass spectrometry analysis (Hager et al., 2008a; 2010). The ellagitannin peaks were quantified at 255 nm as ellagic acid equivalents using external calibration curves of ellagic acid, with results expressed as milligram ellagic acid equivalents per 100 g of fresh berry weight. The flavonols were quantified at 360 nm as rutin with results expressed as equivalents per 100 g of fresh berry weight.

Anthocyanins. Sample extracts (3 mL) were dried using a Speed Vac concentrator and resuspended in 2 mL of 3% formic acid. The reconstituted samples were filtered through 0.45 µm PTFE syringe filters (Varian, Inc., Palo Alto, CA) before HPLC analysis. The anthocyanin analysis by HPLC was performed based on previous methods (Cho et al., 2004; Hager et al., 2008b) with a 250 × 4.6 mm Symmetry C₁₈ column (Waters Corp.). The mobile phase consisted of a binary gradient of 5% formic acid (A) and 100% methanol (B). The flow rate was 1.0 mL·min⁻¹ with a linear gradient from 2% to 60% B over 60 min. The anthocyanin peaks were quantified at 510 nm using a photodiode array detector. All anthocyanins (cyanidin 3-glucoside, cyanidin 3-rutinoside, cyanidin 3-xyloside, cyanidin 3-malonylglucoside, and cyanidin 3-dioxalylglucoside) were quantified as cyanidin 3-glucoside (acy) equivalents with total monomeric anthocyanins results expressed as milligrams per 100 g of fresh berry weight.

Total phenolics. Total phenolics were measured using the Folin–Ciocalteu assay (Slinkard and Singleton, 1977) with a gallic acid standard and a consistent standard curve based on serial dilutions. Absorbencies were measured at 760 nm, and results were expressed as milligrams per 100 g of fresh berry weight of gallic acid equivalents.

Descriptive and consumer sensory analysis

Descriptive and consumer sensory analyses of the fresh blackberries were performed at the Sensory and Consumer Research Center at the University of Arkansas, Fayetteville, the day after each harvest. Six genotypes were sensory evaluated in the first week of harvest, then five genotypes were evaluated after harvest the next week. The genotypes were evaluated on two different dates to avoid panel fatigue. Before serving, the blackberries were gently rinsed, placed on trays lined with paper towels, and allowed to air-dry. For descriptive and consumer sensory analysis, each panelist evaluated three to five berries for each genotype. The blackberry samples were served

sequentially monadically at room temperature (24 °C) with random three-digit codes in a randomized complete block design. Panelists were instructed to cleanse their palates with unsalted crackers and water between samples. Expectorant cups were also provided. In both the descriptive and consumer analysis, the panelists evaluated aspects of the pyrenes in the blackberries, but used the term “seeds.”

Descriptive analysis. The trained panelists for this descriptive sensory analysis had over 8 years of experience working together to descriptively evaluate a wide range of products and were paid on an hourly basis. The panelists were trained to use a modified Sensory Spectrum® method, an objective method for describing the intensity of attributes in products using references for the attributes. The descriptive panelists (n = 9) developed a lexicon of sensory terms for blackberries through consensus (Table 1; Fig. 1) during orientation and practice sessions and evaluated the genotypes in duplicate. Serving order was randomized across each duplication (replication) to prevent presentation order bias. Descriptive panelists were trained with an absolute scale anchored by references. The panelists assessed each attribute per genotype and replication at a particular intensity according to the reference points and using the universal aromatic scale. The descriptive panel identified fresh blackberry attributes for appearance (n = 8), basic tastes (n = 3), feeling factors (n = 2), aromatics (n = 8), and texture (n = 7) and evaluated those attributes using a 15-point scale (0 = less of the attribute; 15 = more of the attribute in terms of intensity). The uniformity of the berries for flavor and texture was included in the lexicon and evaluated, but the data were not presented. The reference for the color of the blackberries was from the Royal Horticulture Society Colour Chart (fifth edition, London) Black Group 203A = 15.0 score for intensity. The 203A had values of $L^* = 34.32$, $C^* = 5.16$, $h = 284.04$, $a = 0.87$, and $b = 3.65$.

Consumer analysis. Consumers (n = 74) were recruited from a database (n ≈ 5500) based on consumption and purchasing habits and liking of fresh blackberries. Consumers selected for this study indicated they purchase fresh blackberries at least once a month and that they like blackberries. All 74 consumers evaluated the 11 genotypes and were paid with gift card incentives. The consumer panel was comprised of 13 males and 61 females ages 18 to over 65 years from a range of incomes from less than \$15,000 to more than \$100,000. The consumers were also asked questions regarding purchase and consumption habits for fresh blackberries, where multiple responses were allowed. The consumers evaluated appearance, size, shape, color, overall impression, overall flavor, and firmness of blackberries on a 9-point verbal hedonic scale (1 = extremely dislike; 9 = like extremely). The consumers also evaluated size, blackberry flavor, sweetness, sourness, bitterness, astringency, firmness, crispness,

and seediness of blackberries on a 5-point JAR scale (1 = not nearly enough; 3 = JAR; 5 = much too much). The consumers evaluated the appearance of blackberry attributes before tasting the samples. Consumer responses were collected via Compusense 5 (version 4.6; Compusense, Guelph, Canada).

Statistical design and analyses

After harvest, the fruit from each of the 11 genotypes was randomly selected for physicochemical and sensory analysis. The physicochemical and sensory data were analyzed by analysis of variance. Associations among all dependent variables were determined using multivariate pairwise correlation coefficients of the mean values using JMP® (version 12.0; SAS Institute, Cary, NC). Correlations were used to test the relationship between/within physicochemical attributes and sensory attributes, with significant correlations reported ($P = 0.05$). To relate consumer liking data with descriptive and analytical data, principal component regression was performed using JMP®.

Physicochemical. For the physicochemical data, the genotypes were evaluated in triplicate and data were analyzed using JMP®. Tukey's honestly significant difference was used for mean separation ($P = 0.05$).

Sensory. For descriptive analysis, the genotypes were evaluated by nine panelists in duplicate. For the consumer analysis, the genotypes were evaluated by 74 consumer panelists. Least significant difference was used for mean separation ($P = 0.05$) of the sensory data in a customized reporting system. To identify blackberry attribute improvements, penalty analysis was performed using the JAR data for the highest scored genotype in terms of overall liking using JMP® and Microsoft Excel (Microsoft Office 365; Microsoft, Seattle, WA).

Results and Discussion

The challenge of this research was to plan a complete study for a fresh-market crop with variable harvest times and unpredictable weather for harvest, particularly when arranging with sensory evaluations. Eleven blackberry genotypes (five cultivars and six selections) from the University of Arkansas Fruit Breeding Program were evaluated for physicochemical and sensory attributes. This is one of the first research publications on fresh blackberry genotypes to comprehensively compare physicochemical attributes (berry and pyrene attributes, composition, and nutraceutical content) of blackberries with sensory attributes (descriptive and consumer sensory).

Physicochemical analysis

Berry and pyrene attributes. The berry and pyrene attributes of the blackberries varied significantly by genotype, particularly size attributes. The blackberries had berry weights from 6.0 to 14.3 g, berry lengths from 27.5 to 43.7 mm, berry widths from 22.2 to 26.9 mm, drupelets/berry from 50.2 to 125.8,

Table 1. Lexicon developed for fresh-market blackberry attributes by a descriptive sensory panel with nine trained panelists.

Term	Definition	Technique	Reference
Appearance			
Color	The degree of black in the sample	Observe the sample and rate the degree to which the sample is black in appearance (red to black).	Black group, 203 A = 15.0 Royal Horticultural Society Colour chart
Uniformity of color	The amount of red drupelets vs. black drupelets in the sample	Observe the sample and rate the degree to which the sample is uniform in appearance (ununiform to uniform).	Ratio of red to black drupelets 0% = 0, 50% = 7.5, 100% = 15
Size of berry	The visual size of the overall sample	Observe the sample and determine the overall size of the sample (small to large).	A = 5.0, B = 10.0 (Fig. 1)
Size of drupelets	The visual size of the drupelets on the berry	Observe the sample and determine the overall size of the drupelets on the sample (small to large).	C = 4.0, B = 12.0 (Fig. 1)
Uniformity of drupelets	The amount of small vs. large drupelets in the sample	Observe the sample and rate the degree to which the drupelets are uniform in appearance (ununiform to uniform).	C = 7.0, B = 13.0 (Fig. 1)
Amount of styles	The visual amount of styles on the sample	Observe the berry and determine the amount of styles on the surface of the sample (none to much).	Raspberry = 12.0
Amount of blemishes/deformities	The visual amount of blemishes/deformities on the sample	Observe the berry and determine the amount of blemishes/deformities on the surface of the sample (none to much).	Ratio of deformed drupelets to normal drupelets 0% = 0, 50% = 7.5, 100% = 15
Glossy	The degree to which the surface of the berry shines	Observe the sample and determine the degree to which the surface shines (dull to wet/shiny).	Raspberry = 3.0, glossy photo paper = 15.0
Basic tastes			
Sweet	The basic taste, perceived on the tongue, stimulated by sugars and high-potency sweeteners	Solutions of sucrose in spring water	2% = 2.0, 5% = 5.0, 10% = 10.0, 16% = 15.0
Sour	The basic taste, perceived on the tongue, stimulated by acids, such as citric acid	Solutions of citric acid in spring water	0.05% = 2.0, 0.08% = 5.0, 0.15% = 10.0, 0.20% = 15.0
Bitter	The basic taste, perceived on the tongue, stimulated by substances such as quinine, caffeine, and certain other alkaloids	Solutions of caffeine in spring water	0.05% = 2.0, 0.08% = 5.0, 0.15% = 10.0, 0.20% = 15.0
Aromatics			
Overall aromatic impact	The overall impact of all aromatics in the berry	Combination of all aromatics	Intensities based on universal scale ^z
Blackberry	The aromatic associated with blackberries	Fresh blackberries, blackberry jam	Intensities based on universal scale
Earthy/dirty	The aromatic associated with damp soil or wet foliage	Damp potting soil, allspice	Intensities based on universal scale
Green/unripe	The aromatic associated with freshly cut green vegetation; unripe	Unripe banana	Intensities based on universal scale
Overripe/fermented	The aromatic associated with overripe fruit	Over ripened fruit	Intensities based on universal scale
Chemical	Any of a variety of off-flavors associated with petroleum, sulfur, wet paper, paint, alcohol, soap, resin, solvents, wax, etc.	Combination of a variety of chemical off-flavors	Intensities based on universal scale
Mold/mildew	The aromatic associated with moldy or mildew aromas	Old mildewed clothes	Intensities based on universal scale
Metallic	The aromatic associated with metals, tinny or iron	Canned pineapple (sniff can only)	Intensities based on universal scale
Feeling factors			
Astringent	The feeling factor on the tongue or other surfaces of the mouth described as puckering or drying	Chew sample to point of swallow, expectorate, and feel surfaces of the mouth. Swish references in mouth, swallow, or expectorate and wait 5 s.	0.053 g alum/500 mL water = 6.0
Metallic	The aromatic associated with metals, tinny, or iron or a flat chemical feeling factor stimulated on the tongue by metal coins	Tin foil to bite	Intensities based on universal scale
Texture			
Firmness	The force required to compress the sample.	Compress or bite through sample one time with molars or incisors (soft to hard).	Cream cheese = 1.0, egg white = 2.5, American cheese = 4.5, beef frank = 5.5, olive = 7.0, peanut = 9.5, almond = 11.0

(Continued on next page)

Table 1. (Continued) Lexicon developed for fresh-market blackberry attributes by a descriptive sensory panel with nine trained panelists.

Term	Definition	Technique	Reference
Moisture release	The amount of wetness or moistness felt in the mouth after one bite or chew	Compress sample with molars one time only (dry to wet).	Banana = 1.0, carrot = 2.0, mushroom = 4.0, snap beans = 7.0, cucumber = 8.0, apple = 10.0, honeydew = 12.0, orange = 15.0 (chew reference five times)
Popping/bursting	The degree the drupelets pop/burst while chewing	Chew the sample and evaluate the degree the drupelets pop/burst while chewing (none to much).	Pomegranate seeds = 12.0
Size of seeds	The amount of space a particle fills in your mouth. How big are the seeds?	A = sesame seeds, B = dill seeds (small to large).	A = 5.0, B = 9.0
Amount of seeds	The number of seeds in your mouth	0.4 g dill seed/10 g apple sauce; $\approx$ 182 seeds (none to much).	B = 7.0
Toothpack	The amount of product packed into the crowns of your teeth after mastication	Chew sample 4–5 times, expectorate and feel the surface of the crowns of the teeth to evaluate (none to much).	Cap'n Crunch® cereal = 5.0, Heath bar® = 10.0
Loose particles	The amount of particles remaining in and on the surface of the mouth after swallowing	Chew sample with molars, swallow and evaluate (none to much).	Carrot = 10.0
Uniformity			
Uniformity of flavor	How uniform is the entire sample in aromatics	After tasting all four berries on your plate, how uniform are the aromatics over the four berries? (Ununiform to uniform)	Ratio of low to high 0% = 0, 50% = 7.5, 100% = 15
Uniformity of texture	How uniform is the entire sample in texture	After tasting all four berries on your plate, how uniform is the texture over the four berries? (Ununiform to uniform)	Ratio of low to high 0% = 0, 50% = 7.5, 100% = 15

*Intensities based on universal scale (saltine = 3.0; applesauce = 7.0; orange juice = 10.0; grape juice = 14.0; Big Red Gum® = 15.0).

pyrene weight/berry from 0.18 to 0.43 g, and pyrenes/berry from 51.0 to 115.0 (Table 2). 'Natchez' had the greatest berry weight, berry length, drupelets/berry, pyrene weight/berry, and pyrenes/berry. 'Natchez' has been one of the most widely planted of the Arkansas-released cultivars in the past 5 years due to its large size and early ripening (J.R. Clark, personal communication). A-2453 had the smallest berry weight, berry length, drupelets/berry, pyrene weight/berry, and pyrenes/berry. Although A-2453 had lower yields than other University of Arkansas cultivars limiting its commercial potential, it is valuable as a parent due to unique firmness and postharvest potential (J.R. Clark, personal communication).

There were many correlations within berry and pyrene attributes. Berry weight and length was significantly correlated ($r = 0.73$ – 0.93) to drupelets/berry, pyrene weight/berry, and pyrenes/berry. Moore et al. (1974) also found that pyrene weight and number were positively correlated with blackberry weight. Drupelets/berry was correlated to pyrene weight/berry ($r = 0.88$) and pyrenes/berry ($r = 0.96$), whereas pyrene weight/berry and pyrenes/berry were also highly correlated ($r = 0.96$). The bigger the berry, like 'Natchez', especially in length, the more the drupelets, and pyrenes, whereas the opposite occurred with a smaller berry like A-2453.

Composition. Composition values were within a commercially acceptable range for fresh blackberries (Table 2). The blackberries had soluble solids levels 8.1% to 11.0%, pH values from 3.0 to 3.6, titratable acidity from 0.7% to 1.4%, and soluble solids/titratable acidity ratio of 6.2 to 16.5. When working on blackberry development in the Arkansas breeding program, the goal of the blackberry

breeding program is to have a titratable acidity no greater than 1% (J.R. Clark, personal communication). Reyes-Carmona et al. (2005) evaluated blackberry genotypes in Mexico and United States and found soluble solids from 7.5% to 16.1%, pH from 2.3 to 4.3 and titratable acidity from 1.0% to 4.2%; according to these authors, blackberry composition was strongly dependent on genotype rather than climate or season.

The influence of soluble solids and titratable acidity on perceived flavor is complex in a blackberry matrix. A-2491 had the highest soluble solids and A-2418 had the lowest, while A-2418 had the highest titratable acidity and 'Ouachita' had the lowest (Table 2). Soluble solids/titratable acidity ratio is often used to determine the balance of perceived sweetness or sourness in a product. 'Ouachita' had the highest soluble solids/acid ratio (16.5), A-2418 had the lowest (6.2), but A-2491 (highest soluble solids) had a soluble solids/titratable acidity ratio of 13.5. According to Crisosto and Crisosto (2005), the relationship between titratable acidity and soluble solids has an important role in consumer acceptance of other fruits like peaches and nectarines [*Prunus persica* (L.) Batsch]; in their study consumer acceptance was influenced by the balance between titratable acidity and soluble solids rather than soluble solids alone. Compared with other fruits, blackberries have a low soluble solids/titratable acidity ratio. de Souza et al. (2014) showed that the average soluble solids/titratable acidity ratio of blackberries was 6.7, whereas the optimum soluble solids/acid ratio for muscadine grapes (*Vitis rotundifolia* Michaux) was $\approx$ 30, with 25 to 35 being acceptable (Flora, 1979; Walker et al., 2001). The soluble solids/titratable acidity ratios of

blackberries are lower than muscadine grapes because the soluble solids of blackberries are $\approx$ 50% lower than muscadines and the titratable acidity of blackberries is more than muscadines. The pH of the blackberries was negatively correlated to the titratable acidity ($r = -0.91$), but soluble solids were not significantly correlated to pH or titratable acidity. As expected, the soluble solids/titratable acidity ratio was positively correlated to the soluble solids ($r = 0.66$) and pH ($r = 0.84$) and negatively correlated to titratable acidity ($r = -0.95$). Thus, in terms of solids/titratable acidity ratio, we consistently found weak correlations with soluble solids compared with stronger correlations with titratable acidity because titratable acidity can have four times the impact on ratio for blackberries.

Nutraceutical content. The blackberries had total ellagitannins content from 20.6 to 45.4 mg ellagic acid equivalent/100 g, total flavonols from 7.7 to 16.1 mg rutin equivalent/100 g, total anthocyanins from 55.4 to 247 mg acy/100 g, and total phenolics from 434 to 606 mg gallic acid equivalent/100 g (Table 3). The phenolic contents varied greatly among genotypes. Siriwoharn et al. (2004) evaluated blackberry genotypes from the northwestern United States and found similar results with total ellagitannins from 7.7 to 27.2 mg ellagic acid equivalent/100 g, total flavonols from 4.0 to 8.7 mg rutin equivalent/100 g, total anthocyanins from 131 to 256 mg acy/100 g, and total phenolics from 682 to 1040 mg gallic acid equivalent/100 g. Benvenuti et al. (2004) found 67 to 119 mg acy/100 g for total anthocyanins and 193 to 352 mg gallic acid equivalent/100 g for total phenolics in blackberries. 'Osage' had the highest total flavonols and

Fig. 1. Reference used by the descriptive panel to score the size of blackberries (A = 5 with berry length of 25 mm and B = 10 with berry length of 40 mm), size of drupelets of the blackberries (C = 4 and B = 12), and uniformity of drupelets of the blackberries (C = 7 and B = 13) on a 15-point scale.

total anthocyanins. ‘Prime-Ark® Traveler’ had the lowest total flavonols and total anthocyanins, and ‘Ouachita’ had the lowest total ellagitannins and total phenolics. A-2434 had the highest total ellagitannins. A-2453 had the highest total phenolics, but was the smallest berry with a relatively high soluble solids level and low titratable acidity. Total phenolics was slightly correlated to total ellagitannins ($r = 0.61$) and total flavonols ($r = 0.75$).

Comparisons among physiochemical attributes. There were not many significant correlations among the physiochemical attributes (berry and pyrene attributes vs. composition vs. nutraceutical content). However, titratable acidity and soluble solids/titratable acidity ratio was correlated with pyrene weight/berry ($r = 0.71$ and $r = -0.72$, respectively) and pyrenes/berry ($r = 0.65$ and $r = -0.68$, respectively), indicating that blackberries with more and larger pyrenes had higher titratable acidity and lower soluble solids/titratable acidity ratio among these genotypes. The correlation between titratable acidity and soluble solids/titratable acidity ratio and pyrenes was significant, titratable acidity and soluble solids/titratable acidity ratio differences could be attributed to the number of pyrenes. Since titratable acidity is a significant attribute for blackberries, the relationship between pyrenes and titratable acidity should be further investigated. The blackberry pH was negatively correlated with berry length ($r = -0.64$), but this was the only size attribute of the berry with correlations to composition. With the genotypes in our study, the bigger the blackberry, the lower the pH and higher titratable acidity. This relationship may not be found if other genotypes are investigated.

Sensory analysis

Descriptive sensory analysis. The lexicon developed by the descriptive panel included references used by the panelists to evaluate the appearance, basic tastes, feeling factors, aromatics, and texture of fresh blackberries (Table 1). This lexicon can be used by other

programs to evaluate the attributes of fresh blackberries or modified for use with other fresh fruit.

Appearance attributes. The appearance attributes of blackberries are an important attribute for fresh market because consumers can purchase blackberries based on appearance in a clamshell container. The appearance attributes of the blackberries evaluated included color, uniformity of color, size of berry, size of drupelets, uniformity of drupelets, amount of styles, amount of blemishes, and glossiness (Table 4). The color of the blackberries was scored in the black range. The uniformity of color was 87% to 94% indicating mostly black berry and drupelet color. Some red drupelets were present on some genotypes of the berries stored overnight at 2 °C before evaluation. The descriptive panel scored the size of the berries from 7.1 to 12.1 on the 15-point scale as compared with standards with berry length of 25 mm = 5 to 40 mm = 10 (Fig. 1). ‘Natchez’ was the largest berry and A-2453 the smallest. A-2491 had larger and more uniform drupelets. ‘Prime-Ark® 45’ had the smallest drupelets and ‘Ouachita’ had the least uniform drupelets on a berry. A-2453 was perceived to have the least amount of styles on a berry, whereas ‘Ouachita’ had the most. The amount of blemishes on the berries were low (0% to 25%) with A-2453 the least. The glossiness of the berry was based on standards of commercially purchased fresh raspberries = 5 (dull/matte in appearance) and glossy photo paper = 15 with values of the genotypes ranging from 8.4 to 12.2. The descriptive panel identified A-2453 as the glossiest berry (Fig. 2A).

Basic tastes. The panelists evaluated the basic tastes (sweet, sour, and bitter) of the blackberries (Table 5). The panelists found the sweetness of the blackberries ranged from 3.6 to 4.4 with a 2 = 2% sucrose solution and 5 = 5% sucrose solution. Although berry soluble solids levels ranged from 8% to 11%, panelists found no significant differences

in descriptive sweetness among the genotypes. In terms of sourness, the berries ranged from 3.8 to 5.4 with 2 = 0.05% citric acid solution and 5 = 0.08% citric acid solution. The blackberries were very low in bitterness (1.9 to 2.6 with a 2 = 0.05% solution of caffeine in water). A-2491 was rated as the least sour and bitter and A-2416 as the most sour. As compared with A-2491, A-2416 had 1.5% less soluble solids, 0.3% more titratable acidity, and 30% less soluble solids/titratable ratio.

Feeling factors. The panelists evaluated the feeling factors (astringent and metallic) of the blackberries and found no differences among the genotypes. The genotypes were about the same level of astringency with a reference of 0.53 g alum/500 mL water (≈ 6). The metallic feeling factors (biting into tin foil as a reference) of the blackberries were low.

Aromatic attributes. The aromatic attributes (volatiles perceived by the olfactory system while chewing a sample in the mouth) of the blackberries included overall aromatic impact, blackberry, earthy/dirty, green/unripe, overripe/fermented, chemical, mold/mildew, and metallic (Table 5). The intensity of overall aromatics ranged from 7.6 to 8.2, with ‘Natchez’ having the highest intensity. There was no difference in the genotypes for blackberry, mold/mildew, or metallic aromatics. The overripe/fermented, chemical, earthy/dirty, and green/unripe aromatic intensities were very low. Wang et al. (2005) found that berries grown in two different regions (Oregon vs. Arkansas) had similar composition, but had differences in volatile aroma compounds. The aromatic attributes play a key role in the “taste” of the blackberries, and overall aromatic impact and blackberry aromatics were the highest scored intensities in the midrange of the 15-point scale.

Texture attributes. The texture attributes included firmness, moisture release, popping/bursting, size of seeds, amount of seeds, toothpack, and loose particles (Table 5). The descriptive panel differentiated firmness of the berries (3.1 to 4.2 with references of egg white = 2.5 and American cheese = 4.5) and popping/bursting (degree the drupelets pop/burst as compared with pomegranate seeds = 12). A-2453 was the most firm, and ‘Natchez’ and ‘Prime-Ark® 45’ were the least firm (Fig. 2B). A-2453 had a significantly higher popping/bursting attribute as compared with the other genotypes, which is a unique trait of this genotype. The berries were moist (7.9 to 8.6) as compared with cucumber = 8 for moisture release, but there was no differences among genotypes. The panelists did not detect any toothpack attributes for the blackberries. The panelists could not identify differences in the size of the pyrenes, the amount of pyrenes, or loose particles of the blackberry genotypes evaluated. The pyrenes were similar in size to a sesame seed with less pyrenes as compared with the reference (182 dill seeds/10 g applesauce). Although numerous and large

Table 2. Berry, pyrene, and composition attributes for blackberry genotypes, Clarksville, AR, 2014.

Genotype	Berry wt (g)	Berry length (mm)	Berry width (mm)	Drupelets/ berry	Pyrene wt (g)/berry	Pyrenes/ berry	Soluble solids (%)	pH	Titrateable acidity (%) ^z	Soluble solids/titrateable acidity ratio
A-2416	11.06 ab ^y	36.80 ab	24.81 ab	88.55 b	0.28 bcd	83.22 b	9.47 ab	3.16 ab	1.01 ab	9.54 ab
A-2418	9.66 bc	32.90 bc	25.31 ab	84.22 b	0.38 ab	94.22 ab	8.07 b	3.08 b	1.35 a	6.17 b
A-2434	9.03 bcd	34.46 bc	24.30 ab	86.22 b	0.36 ab	88.78 ab	9.73 ab	3.05 b	1.16 ab	9.14 ab
A-2450	9.05 bcd	37.32 ab	22.16 b	92.22 b	0.32 abc	92.00 ab	8.93 ab	3.00 b	1.16 ab	7.68 ab
A-2453	6.01 d	27.47 c	24.85 ab	50.22 c	0.18 d	51.00 c	10.63 a	3.37 ab	0.75 ab	14.63 ab
A-2491	9.70 bc	36.76 ab	23.07 ab	81.78 b	0.28 bcd	84.78 b	10.97 a	3.20 ab	0.97 ab	13.49 ab
Natchez	14.26 a	43.68 a	25.96 ab	125.83 a	0.43 a	115.00 a	10.17 ab	3.17 ab	1.03 ab	9.93 ab
Osage	7.29 cd	27.81 c	26.92 a	70.22 bc	0.26 bcd	72.33 bc	8.90 ab	3.58 a	0.69 b	12.82 ab
Ouachita	8.80 bcd	29.08 bc	26.56 ab	69.78 bc	0.23 cd	66.78 bc	10.60 a	3.43 ab	0.66 b	16.46 a
Prime-Ark® 45	7.64 cd	33.43 bc	22.71 ab	85.78 b	0.32 abc	90.22 ab	9.47 ab	3.38 ab	0.81 ab	12.30 ab
Prime-Ark® Traveler	8.45 bcd	30.80 bc	22.20 b	76.11 b	0.27 bcd	78.44 bc	8.97 ab	3.20 ab	0.92 ab	10.23 ab
P value	<0.0001	<0.0001	0.0065	<0.0001	<0.0001	<0.0001	0.0065	0.0020	0.0135	0.0365

^zCalculated as percent citric acid.^yGenotypes were evaluated in triplicate. Means with different letter(s) for each attribute are significantly different ($P < 0.05$) using Tukey's honestly significant difference.Table 3. Nutraceutical attributes^z for blackberry genotypes, Clarksville, AR, 2014.

Genotype	Total ellagitannins (mg ellagic acid equivalents/100 g)	Total flavonols (mg rutin equivalents/100 g)	Total anthocyanins (mg acy/100 g)	Total phenolics (mg gallic acid equivalents/100 g)
A-2416	41.96 ab ^y	12.10 a	191.10 abc	603.13 a
A-2418	43.10 ab	12.76 a	181.86 abcd	555.66 ab
A-2434	45.43 a	12.76 a	206.56 ab	603.63 a
A-2450	27.36 c	12.26 a	199.23 abc	573.83 ab
A-2453	39.90 ab	15.20 a	119.96 cde	606.33 a
A-2491	30.20 abc	9.33 a	107.70 de	518.73 ab
Natchez	38.76 ab	8.96 a	183.76 abcd	528.50 ab
Osage	29.46 abc	16.10 a	246.53 a	580.96 ab
Ouachita	20.63 c	8.93 a	173.03 abcd	434.20 b
Prime-Ark® 45	36.86 abc	13.30 a	146.46 bcd	517.20 ab
Prime-Ark® Traveler	33.86 abc	7.70 a	55.36 e	463.80 ab
P value	0.0005	0.1524	<0.0001	0.0078

^zNutraceuticals of blackberries calculated as fresh weight for total ellagitannins; total flavonols; total anthocyanins [mg cyanidin 3-glucoside (acy)/100 g]; total phenolics.^yGenotypes were evaluated in triplicate. Means with different letter(s) for each attribute are significantly different ($P < 0.05$) using Tukey's honestly significant difference.

Table 4. Descriptive sensory appearance attributes for blackberry genotypes evaluated on a 15-point scale (0 = less of the attribute; 15 = more of the attribute in terms of intensity), Clarksville, AR, 2014.

Genotype	Color	Uniformity of color	Size of berry	Size of drupelets	Uniformity of drupelets	Amount of styles	Amount of blemishes	Glossiness
A-2416	13.11 d ^z	12.79 c	10.36 b	11.15 bc	10.33 cdef	3.62 cd	3.86 a	8.35 f
A-2418	13.99 ab	13.70 ab	10.41 b	11.31 abc	10.97 abcd	3.72 cd	3.75 a	10.37 de
A-2434	13.61 abcd	13.60 ab	10.71 b	10.87 bcd	9.68 ef	4.58 ab	3.86 a	9.77 e
A-2450	13.58 abcd	13.83 ab	10.42 b	10.88 bcd	10.73 abcd	2.92 de	2.01 bc	11.44 abc
A-2453	14.10 a	14.13 a	7.10 e	11.41 ab	11.55 ab	2.29 e	1.64 c	12.17 a
A-2491	13.64 abcd	13.81 ab	10.72 b	11.96 a	11.61 a	5.02 a	2.03 bc	11.62 ab
Natchez	13.50 bcd	13.66 ab	12.08 a	11.61 ab	11.17 abc	4.47 abc	2.42 b	11.39 bc
Osage	13.93 ab	13.97 a	8.19 d	9.68 ef	10.59 bcde	3.88 bc	3.19 a	10.34 de
Ouachita	13.81 abc	13.57 ab	8.43 cd	10.60 cd	9.57 f	5.12 a	3.58 a	10.32 de
Prime-Ark® 45	13.26 cd	13.31 bc	8.64 cd	9.45 f	10.04 def	3.71 cd	2.04 bc	10.22 de
Prime-Ark® Traveler	13.91 ab	13.77 ab	9.35 c	10.29 de	10.39 cdef	4.27 abc	2.14 bc	10.86 cd
P value	0.023	0.016	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

^zGenotypes were evaluated in duplicate by nine trained panelists. Means with different letter(s) for each attribute are significantly different ($P < 0.05$) using least significant difference.

pyrenes are thought to be objectionable, the panelists could not differentiate these attributes for these genotypes.

Consumer sensory analysis

The consumer panel ($n = 74$) evaluated appearance, size, shape, color, overall impression, overall flavor, and firmness of fresh blackberries on a 9-point verbal hedonic scale and blackberry flavor, sweetness, tartness, bitterness, astringency, firmness, crispness, and seediness of blackberries on

a 5-point JAR scale (Tables 6 and 7). Consumers in this study indicated that they purchased fresh blackberries at a grocery store (73%), farmers market (55%), pick-your-own farm (32%), other locations (12%), natural food stores (8%), and food co-ops (5%). Twenty-six percent of the consumers indicated that they consumed fresh blackberries once per week to once per month, whereas 4% claimed they consumed fresh blackberries daily. Consumers indicated that they used fresh blackberries by

consuming fresh (95%), baking/cooking (68%), freezing (43%), preserves/jams (27%), and other (4% smoothies and cocktails). The consumers were asked what drives them to purchase fresh blackberries with quality (77%), availability, seasonality and price (66%), and consistency (8%) as responses. Consumers were also asked what drives them to not purchase fresh blackberries, and the responses were price (77%), quality (72%), availability (34%), seasonality (24%), and consistency (3%).

Hedonic liking scale. All of the attributes evaluated by consumers for the blackberry genotypes in this study were scored from 5 to

8 (5 = neither like nor dislike; 6 = like slightly; 7 = like moderately; and 8 = like very much) on the hedonic scale (Table 6).

Berry appearance, size, shape, and color were the first attributes evaluated by the consumers and the consumers scored these attributes 6.6 to 7.9. 'Prime-Ark® Traveler' (8.5 g berry) had the highest liking scores for appearance, whereas A-2416 (11 g berry) had the lowest for appearance, size, and color. Consumers liked a medium-sized berry vs. a larger berry. Consumer panelists liked the firmness of the genotypes, but found no differences among genotypes. This was a noteworthy finding, as A-2453 was a uniquely firm berry, and it was of interest to determine if consumers considered this blackberry too firm. From the hedonic liking data, the percent of the panelist's responses were also calculated on a collapsed scale (data not shown). The collapsed scale had panelists that did not like the attribute (1 to 4 on the hedonic scale) and those that like the attribute (6 to 9 on the hedonic scale). For instance, 95% and 92% of the consumers liked 'Prime-Ark® 45' and A-2453, respectively, where the percent of the consumers scored the attribute on the hedonic score of 6 to 9. For instance, the consumers liked the appearance of 'Prime-Ark® 45' (95%) and A-2453 (92%), which was the total percent from the hedonic scores 6 to 9. 'Prime-Ark® Traveler' and 'Prime-Ark® 45' had the highest liking scores for size (Fig. 3A), and 91% of the consumers liked the size of 'Prime-Ark® 45' and A-2491. 'Natchez' and A-2416 (the two largest berries) had 19% to 20% dislike of the size. Consumers did not find differences in the shape of the berry, but 82% to 91% of the consumers liked the shape. Consumers (86% to 97%) indicated that A-2453 had the highest liking for berry color.

In terms of overall impression and overall flavor, A-2491 and 'Prime-Ark® Traveler' had the highest liking values, whereas A-2434 had the lowest (Table 6; Fig. 3B). A-2491 and 'Prime-Ark® Traveler' had high liking values and had roughly a 9 g berry weight with 10% soluble solids, 0.95% titratable acidity, and a soluble solids/titratable acid ratio of 11.8. About 79% to 89% of the consumers liked A-2491 and 'Prime-Ark® Traveler' and about 42% of the consumers disliked A-2434 for overall impression and

Fig. 2. Descriptive sensory glossiness intensity (A) and firmness intensity (B) attribute for blackberry genotypes evaluated on a 15-point scale (0 = less of the attribute; 15 = more of the attribute in terms of intensity), 2014. *Genotypes evaluated by nine trained panelists in duplicate. Means with different letter(s) for each attribute are significantly different ($P < 0.05$) using least significant difference.

Table 5. Descriptive sensory basic tastes, aromatic attributes, and texture attributes for blackberry genotypes evaluated on a 15-point scale (0 = less of the attribute; 15 = more of the attribute in terms of intensity), Clarksville, AR, 2014.

Genotype	Basic tastes			Aromatics			Texture	
	Sweet	Sour	Bitter	Overall aromatic impact	Blackberry	Earthy/dirty	Green/unripe	Firmness
A-2416	3.61 a ^z	5.40 a	2.58 ab	7.85 bcde	6.74 a	1.22 d	3.03 a	3.69 bc
A-2418	4.11 a	4.84 abc	2.31 ab	7.96 abcd	6.87 a	1.26 d	2.07 bc	3.94 ab
A-2434	3.79 a	4.93 ab	2.62 a	7.64 e	6.70 a	2.44 a	2.74 ab	3.80 bc
A-2450	3.71 a	4.62 bcd	2.28 abc	7.74 cde	6.68 a	1.96 ab	2.26 abc	3.62 cde
A-2453	3.86 a	4.12 cde	1.91 cd	7.92 abcde	7.02 a	1.82 bc	2.42 ab	4.21 a
A-2491	4.20 a	3.84 e	1.88 d	8.07 ab	7.23 a	1.23 d	1.56 c	3.36 ef
Natchez	4.35 a	3.87 e	2.21 bcd	8.16 a	7.20 a	1.27 d	1.49 c	3.18 f
Osage	4.32 a	4.27 bcde	2.27 abc	7.66 de	6.71 a	1.41 cd	2.13 bc	3.56 cde
Ouachita	4.21 a	4.23 bcde	2.44 ab	7.89 abcde	6.83 a	1.61 bcd	2.40 ab	3.63 cd
Prime-Ark® 45	3.73 a	4.33 bcde	2.23 bcd	7.94 abcd	6.95 a	1.59 bcd	1.92 bc	3.14 f
Prime-Ark® Traveler	4.23 a	3.95 de	1.92 cd	7.99 abc	6.90 a	1.61 bcd	2.17 bc	3.42 de
P value	0.242	<0.0001	<0.0001	0.022	0.069	<0.0001	0.015	<0.0001

^zGenotypes were evaluated in duplicate by nine trained panelists. Means with different letter(s) for each attribute are significantly different ($P < 0.05$) using least significant difference.

Table 6. Consumer sensory attributes for blackberry genotypes evaluated on a 9-point hedonic scale (1 = dislike extremely; 5 = neither like nor dislike; 9 = like extremely), Clarksville, AR, 2014.

Genotype	Appearance	Size	Shape	Color	Overall impression	Overall flavor	Firmness
A-2416	6.76 d ²	6.62 c	6.96 a	7.12 d	5.88 ef	5.76 ef	6.82 a
A-2418	7.27 bc	6.93 bc	7.28 a	7.64 bc	6.16 de	6.07 de	7.20 a
A-2434	7.09 cd	7.01 bc	7.08 a	7.59 bc	5.42 f	5.27 f	6.81 a
A-2450	7.39 abc	7.11 ab	6.95 a	7.61 bc	5.88 ef	5.70 ef	6.88 a
A-2453	7.59 ab	7.16 ab	7.31 a	7.93 a	6.59 bcd	6.51 cd	6.95 a
A-2491	7.46 abc	7.34 ab	7.35 a	7.86 ab	7.28 a	7.26 a	7.31 a
Natchez	7.34 abc	6.95 bc	7.26 a	7.66 abc	7.07 ab	6.92 abc	6.99 a
Osage	7.35 abc	7.01 bc	7.14 a	7.82 abc	6.91 abc	6.73 abc	6.78 a
Ouachita	7.19 c	7.20 ab	7.26 a	7.54 c	6.58 bcd	6.55 bcd	7.26 a
Prime-Ark® 45	7.65 a	7.46 a	7.50 a	7.70 abc	6.51 cd	6.41 cd	6.96 a
Prime-Ark® Traveler	7.68 a	7.49 a	7.46 a	7.88 ab	7.18 a	7.09 ab	7.11 a
P value	<0.0001	0.003	0.054	<0.0001	<0.0001	<0.0001	0.157

²Genotypes were evaluated by 74 consumer panelists. Means with different letter(s) for each attribute are significantly different ($P < 0.05$) using least significant difference.

Table 7. Percent (%) of consumer sensory attributes for blackberry genotypes on a collapsed 5-point just about right (JAR)² scale, Clarksville, AR, 2014.

Genotype	Size			Sweetness			Sourness			Bitterness			Blackberry aromatic			Firmness		
	Too small	JAR	Too big	Not sweet	JAR	Too sweet	Not sour	JAR	Too sour	Not bitter	JAR	Too bitter	Too low	JAR	Too high	Not firm	JAR	Too firm
A-2416	3	54	43	66	33	1	2	33	65	1	60	39	31	51	18	26	69	5
A-2418	5	54	41	61	39	0	5	36	59	4	55	41	31	57	12	7	89	4
A-2434	4	66	30	74	26	0	7	24	69	1	31	68	38	38	24	15	78	7
A-2450	4	62	34	84	16	0	1	27	72	0	35	65	42	39	19	12	72	16
A-2453	30	65	5	56	43	1	18	54	28	7	70	23	35	59	6	7	66	24
A-2491	8	65	27	28	70	1	6	79	15	6	78	16	18	74	8	14	85	1
Natchez	0	31	69	47	52	1	15	47	38	4	72	24	36	51	13	35	62	3
Osage	26	65	9	41	55	4	10	68	22	8	81	11	32	64	4	32	68	0
Ouachita	15	77	8	52	47	1	5	57	38	1	65	34	31	61	8	9	84	7
Prime-Ark® 45	11	74	15	64	35	1	7	46	47	8	50	42	34	49	17	16	80	4
Prime-Ark® Traveler	7	76	17	39	61	0	5	66	29	4	68	28	31	66	3	20	74	6

²Genotypes were evaluated by 74 consumer panelists. The 5-point JAR scale (1 = much too little; 2 = too little; 3 = JAR; 4 = too much; 5 = much too much) was collapsed to Too Low, JAR, and Too Much.

overall flavor. A-2434 had a 9 g berry weight with 9.7% soluble solids, 1.2% titratable acidity, and a soluble solids/titratable acidity ratio of 9.1.

JAR scale. For analysis, the JAR data were collapsed to “Too Low”, JAR, and “Too Much” (Table 7). Ideally in JAR evaluations, it is desired that at least 75% of participants consider an attribute JAR. Seventy-seven percent of the consumers found ‘Ouachita’ (8.8 g weight, 29 mm length, and 27 mm width) JAR in terms of blackberry size, followed closely by ‘Prime-Ark® Traveler’ and ‘Prime-Ark® 45’. Consumers found A-2491 JAR for astringency (89%) and sourness (78%). Firmness and crispness had similar results with 89% of the consumers finding A-2418 JAR. ‘Natchez’ was 90% JAR for seediness. ‘Prime-Ark® Traveler’ and A-2491 had JAR for sweetness of 61% and 70%, respectively.

Examining the attributes in the “Too Low” or “Too Much” categories can also provide guidance on attributes for genotypes that need improvements for commercial potential. Attributes with more than 15% in either the “Too Low” or “Too Much” categories need to be examined. About 69% of the consumers found ‘Natchez’ (14 g weight, 44 mm length, and 26 mm width) too large. Consumers found A-2450 not sweet (84%) and too sour (72%); A-2450 had a soluble solids/titratable acidity ratio of 7.7. Consumers found A-2434 too astringent (45%) and too bitter (69%). Consumers found A-2453

too seedy (36%) and too firm (24%) and ‘Natchez’ too soft (35%). Consumers might have found A-2453 “seedy” because it was a small, firm genotype, whereas ‘Natchez’ was a large, soft genotype.

To further identify blackberry attribute improvements, penalty analysis was performed using the JAR data for the highest scored genotype in terms of overall liking. Penalties consider the mean drop (difference in liking between JAR attributes and “Too Low” or “Too Much”) and the proportion of individuals in each of those categories. To increase the commercial potential for future blackberry developments, we can take the most-liked genotype (A-2491) and perform penalty analysis to define the attributes of A-2491 that were too low or too high. By identifying the penalties on the highest scoring genotype, we can identify areas of improvement for blackberries. A-2491 had penalties for “Too Little” crispness, sweetness, and blackberry flavor and “Too Much” bitterness and sourness. Penalties for these attributes range from -0.19 to -0.74 meaning that these attributes were of borderline concern according to standardized penalty analysis procedures (ASTM, 2009). According to this analysis, blackberry improvements to this genotype should include an increase in sweetness and blackberry flavor and decreased sourness and bitterness. If one examines the most-liked blackberry genotype for needed improvements, then the breeding efforts could focus on the

potential to create the “perfect” blackberry. Increased liking of blackberries increases consumer repurchase rates in commercial markets.

Comparisons within sensory attributes

Consumer overall impression and overall flavor for the blackberries was highly correlated ($r = 0.99$). Both were positively correlated to consumer liking of shape and color and descriptive sweetness and blackberry flavor and negatively correlated to descriptive sourness, bitterness, green/unripe, and amount of seeds. Consumer liking of blackberry appearance was positively correlated with consumer liking of berry size ($r = 0.86$), shape ($r = 0.75$), and color ($r = 0.88$) and descriptive uniformity of color ($r = 0.63$) and glossiness ($r = 0.75$) of the blackberries and negatively correlated to the amount of descriptive blemishes ($r = -0.83$).

Comparisons between physiochemical and sensory

Correlations and principal component analysis were used to determine the relationship between the physiochemical and sensory data. Berry weight, berry length, drupelet number/berry, and pyrenes/berry were positively correlated to descriptive size of berry ($r = 0.88$ to 0.91). Descriptive firmness and popping/bursting were negatively correlated to drupelets/berry ($r = -0.61$ to -0.65). The soluble solids content of the blackberries was not correlated to any of the sensory data. The

descriptive size of the berries was negatively correlated to pH ($r = -0.75$) and positively correlated to titratable acidity ($r = 0.74$). Total phenolics and total flavonols were negatively correlated with consumer liking of firmness of the blackberries and negatively correlated with descriptive overall aromatic impact ($r = -0.61$). Although individual phenolic acids in blackberries were not measured, they could impact the overall aromatics. Total phenolics and total anthocyanins were negatively correlated to the consumer liking of size of berry and shape of berry. Total anthocyanins were positively correlated to descriptive bitterness of the blackberries ($r = 0.74$). Soares et al. (2013) suggested that anthocyanins and hydrolysable tannins could be the major phenolic compounds responsible for the bitterness in fruits and derived products where malvidin-3-glucoside activated and β -1,2,3,4,6-penta-O-galloyl-D-glucopyranose activated the human bitter taste receptors.

For the principal component analysis, three principal components explaining 62.4% of variance of physicochemical and descriptive data were identified using means as the data matrix (Table 8). Overall liking scores were regressed against the three principal components to determine positive and negative drivers of consumer liking for fresh blackberries. Significant effects were found for principal components 1 and 3 ($P = 0.0003$ and 0.0130 , respectively). Liking of fresh blackberries was highest when attributes loading negatively on principal 1 and positively on principal 3 were highest. Positive and negative drivers of liking were identified for these blackberry genotypes. The positive drivers in principal component 1 were glossiness, loose particles, overall aromatic impact, blackberry aromatic, and uniformity of drupelets associated with the advanced selection A-2491, whereas the negative drivers were bitterness, sourness, amount of blemishes, amount of seeds, green/unripe, and metallic associated with A-2434. Though not significant, the principal component 2 had non drivers of firmness and chemical associated with A-2453 and drupelets/berry, pyrenes/berry, berry weight, size of berry, and moisture release associated with 'Natchez'. The positive drivers in principal component 3 were berry width, sweetness, pH, and amount of styles associated with 'Ouachita' and 'Osage', whereas the negative drivers were associated with A-2450. Since over 70% of the consumer panelists indicated that they purchased blackberries in a grocery store, it is important to determine the drivers of liking to increase commercial potential.

Conclusions

This research provided insight into physiochemical attributes of fresh blackberries and how these attributes are perceived by consumers. The descriptive and consumer sensory panels identified and evaluated marketable attributes of fresh blackberries. Although firmness of blackberries has the

potential to positively influence the fresh-market shipping industry, the appearance attributes, such as size, shape, color, and

glossiness of the blackberries can positively influence consumer purchasing. In this study of blackberry genotypes with a berry

Fig. 3. Consumer sensory attributes for liking of (A) size and (B) overall impression for the blackberry genotypes evaluated on a 9-point hedonic scale (1 = dislike extremely, 5 = neither like nor dislike, 9 = like extremely), 2014. *Genotypes were evaluated by 74 consumer panelists. Means with different letter(s) for each attribute are significantly different ($P < 0.05$) using least significant difference.

Table 8. Drivers of liking for fresh blackberries determined by principal component regression,² Clarksville, AR, 2014.

Principal component	Low on dimension 1	High on dimension 2
1	Positive drivers: glossiness, loose particles, overall aromatic impact, blackberry aromatic, uniformity of drupelets Key sample: A-2491	Negative drivers: bitterness, sourness, amount of blemishes, amount of seeds, green/unripe, metallic Key sample: A-2434
2	Nondrivers: firmness, chemical Key sample: A-2453	Nondrivers: drupelets/berry, pyrenes/berry, berry weight, size of berry, moisture release Key sample: Natchez
3	Negative drivers: narrow berry, lower intensities of sweetness, pH, amount of styles Key samples: A-2450	Positive drivers: wider berry, higher intensities of sweetness, pH, amount of styles Key samples: Ouachita and Osage

²Three principal components explaining 62.4% of variance of physiochemical and descriptive sensory data were identified using means as the data matrix. Significant effects were found for principal components 1 and 3 ($P = 0.0003$ and 0.0130 , respectively).

weight range of 6 to 14 g, consumers liked mid-sized berries rather than large berries. Although sweetness of the blackberries was an important positive attribute, the sourness of the blackberries had more of a negative impact on the liking of the blackberries. The trained descriptive panel using references could not distinguish differences in sweetness among these genotypes, but could easily differentiate sourness. Although blackberry growers typically focus on growing sweeter berries, the perception of sweetness is actually a balance of sweetness and sourness, which should be considered when advancing breeding selections or choosing cultivars for planting. To produce commercially marketed fresh-market blackberries, there are many characteristics that are important, but our data for these genotypes suggest that a desired fresh-market blackberry should have a berry weight of 8 to 10 g, soluble solids of 9% to 11%, titratable acidity of 0.9% to 1%, and a soluble solids/titratable acid ratio of 10 to 13. However, optimum sugar and acidity levels require more investigation as well as other important factors in flavor and aromatics. Evaluating the physiochemical and sensory attributes of fresh fruit is an important tool that can be used to determine commercial potential for selections and cultivars.

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