12-2018

Ripeness Attributes of Arkansas-grown Peaches and Nectarines at Harvest and During Postharvest Storage

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Abstract

Evaluating ripeness attributes of peaches and nectarines helps determine feasibility for commercial markets. Five cultivars (Amoore Sweet, Bowden, Bradley, Effie, and Souvenirs) and five breeding selections (A-663 CN, A-794 CN, A-811 CN, A-819, and A-885) were hand harvested in 2017 from the University of Arkansas System Division of Agriculture's Fruit Research Station in Clarksville, AR. The tree-ripened fruit was evaluated at harvest (day 0), and commercially-ripened fruit (ripened during storage) was evaluated at 0, 7 and 14 d storage at 4° C. The attributes of tree and commercially-ripened fruit varied at harvest and included chlorophyll (0.04-0.86 abs), weight (132-264 g), soluble solids (7.23-12.57%), pH (3.18-4.66), titratable acidity (0.16-1.21%), and flesh firmness (6.92-35.72 N). At harvest, tree-ripened fruit had higher fruit weight, soluble solids, and pH and lower chlorophyll, titratable acidity, and firmness than commercially-ripened fruit. For the tree-ripened fruit, A-811 CN was the largest, A-794 CN had the highest soluble solids and titratable acidity, and Amoore Sweet was the firmest. For tree and commercially-ripened fruit, the flesh of the fruit was more yellow than the skin, A-663 CN had the lowest total hydroxycinnamic acids, and there were no differences in sugar levels. During storage of commercially-ripened fruit, chlorophyll and fruit weight decreased, while soluble solids increased. Some ripeness attributes of the commercially-ripened fruit, such as chlorophyll and weight, were not achieved as compared to the tree-ripened fruit. This study provides insight on the potential for releasing new peach and nectarine genotypes from the University of Arkansas Fruit Breeding Program.

Introduction and Literature Review

Peaches and nectarines (*Prunus persica* L.) are a valuable fresh-market crop worldwide and are classified as climacteric fruit, fruit that ripens after harvest. Peaches and nectarines can vary greatly in shape (round, flat, or beaked), skin type (pubescent or smooth-skinned), stone type (freestone or clingstone), flesh color (white, yellow, or red), and flesh type (melting, slow melting, or non-melting) with a wide range of sweetness and acidity (Brovelli et al., 1999). Melting-flesh peaches are commonly used in fresh market, and the tertiary ripening phase is generally called the 'melting' stage (Ghiani et al., 2011). The difference between melting and non-melting peaches is increased enzymatic capacity for pectin degradation in melting-flesh types (Maw, 2003). Peaches and nectarines are similar genetically, however, nectarines are smooth-skinned, and peaches have a fuzzy exterior. This phenotypic trait of the pubescent, fuzzy exterior is due to the lack or presence of a single recessive allele in the fruit (Layne and Bassi, 2008)

Peaches and nectarines are soft-fleshed and highly perishable fruits, with a limited market life. The maturity at which peaches are harvested greatly influences their flavor, market life, and quality potential. Crisosto and Valero (2008) found that peaches harvested too soon for commercial storage can fail to ripen properly and green ground color (greenish skin around the stem) may never fully disappear. Generally, immature and low-maturity fruit can have inadequate flavor development, which can lead to decreased consumer acceptance. However, overripe fruit can have a shortened postharvest life by the time this fruit reaches the consumers.

Optimum maturity must be defined for each peach cultivar for maximum taste and storage quality, but in all cases, it should assure that the fruit has the ability to ripen satisfactorily (Kader & Mitchell, 1989). The ideal maturity of the fruit varies according to markets; for

example, a tree-ripened peach will be recommended for local markets while a commercially-ripened peach is for distant markets. Maturity indices used from different production areas have reported that flesh color, firmness, and background color changes are correlated to chemical and physical fruit changes during maturation and ripening (Brovelli & Sims, 1998).

A key factor in understanding the fruits' potential for commercial markets is evaluating the postharvest attributes. Postharvest can be defined as the period of time from the moment of harvest to the point of consumption (Florkowski et al., 2014). Post-harvest attributes of fresh-market produce can be related to aroma, texture, flavor, nutraceuticals, composition, and transportation and handling of the product. Peaches immediately begin to deteriorate after harvest but this process can be delayed when the fruit is refrigerated during storage. However, cold storage can cause damage to fruit quality through browning (both skin and flesh), flesh breakdown, loss of juiciness (mealiness or woolliness), discoloration, and loss of flavor (Lauxmann et al., 2014).

The Fruit Breeding Program at the University of Arkansas System Division of Agriculture was founded in 1964 by Dr. James N. Moore. Since then, the program has released over 50 different fruit cultivars including blackberries, table grapes, wine grapes, peaches/nectarines, strawberries, and blueberries (J.R. Clark, pers. comm.). The program focuses on developing fruit cultivars for commercial markets and nurseries with production extending beyond Arkansas to other states and countries. The Fruit Breeding Program, located at the Fruit Research Station in Clarksville, AR, is actively evaluating fruit, including peaches and nectarines, for potential release, and has released 6 peach and 6 nectarine cultivars.

The objective of this study was to evaluate ripeness attributes of Arkansas-grown peaches and nectarines at harvest and during postharvest storage and to provide insight for release of new peach and nectarine cultivars from the University of Arkansas Fruit Breeding Program.

Materials and Methods

Plants and Culture

Ten peach and nectarine genotypes, five cultivars (Amoore Sweet, Bowden, Bradley, Effie, and Souvenirs) and five breeding selections (A-663 CN, A-811 CN, A-794 CN, A-819, and A-885) were evaluated in this study (Table 1). The fruit was harvested from the University of Arkansas Fruit Research Station, Clarksville AR [west-central Arkansas, lat. 35◦31'58"N and long. 93◦24'12"W; USDA hardiness zone 7a; soil type Linker fine sandy loam (Typic Hapludult)]. The trees were either open-center trained and spaced 5.5 m between trees and rows, or trained to a perpendicular-V system with trees spaced 1.9 m in rows spaced 5.5 m apart. All trees were dormant pruned and fertilized annually with either complete or nitrogen fertilizers and drip irrigated as needed. Pests were managed using a program typical for commercial orchards in this area. Fruit were thinned to a distance of 12 to 15 cm between fruit after shuck split but before pit hardening.

Harvest

The peaches and nectarines were hand harvested in the morning (about 7:00-10:00$_{AM}$) on June 23, 2017. Twelve fruit were harvested per genotype, nine commercially-ripened fruit (fruit picked early to ripen during storage) and three tree-ripened fruit (fruit ripened on the tree). The fruit ripeness was screened using a Delta Absorbance (DA) meter (Sintéleiax, Bologu, Italy) to analyze the Chlorophyll A content of the fruit skin (difference of absorbance between 670-720

nm). The standard for commercially-ripened fruit using the DA meter was an I_{AD} value of 0.5 to 1.0, and a value below a 0.25 indicated physiological maturity of tree-ripened fruit. The peaches and nectarines were harvested for each genotype and placed randomly onto pre-labeled corrugated pulp trays with individual wells for each fruit, with one tray per genotype. The commercially-ripened fruit were evaluated for physiochemical attributes at day 0, 7, and 14 at 4 °C with 85-89% relative humidity, and tree-ripened fruit was evaluated only at harvest (day 0).

Physiochemical Analysis

Fruit for physiochemical analysis was done in triplicate per ripeness and genotype. Each replicate was an individual peach or nectarine. The physiochemical analyses included fruit weight, flesh firmness, and composition evaluated at 0, 7, and 14 d at 4 °C. After harvest, fresh fruit weight and firmness were evaluated at the Fruit Research Station, then fruit for compositional analysis was frozen (-10 °C) for analysis at the Food Science Department in Fayetteville, AR. In addition, the skin and flesh color, organic acids, sugars, and nutraceuticals of the fruit were evaluated at day 0.

Weight. Fruit weight was measured on a digital scale (Mettler Toledo JL6001GE, Columbus, OH) in triplicate. Fruit weight was the weight of a whole, intact peach or nectarine.

Color. The color of the fruit skin and flesh was analyzed using a Konica Minolta CR-400 Chroma Meter (Konica Minolta Inc, Ramsey, NJ). The L*, chroma, and hue angle were evaluated. Color analysis was done to determine Commission Internationale de l'Eclairage (CIE) Lab transmission values of L*=100, a*=0, and b*=0 (C.I.E. 1986). The CIELAB system describes color variations as perceived by the human eye. CIELAB is a uniform three-dimensional space defined by colorimetric coordinates, L*, a*, and b*. The vertical axis L* measures lightness from completely opaque (0) to completely transparent (100), while on the

hue-circle, +a* red, -a* green, +b* yellow, and -b* blue were measured. Hue angle, calculated as arctan (b*/a*), described color in angles from 0 to 360° (0° is red, 90° is yellow, 180° is green, 270° is blue, and 360° is red). Chroma, calculated as $((a^*)^2 + (b^*)^2)^{0.5}$, identified color by which a sample appears to differ from gray of the same lightness and corresponds to intensity of the perceived color. Skin color was evaluated on three locations (90°, 180°, and 270° to the right of the suture). Immediately after cutting the fruit in half, the flesh was analyzed for color similarly in three locations.

Firmness. Flesh firmness was measured using a Stable Micro Systems TA.XT2 Texture Analyzer (Texture Technologies Corporation, Hamilton, MA). Prior to the firmness measurement, a section of the fruit skin was removed by slicing off a 5 mm section. The fruit was then placed on a flat surface. Firmness of the fruit flesh was evaluated at three locations per fruit (90°, 180°, and 270° to the right of the suture) using the 2-mm-diameter probe, at a rate of 2 mm/s with a trigger force of 0.02 N. Force to penetrate the fruit flesh was measured in Newtons (N).

Composition. The fruit half for composition was frozen (-10 °C) then thawed for analysis of soluble solids, pH, and titratable acidity. The other half of the fruit was used for nutraceutical analysis. Each fruit half (skin and flesh) was macerated in a blender, then the juice was centrifuged at 5,000 rpm for 8 min and strained through cheese cloth. The pH and titratable acidity were measured using the Titrino plus 862 compact titrosampler (Metrohm AG, Herisan, Switzerland) with the electrode standardized to pH 4.00, 7.00, and 10.00 buffers. Titratable acidity was determined using ~6 g of juice diluted with 50 mL deionized, degassed water with a titration using 0.1 N sodium hydroxide to an endpoint of pH 8.2. Titratable acidity was expressed as percentage of malic acid. Soluble solids (expressed as percent) were measured using an Abbe

Mark II refractometer (Bausch and Lomb, Scientific Instrument, Keene, NH). Organic acids and sugars of the fruit were determined using high performance liquid chromatography (HPLC). The remaining juice from compositional analysis was filtered through a 0.45 μm nylon filter (VWR International, Radnor, PA) and analyzed using HPLC.

Glucose, fructose, isocitric acid, and malic acid of the fruit was measured using previously established HPLC procedures (Segantini et al., 2018; Walker et al., 2003). The HPLC was equipped with a Bio-Rad HPLC Organic Acid Analysis Aminex HPX-87H ion exclusion column (300 × 7.8 mm), Bio-Rad HPLC Fast Acid Analysis column (100 x 7.8 mm), and a Bio-Rad HPLC column for fermentation monitoring (150 × 7.8 mm) in series (Bio-Rad, Hercules,CA). A Bio-Rad Micro-Guard Cation-H refill cartridge (30 × 4.5 mm) was used for a guard column. Columns were maintained at 65 °C by a temperature control unit. Mobile phase consisted of a pH 2.28 solution of sulfuric acid and water with a resistivity of 18 M obtained from a Millipore Milli-Q reagent water system. The sulfuric acid solution was used as the solvent with 0.45 mL/min flow rate. The solvent delivery system was a Waters 515 HPLC pump equipped with a Waters 717 plus autosampler (Waters Corporation, Milford, MA). Injection volumes were 10 μL for all samples, and run time for completion was 35 min. A Waters 410 differential refractometer to measure refractive index connected in series with a Waters 996 photodiode array detector monitored the eluting compounds. Isocitric and malic acids were detected by photodiode array at 210 nm and glucose and fructose were detected by the differential refractometer. The peaks were quantified using external standard calibration based on peak height estimation with baseline integration. Individual sugars and acids were expressed as g/100 g, and total sugars (glucose + fructose) and total organic acids (isocitric + malic) were expressed as g/100 g.

Nutraceuticals. Total anthocyanins, total hydroxycinnamic acids, total carotenoids, and total flavonols were measured by HPLC and ultraviolet-visible (UV-Vis) spectroscopy following methods described by Cho et al. (2004; 2005), and Hager et al. (2008). The fruit was homogenized three times for 1 min in alternating washes of 80 ml of extraction solution containing methanol/water/formic acid (60:37:3 v/v/v) and acetone/water/acetic (70:29.5:0.5 v/v/v) to the smallest particle size using a Euro Turrax T18 Tissuemizer. Homogenates were centrifuged for 5 min at 10,000 rpm and filtered. The samples were taken to a final volume of 250 mL with extraction solvent and stored at -70 °C until analysis. All samples were passed through 0.45 μm filters prior to HPLC analysis. Equivalents for the peach and nectarine nutraceuticals were determined from previous literature for the most common compounds for each class of phenolics (Brown et al., 2014; Ceccarelli et al., 2016; Gil et al., 2002).

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

Total carotenoids. Methods adapted from Biehler et al. (2010) and Gross (1991) were used for saponification and quantification of carotenoids. Sample extracts (50 mL) were

saponified to reduce chlorophyll interference in samples. Samples were heated at 60 °C for 1 hr with 1 g of butylated hydroxytoluene (BHT) and 30 mL of 5% sodium hydroxide in methanol. The sample was extracted three times using water, ethanol, and hexane solvent. The hexane fraction was evaporated using a rotary evaporator (Buchi, New Castle, DE) to dryness and brought up to a known volume with acetone. The reconstituted extract was sonicated for 2 min. Total carotenoids were quantified using a 8452A Diode Array Spectrophotometer (Hewlett Packard, Palo Alto, CA) at 452 nm using an extinction coefficient of 140663 mol/L with results expressed as micrograms beta-carotene equivalents per 100 g fresh fruit weight.

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

Design and Statistical Analysis

After harvest, the fruit from each of the two ripeness types and ten genotypes were completely randomized. The commercially-ripened fruit was stored at 4 °C for 0, 7, and 14 d, and the tree-ripened fruit was evaluated at day 0. Statistical analyses were conducted using JMP® (version 13.2.0; SAS Institute, Cary, NC). A univariate analysis of variance (ANOVA) was used to determine the significance of main factors (genotype and storage) and interactions. Tukey's Honestly Significant Difference (HSD) test was used to detect significant differences ($p < 0.05$) among means and verify interactions at 95% significance level. Physiochemical attributes were evaluated in triplicate for each genotype and ripeness.

Results and Discussion

At harvest and during storage, the peaches and nectarines were within a commercially acceptable range for the attributes evaluated (chlorophyll, fruit weight, soluble solids, pH, titratable acidity, and firmness). The tree and commercially-ripened fruit were evaluated for physiochemical attributes at harvest, and the commercially-ripened fruit was evaluated for physiochemical attributes during storage.

Physiochemical Attributes at Harvest

At harvest for the tree-ripened fruit, the peaches and nectarines had a chlorophyll of 0.04-0.17 abs, fruit weight of 142.33-247.67 g, soluble solids of 7.80-12.57%, pH of 3.43-4.66, titratable acidity of 0.17-0.88%, and firmness of 6.92-18.28 N (Table 2). There were no significant differences between genotypes for chlorophyll or fruit weight. The average chlorophyll level and fruit weight for these genotypes were 0.12 abs. and 204.90 g, respectively. These chlorophyll levels at harvest were expected since the DA meter was used to screen the fruit. Although not significantly different, A-811 CN was the largest fruit and 'Effie' the smallest. Previously reported fruit weight for 'Amoore Sweet', 'Bowden', 'Bradley', and 'Souvenirs' was lower than fruit in this research (Clark and Sandefur, 2013a; 2013b, Clark et al., 2001). There were significant differences between genotypes for soluble solids, pH, titratable acidity, and firmness. A-663 CN (7.80%) had the lowest soluble solids. A-885 (0.17%) had the lowest titratable acidity. A-794 CN had the highest soluble solids and titratable acidity, 12.57% and 0.88%, respectively. Clark and Sandefur (2013a) reported two-year averages of soluble solids for 'Amoore Sweet' (17.3%), 'Bowden' (14.9%), 'Bradley' (14.8%), and 'Souvenirs' (14.1%), which were higher than the soluble solids of fruit in this study. There was a high incidence of rainfall in Clarksville in 2017 prior to harvest of the fruit, which could have caused the lower soluble solids in this study. A-819 (4.66) had the highest pH, and 'Bowden' (3.43) had

the lowest. ‘Souvenirs’ (6.92 N) had the lowest firmness, and ‘Amoore Sweet’ (18.28 N) was the firmest. Amoore Sweet is a non-melting flesh nectarine with a flesh type that is very firm and rubbery in texture (Sandefur, et al., 2011).

At harvest for the commercially-ripened fruit, the peaches and nectarines had a chlorophyll of 0.32-0.86 abs, fruit weight of 132.00-264.00 g, soluble solids of 7.23-12.17%, pH of 3.18-4.62, titratable acidity 0.16-1.21%, and firmness of 9.06-35.72 N. There were significant differences between genotypes for all of these attributes. A-663 CN (0.86 abs) had the highest chlorophyll and ‘Souvenirs’ (0.32 abs) the lowest. ‘Effie’ (264.00 g) was the larger than A-663 CN (132.00 g) and A-794 CN (135.33 g). A-885 (12.17%) had higher soluble solids than A-819 (7.23%). A-819, A-885, Amoore Sweet, and Souvenirs had higher pH than A-663 CN, A-794 CN, A-811 CN, Bowden, and Bradley. A-794 CN (1.21%) had a higher titratable acidity than Souvenirs (4.15%). Souvenirs (35.72 N) and A-794 CN (32.67 N) were firmer than A-819 (9.06 N).

The attributes of the tree and commercially-ripened fruit had the highest soluble solids and lowest titratable acidity, 12.17% and 0.16%, respectively. A-819 had the lowest soluble solids, highest pH, and lowest firmness, 7.23%, 4.62, and 9.06 N, respectively. A-794 CN had the lowest pH and highest titratable acidity 3.18 and 1.21%, respectively. ‘Souvenirs’ (35.72 N) was the firmest.

The attributes of the tree-ripened fruit and the commercially-ripened fruit varied at harvest. In general, commercially-ripened fruit had higher chlorophyll, titratable acidity, and firmness than tree-ripened fruit (Figure 1). However, tree-ripened fruit had slightly higher fruit weight, soluble solids, and pH than commercially-ripened fruit. Zhang et al. (2017) showed high correlations between firmness and chlorophyll of peaches. A similar study on California free

stone peaches concluded increased maturity of peaches at harvest (tree-ripened peaches) are characterized by decreasing flesh firmness and titratable acidity, as well as increasing soluble solids (Rood, 1957).

Color attributes (L*, chroma, and hue) of the skin and flesh of the peaches and nectarines were evaluated at harvest. All flesh and skin color attributes for the tree and commercially-ripened fruit were significant except for L* value for flesh of tree-ripened fruit (Table 3). For the tree-ripened fruit, the range of the skin color was L* of 42.97 to 68.03, chroma of 32.46 to 61.41 and hue of 31.79 to 71.32, and the range of the flesh color was L* of 60.68 to 78.03, chroma of 18.69 to 50.14 and hue of 58.90 to 98.97. For the commercially-ripened fruit, the range of the skin color was L* of 46.05 to 70.19, chroma of 33.22 to 56.30, and hue of 36.30 to 79.10, and the range of the flesh color was L* of 59.61 to 79.03, chroma of 14.38 to 55.25 and hue of 70.23 to 100.23 (Table 3). The L* values of the flesh and skin of the peaches and nectarines were in the mid-range between opaque (0) and transparent (100). In general, the hue of the flesh and skin of the peaches and nectarines was between 0° (red) and 90° (yellow) with the flesh having a trend for higher (more yellow) values than the skin. There were not trends with chroma values. The skin of A-811 CN for both tree and commercially-ripened fruit had the highest L* value and hue value, whereas Bradley had the highest chroma value. In terms of the flesh color, Bowden had the highest L* value for both tree and commercially-ripe fruit, though not significantly for the tree-ripened fruit.

Individual and total organic acids and sugars of the peaches and nectarines were evaluated at harvest. There were not any significant differences in the genotypes for sugars or acids of tree-ripened fruit or the sugars of the commercially-ripened fruit. For the tree-ripened fruit, the range of the acids was isocitric acid of 0.06 to 0.49 g/100 g, malic acid of 0.03 to 0.49

g/100 g and total organic acids of 0.08 to 0.89 g/100 g. The range of the sugars was glucose of 0.63 to 5.17 g/100 g, fructose of 1.34 to 5.65 g/100 g, and total sugars of 2.40 to 10.82 g/100 g (Table 4). For the commercially-ripened fruit, the range of the acids was isocitric acid of 0.06 to 0.90 g/100 g, malic acid of 0.03 to 0.71 g/100 g and total organic acids of 0.09 to 1.60 g/100 g. The range of the sugars was glucose of 0.52 to 4.78 g/100 g, fructose of 0.90 to 4.97 g/100 g, and total sugars of 1.42 to 9.75 g/100 g (Table 4). Although not significantly different, tree-ripened Bowden had the highest isocitric acid, whereas A-663 CN had the highest malic acid and total organic acids. In addition, A-819 had one of the lowest individual and total acids, and A-885 had the highest individual and total sugars. For both tree and commercially-ripe fruit, A-885 had the lowest total organic acids, which makes sense since it is a low acid peach. For commercially-ripened fruit, genotype had an impact on isocitric acid, malic acid, and total organic acids. A-794 CN had the highest total organic acid, as this is a high acid nectarine. Bowden had the highest individual and total sugars, whereas A-819 had the lowest.

For the tree-ripened fruit, the range of the nutraceuticals was total anthocyanins of 0.31 to 2.78 mg/100g, total hydroxycinnamic acids of 3.26 to 25.68 mg/100 g, total flavonols of 1.35-to 7.84 mg/100 g, and carotenoids of 93.19 to 628.21 µg/100 g (Table 5). For the commercially-ripened fruit, the range of the nutraceuticals was total anthocyanins of 0.44 to 11.61 mg/100 g, total hydroxycinnamic acids of 3.43 to 23.66 mg/100 g, total flavonols of 1.89 to 6.76 mg/100 g, and carotenoids of 97.21 to 593.53 µg/100 g (Table 5). For tree-ripened fruit, A-663 CN had the lowest total hydroxycinnamic acids and the highest total flavonols, whereas A-819 had the highest total hydroxycinnamic acids and Souvenirs had the lowest total flavonols. For commercially-ripened fruit, A-663 CN had both the lowest total anthocyanins and total

hydroxycinnamic acids. In addition, A-663 CN had the highest carotenoids. Amoore Sweet had the highest hydroxycinnamic acids and the lowest flavonols.

Physiochemical Attributes of Commercially-ripened Fruit during Storage

The physiochemical attributes of the commercially-ripened fruit were evaluated during storage. The storage x genotype interaction was not significant for chlorophyll, fruit weight, soluble solids, pH, and titratable acidity, but was significant for firmness (Table 6 and Figure 2). During storage chlorophyll and fruit weight significantly decreased, while soluble solids increased (Table 3). There were no significant changes in pH or titratable acidity during storage. The average pH and titratable acidity during storage were 3.86 and 0.66%, respectively. When compared to fruit from day 14, fruit from day 0 had higher chlorophyll (0.62 abs) and fruit weight (187.40 g). Soluble solids were significantly lower at day 0 (9.13%) compared to days 7 and 14, 10.54% and 11.08%, respectively. Cirilli et al. (2016) found that once a peach or nectarine was picked, the soluble solids did not increase significantly, but the acidity decreased as the peach ripens due to enzyme metabolism.

During storage, genotypes differed significantly. A-663 CN and ‘Bradley’ (0.75 abs), had higher chlorophyll than A-885 (0.35 abs) and Souvenir (0.37 abs). For fruit weight, ‘Effie’ (203.11 g) was larger than A-794 CN (120.00 g). A-794 CN had a lower pH than A-819 and A-885. Effie (12.02%) and A-794 (11.96%) had higher soluble solids than A-819 (8.22%). A-885 (0.21%) had a lower titratable acidity than A-794 CN (1.25%).

The storage x genotype interaction was significant for firmness, but data for firmness was lost for ‘Amoore Sweet’ and A-885 at day 14 of storage. Among most of the genotypes, there was a general trend for firmness to increase from day 0 to day 7, but then decrease from day 7 to day 14 (Figure. 2). This softening behavior, with an initial stage of an increase in firmness,

followed by a rapid loss of firmness was also shown when assessing blueberry softening (Paniagua et al., 2013). There was a correlation between firming of blueberries during storage with very low moisture loss. ‘Souvenirs’ had the highest firmness at day 0, but the lowest at day 14, and the firmness decreased during storage. Clark and Sandefur (2013b) indicated that ‘Souvenirs’, a slow-melting-flesh peach, had excellent postharvest storage potential. A-819 had the lowest firmness on day 0, but firmness increased during storage. At day 14, A-663 CN, a non-melting nectarine, had the highest firmness.

Regardless of genotype, there was a decrease in chlorophyll and weight loss and an increase in soluble solids during storage, but there was not much change in pH and titratable acidity (Figure 3). There was also lower flesh firmness at day 14 when compared to day 0.

Conclusions

Understanding the postharvest physiology of the 10 peach and nectarine genotypes evaluated from the University of Arkansas System Division of Agriculture’s Fruit Breeding Program has identified possible maturity indices for each genotype. The data revealed high variability in ripeness parameters between the genotypes evaluated, indicating that genotype was the most important factor for determining postharvest quality and extended shelf-life. However, picking fruit to ripen during storage does impact the ripeness attributes when compared to picking fruit at tree ripeness.

The attributes of the tree-ripened fruit and the commercially-ripened fruit varied at harvest with commercially-ripened fruit having higher chlorophyll, titratable acidity, and firmness than tree-ripened fruit. However, tree-ripened fruit had slightly higher fruit weight, soluble solids, and pH than commercially-ripened fruit. For the tree-ripened fruit at harvest, A-811 CN was the largest fruit, A-794 CN had the highest soluble solids and titratable acidity, ‘Souvenirs’ had the lowest firmness, and ‘Amoore Sweet’ was the firmest. The flesh of the fruit

had a trend for higher (more yellow) values than the skin. The skin of A-811 CN for both tree and commercially-ripened fruit had the highest L* value and hue value. There were not any differences in the genotypes for sugars of tree or commercially-ripened fruit. For tree and commercially-ripened fruit, A-663 CN had the lowest total hydroxycinnamic acids.

During storage of the commercially-ripened fruit, there was a decrease in chlorophyll and weight loss and an increase in soluble solids, but there was not much change in pH and titratable acidity. During storage, A-885 had the lowest chlorophyll, 'Effie' was the largest and had the highest soluble solids, and A-794 CN had the lowest fruit weight, lowest pH, and highest titratable acidity. The titratable acidity and soluble solids reached the potential of tree-ripened fruit after 7 days of storage. However, some ripeness attributes of the commercially-ripened fruit, such as chlorophyll and fruit weight, were not achieved as compared to the tree-ripened fruit. The firmness of the commercially-ripened fruit at harvest increased from day 0 to day 7, but decreased from day 7 to day 14. Some of the genotypes evaluated performed well regardless of the fruit was picked to ripen during storage or picked ripe from the tree. The ripeness attributes evaluated will help to determine the optimal harvest time, handling, and storage conditions of peach and nectarines for growers in Arkansas and other regions. This research will provide insight on the potential for releasing new peach and nectarine cultivars from the University of Arkansas System Division of Agriculture's breeding program.

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Table 1. Fresh-market peach and nectarine genotypes harvested 23 June, 2017 from the University of Arkansas Division of Agriculture's Fruit Research Station, Clarksville, Arkansas.

Genotype	Type	Flesh color	Flesh type	Acid type
A-663 CN	Nectarine	Yellow	Non-melting	High
A-794 CN	Nectarine	White	Non-melting	High
A-811 CN	Nectarine	Yellow	Non-melting	High
A-819	Peach	Yellow	Melting	Low
A-885	Peach	White	Melting	Low
Amoore Sweet	Nectarine	Yellow	Non-melting	Low
Bowden	Nectarine	White	Non-melting	High
Bradley	Nectarine	Yellow	Non-melting	High
Effie	Nectarine	White	Non-melting	Low
Souvenirs	Peach	Yellow	Melting	Low

Table 2. Physiochemical attributes of tree-ripened and commercially ripened fresh-market peach and nectarine genotypes at harvest (day 0), University of Arkansas System Division of Agriculture's Fruit Research Station Clarksville, AR (2017).

Ripeness	Genotype	Chlorophyll (abs.) [a]	Fruit weight (g)	Soluble solids (%)	pH	Titratable acidity (%)[b]	Firmness (N)
Tree	**A-663 CN**	0.09 a [c]	177.33 a	7.80 b	3.77 b	0.63 abc	10.61 ab
	A-794 CN	0.15 a	207.67 a	12.57 a	3.55 b	0.88 a	9.42 ab
	A-811 CN	0.04 a	247.67 a	9.30 ab	3.52 b	0.51 a-d	10.61 ab
	A-819	0.15 a	214.33 a	8.33 b	4.66 a	0.40 cd	7.81 b
	A-885	0.15 a	199.67 a	10.60 ab	4.56 a	0.17 d	9.15 ab
	Amoore Sweet	0.12 a	232.67 a	10.40 ab	4.43 a	0.48 bcd	18.28 a
	Bowden	0.17 a	207.33 a	9.40 ab	3.43 b	0.84 ab	12.90 ab
	Bradley	0.05 a	210.00 a	9.17 ab	3.56 b	0.76 abc	11.36 ab
	Effie	0.18 a	142.33 a	10.90 ab	3.80 b	0.39 cd	18.03 a
	Souvenirs	0.07 a	210.00 a	10.77 ab	4.57 a	0.41 cd	6.92 b
P value		*0.2468*	*0.0599*	*0.0119*	*<0.0001*	*<0.0001*	*0.0045*
Commercial	**A-663 CN**	0.86 a	132.00 b	8.15 bc	3.49 c	0.78 bc	23.37 ab
	A-794 CN	0.52 abc	135.33 b	9.30 bc	3.18 c	1.21 a	32.67 a
	A-811 CN	0.51 abc	198.00 ab	8.83 bc	3.39 c	0.93 b	20.97 ab
	A-819	0.59 abc	178.33 ab	7.23 c	4.62 a	0.46 d	9.06 b
	A-885	0.39 bc	163.00 ab	12.17 a	4.54 a	0.16 e	20.14 ab
	Amoore Sweet	0.63 abc	217.67 ab	8.70 bc	4.33 a	0.58 cd	28.09 ab
	Bowden	0.71 abc	212.33 ab	9.70 abc	3.29 c	0.94 ab	22.95 ab
	Bradley	0.82 ab	191.67 ab	7.70 bc	3.33 c	0.74 bcd	15.72 ab
	Effie	0.80 ab	264.00 a	9.60 bc	3.61 bc	0.49 d	27.48 ab
	Souvenirs	0.32 c	181.67 ab	9.90 ab	4.15 ab	0.47 d	35.72 a
P value		*0.0029*	*0.0064*	*<0.0001*	*<0.0001*	*<0.0001*	*0.0075*

[a] Chlorophyll A of fruit skin measured by Delta Absorbance (DA) Meter (difference of absorbance between 670-720 nm) as an indicator of fruit ripeness.
[b] Calculated as percent malic acid.
[c] Genotypes were evaluated in triplicate. Means with different letter(s) for each attribute within ripeness are significantly different ($p < 0.05$) using Tukey's Honestly Significant Difference.

Table 3. Skin and flesh color attributes for fresh-market peach and nectarine genotypes at harvest (day 0), University of Arkansas System Division of Agriculture's Fruit Research Station Clarksville, AR (2017).

		Skin			Flesh		
Ripeness	**Genotype**	**L***	**Chroma**	**Hue**	**L***	**Chroma**	**Hue**
Tree	**A-663 CN**	63.21 a [a]	55.03 ab	68.44 a	70.65 a	51.42 a	88.03 a
	A-794 CN	49.30 bc	36.92 cd	41.76 cd	60.68 a	19.82 c	71.17 ab
	A-811 CN	68.03 a	56.60 ab	71.32 a	65.39 a	50.14 a	91.57 a
	A-819	57.63 ab	48.54 bc	60.58 abc	65.10 a	48.96 a	87.27 a
	A-885	43.60 c	36.99 cd	34.67 d	65.75 a	21.19 c	58.90 b
	Amoore Sweet	64.29 a	54.23 ab	69.31 a	67.72 a	37.39 ab	91.67 a
	Bowden	66.88 a	32.46 d	62.91 ab	78.03 a	24.82 bc	98.97 a
	Bradley	67.56 a	61.41 a	71.14 a	72.43 a	49.95 a	88.40 a
	Effie	42.97 c	40.57 cd	31.79 d	74.44 a	18.69 c	82.77 ab
	Souvenirs	47.92 bc	40.34 cd	44.52 bcd	72.95 a	41.69 a	94.27 a
	P value	*<0.0001*	*<0.0001*	*<0.0001*	*0.0642*	*<0.0001*	*0.0027*
Commercial	**A-663 CN**	63.76 ab	52.83 ab	76.13 ab	72.72 ab	55.25 a	89.33 ab
	A-794 CN	46.05 c	42.21 cde	38.09 c	59.61 b	17.13 d	70.73 c
	A-811 CN	70.19 a	54.84 a	79.10 a	70.40 ab	52.09 a	93.77 ab
	A-819	59.75 ab	47.28 bc	67.90 ab	68.91 ab	51.58 a	85.67 b
	A-885	46.34 c	37.15 ef	36.30 c	69.82 ab	14.38 d	70.23 ab
	Amoore Sweet	61.68 ab	51.99 ab	66.48 ab	60.48 b	40.80 abc	90.53 c
	Bowden	67.03 a	38.07 def	73.98 ab	79.03 a	28.96 bcd	99.90 a
	Bradley	66.82 a	56.30 a	73.93 ab	73.45 ab	53.94 a	88.83 ab
	Effie	64.34 ab	33.22 f	68.64 ab	77.63 a	24.39 cd	100.23 a
	Souvenirs	53.07 bc	43.45 cd	51.81 bc	74.47 ab	44.30 ab	97.60 ab
	P value	*<0.0001*	*<0.0001*	*<0.0001*	*0.0087*	*<0.0001*	*<0.0001*

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

Table 4**.** Organic acids and sugars for fresh-market peach and nectarine genotypes at harvest (day 0), University of Arkansas System Division of Agriculture's Fruit Research Station Clarksville, AR (2017).

Ripeness	Genotype [z]	Isocitric acid (g/100 g)	Malic acid (g/100 g)	Total organic acids (g/100 g)	Glucose (g/100 g)	Fructose (g/100 g)	Total sugars (g/100 g)
Tree	**A-663 CN**	0.40 a [a]	0.49 a	0.89 a	3.10 a	3.06 a	6.16 a
	A-794 CN	0.16 a	0.22 a	0.38 a	2.39 a	2.54 a	4.93 a
	A-811 CN	0.19 a	0.34 a	0.53 a	2.76 a	3.01 a	5.76 a
	A-819	0.06 a	0.03 a	0.08 a	0.90 a	1.50 a	2.40 a
	A-885	0.07 a	0.12 a	0.20 a	5.17 a	5.65 a	10.82 a
	Amoore Sweet	0.08 a	0.04 a	0.12 a	1.40 a	2.13 a	3.53 a
	Bowden	0.49 a	0.25 a	0.74 a	3.79 a	4.12 a	7.91 a
	Bradley	0.13 a	0.23 a	0.36 a	1.53 a	1.62 a	3.15 a
	Effie	0.24 a	0.19 a	0.42 a	3.44 a	3.91 a	7.35 a
	Souvenirs	0.06 a	0.03 a	0.09 a	0.63 a	1.34 a	1.97 a
	P value	0.0318	0.0655	0.0333	0.3263	0.4729	0.4022
Commercial	**A-663 CN**	0.13 ab	0.09 b	0.22 b	1.03 a	1.05 a	2.08 a
	A-794 CN	0.90 a	0.71 a	1.60 a	3.94 a	3.58 a	7.52 a
	A-811 CN	0.21 ab	0.21 ab	0.42 ab	1.45 a	1.54 a	2.99 a
	A-819	0.10 b	0.04 b	0.13 b	0.52 a	0.90 a	1.42 a
	A-885	0.06 b	0.03 b	0.09 b	1.43 a	1.49 a	2.92 a
	Amoore Sweet	0.13 ab	0.06 b	0.19 b	3.31 a	4.80 a	8.10 a
	Bowden	0.79 ab	0.59 ab	1.38 ab	4.78 a	4.97 a	9.75 a
	Bradley	0.22 ab	0.20 ab	0.42 ab	1.03 a	0.93 a	1.97 a
	Effie	0.21 ab	0.10 b	0.31 ab	1.55 a	1.64 a	3.19 a
	Souvenirs	0.41 ab	0.13 ab	0.54 ab	3.33 a	3.53 a	6.87 a
	P value	0.0083	0.0051	0.0051	0.0948	0.0600	0.0781

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

Table 5**.** Nutraceutical for fresh-market peach and nectarine genotypes at harvest (day 0), University of Arkansas System Division of Agriculture's Fruit Research Station Clarksville, AR (2017).

Ripeness	Genotype	Total anthocyanins (mg/100 g)	Total hydroxycinnamic acids (mg/100 g)	Total flavonols (mg/100 g)	Carotenoids (ug/100 g)
Tree	**A-663 CN**	0.31 a [a]	3.26 d	7.84 a	278.05 a
	A-794 CN	2.71 a	7.91 cd	4.50 abc	468.76 a
	A-811 CN	0.62 a	4.24 d	4.45 abc	410.57 a
	A-819	2.34 a	25.68 a	5.92 ab	628.21 a
	A-885	*	*	*	*
	Amoore Sweet	0.83 a	16.93 b	2.62 bc	93.19 a
	Bowden	0.71 a	11.42 bc	3.29 abc	98.76 a
	Bradley	0.90 a	6.12 cd	4.13 abc	51.14 a
	Effie	* [b]	*	*	*
	Souvenirs	2.78 a	4.38 d	1.35 c	378.02 a
	P value	0.1222	<0.001	00057	0.4232
Commercial	**A-663 CN**	0.48	3.43 c	4.57 abc	593.53 a
	A-794 CN	3.32 bc	4.03 c	3.55 abc	466.30 a
	A-811 CN	0.44 c	3.99 c	2.55 c	209.73 a
	A-819	1.83 c	13.03 b	6.76 a	273.45 a
	A-885	11.61 a	14.02 b	2.24 c	273.06 a
	Amoore Sweet	1.28 c	23.66 a	1.89 c	101.04 a
	Bowden	0.88 c	15.33 b	2.90 bc	114.54 a
	Bradley	0.93 c	7.28 bc	5.49 ab	97.21 a
	Effie	*	*	*	*
	Souvenirs	5.24 b	10.41 bc	2.11 c	283.24 a
	P value	<0.0001	<0.0001	0.0004	0.0365

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

[b] Missing data

Table 6. Main and interaction effects for physiochemical attributes of commercially ripened fresh-market peach and nectarine genotypes stored at 4 °C for 0, 7, and 14 days, University of Arkansas System Division of Agriculture's Fruit Research Station, Clarksville, AR (2017).

	Chlorophyll (abs.)	**Fruit weight (g)**	**Soluble solids (%)**	**pH**	**Titratable acidity (%)[a]**
Storage					
0 days	0.62 a[b]	187.40 a	9.13 b	3.79 a	0.68 a
7 days	0.60 a	163.53 b	10.54 a	3.91 a	0.66 a
14 days	0.50 b	150.83 b	11.08 a	3.89 a	0.63 a
P value	<0.0062	<0.0001	<0.0001	*0.1722*	*0.1990*
Genotype					
A-663 CN	0.75 a	138.67 bc	9.12 bcd	3.55 def	0.79 cd
A-794 CN	0.46 bcd	120.00 c	11.96 a	3.21 f	1.25 a
A-811 CN	0.44 cd	178.11 ab	9.63 bcd	3.41 ef	0.93 bc
A-819	0.63 abc	175.00 ab	8.22 d	4.60 a	0.43 f
A-885	0.35 d	162.44 abc	11.41 ab	4.58 a	0.21 g
Amoore Sweet	0.65 abc	180.56 ab	10.47 abcd	4.40 ab	0.51 ef
Bowden	0.68 ab	181.89 ab	10.91 abc	3.27 ef	0.97 b
Bradley	0.75 a	171.56 ab	8.66 cd	3.62 de	0.67 de
Effie	0.64 abc	203.11 a	12.02 a	3.83 cd	0.37 fg
Souvenirs	0.37 d	161.22 abc	10.08 abcd	4.16 bc	0.42 f
P value	*<0.0001*	<0.0001	*<0.0001*	*<0.0001*	*<0.0001*
Storage x Genotype (P value)	*0.2035*	*0.3353*	*0.2019*	*0.4939*	*0.4688*

[a] Calculated as percent malic acid.

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

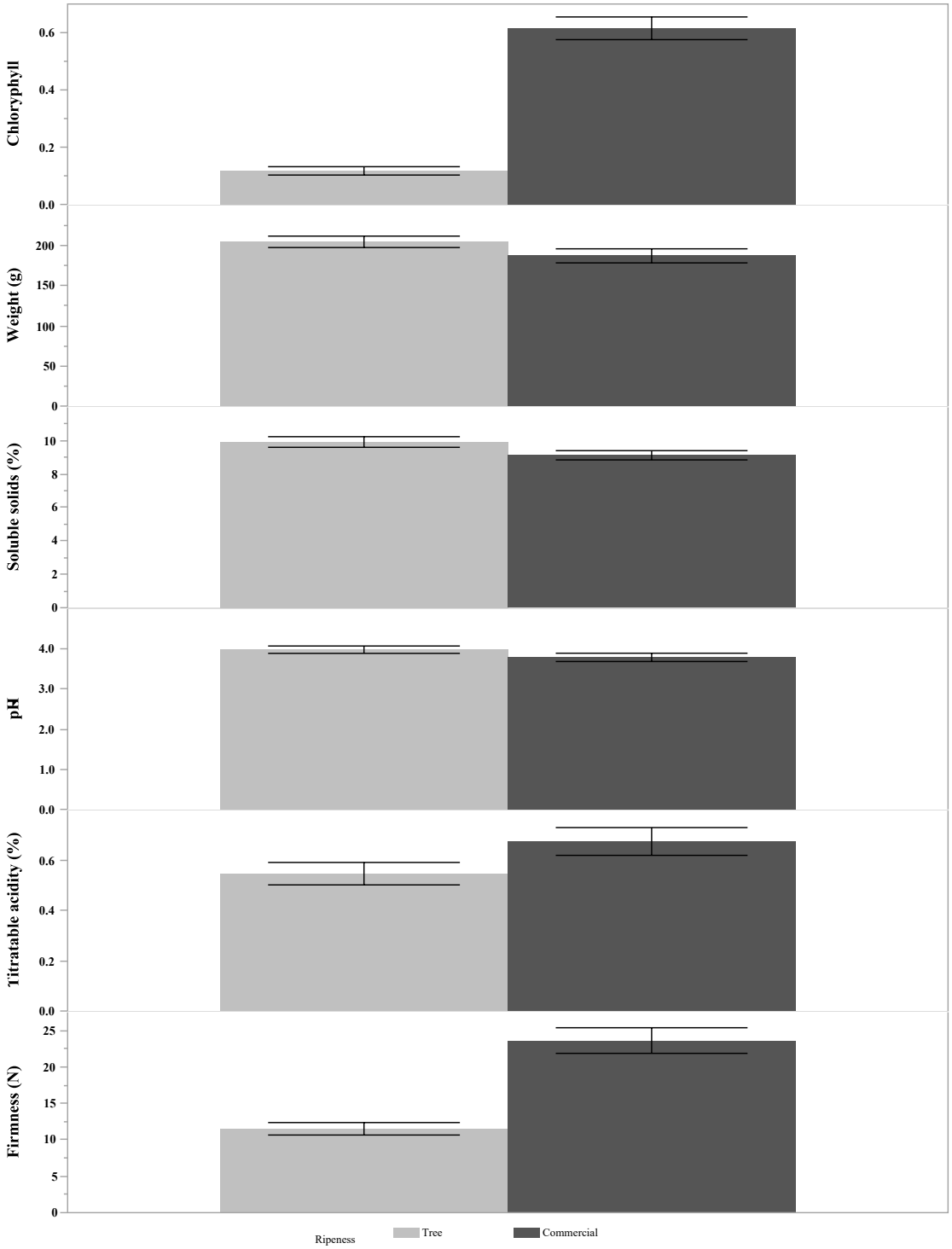

Figure 1. Physiochemical attributes of tree-ripened and commercially ripened fresh-market peach and nectarine genotypes at harvest (day 0), University of Arkansas System Division of Agriculture's Fruit Research Station, Clarksville, AR (2017). Each standard error bar is constructed using 1 standard error from the mean.

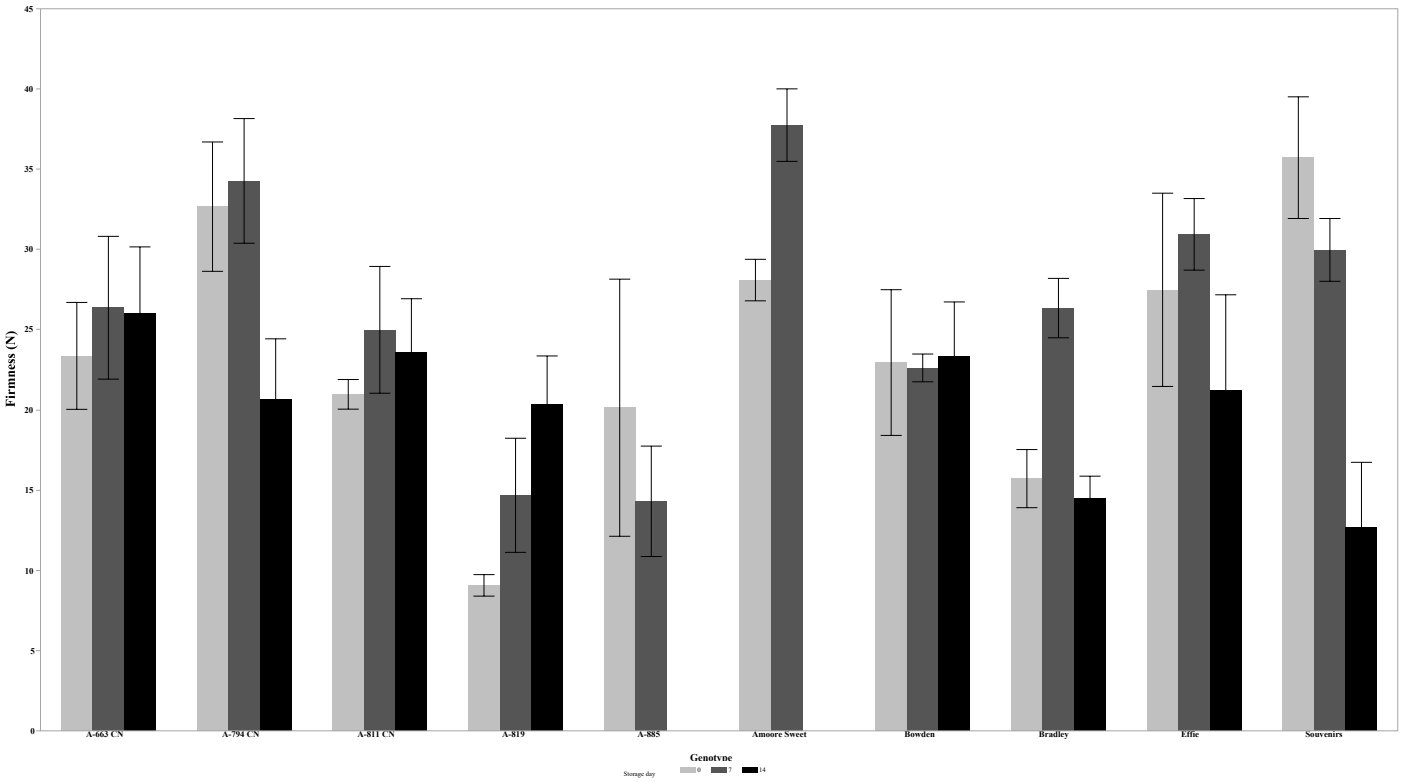

Figure 2. Firmness of commercially ripened fresh-market peach and nectarine genotypes during storage at 0, 7, and 14 days at 4 °C, University of Arkansas System Division of Agriculture's Fruit Research Station, Clarksville, Arkansas (2017). Each standard error bar is constructed using 1 standard error from the mean. Data is missing for Amoore Sweet and A-885 at 14 days of storage.

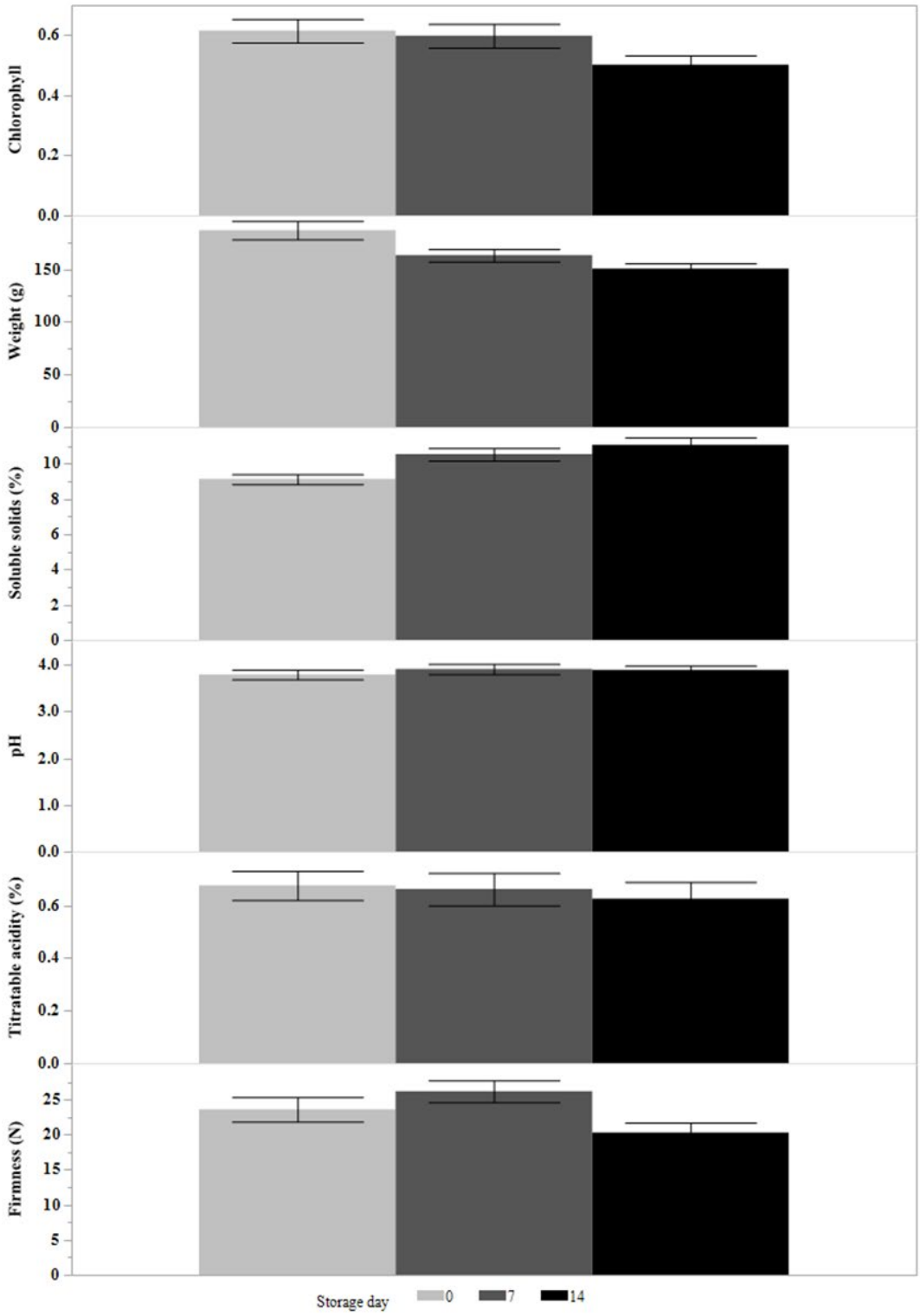

Figure 3. Physiochemical attributes of commercially ripened fresh-market peach and nectarine genotypes during storage at 0, 7, and 14 d at 4 °C, University of Arkansas System Division of Agriculture's Fruit Research Station, Clarksville, Arkansas (2017). Each standard error bar is constructed using 1 standard error from the mean.