Received: 15 May 2023 | Revised: 9 December 2023 | Accepted: 14 December 2023

DOI: 10.1002/jsf2.183

RESEARCH ARTICLE

JSFA Reports

Nitrogen fertilization rates in a subtropical peach orchard: Effect on fruit nutritional value and flavor

Zilfina Rubio Ames[1] | Jeffrey K. Brecht[1] | Mercy A. Olmstead[1] | Denise Tieman[1] | Charles A. Sims[2]

[1]Horticultural Sciences Department, University of Florida, Gainesville, Florida, USA

[2]Food Science and Human Nutrition Department, University of Florida, Gainesville, Florida, USA

Correspondence
Zilfina Rubio Ames, Horticultural Sciences Department, University of Florida, Gainesville, FL, USA.
Email: zilfina.rubioames@uga.edu

Present addresses
Zilfina Rubio Ames, University of Georgia, Tifton Campus, Tifton, Georgia 31793, USA; and Mercy A. Olmstead, Driscoll's, Salinas, California, 93908, USA.

Funding information
Florida Department of Agriculture and Consumer Service, Specialty Crop Block grant, Grant/Award Number: FEID-59-6002052

Abstract

Background: The necessity to help farmers improve yields has resulted in many years of agricultural research focused on productivity and disease resistance, neglecting other areas of fruit quality such as flavor, health benefits, and external appearance. Nitrogen is required for several biochemical processes. However, reducing N fertilization can increase the synthesis of antioxidants and volatile aroma compounds. Four-N rates (0 (N0), 45 (N1), 90 (N2), 179 (N3), and 269 (N4) kg ha^{-1}) were tested each year from 2011 to 2017 in two peach varieties melting flesh (MF) 'TropicBeauty' (TB), a soft texture peach, and non-melting flesh (NMF) 'UFSharp' (UFS), a crispy texture peach, to determine the effect of N on nutritional value and flavor.

Results: The phytochemical composition of the NMF 'UFSharp' (UFS) and MF variety 'TropicBeauty' (TB) were not cleared affected by N rates. Volatile synthesis was little affected by N. The sensory evaluation showed that consumers preferred MF peaches compared with NMF, because of its juiciness.

Conclusions: Nitrogen fertilization had minor effects on peach fruit phytochemical composition, volatile aroma compounds, and consumer acceptability. The N effect could had been influence by pruning practices, training of the orchard, and the delay of fruit developmental period.

KEYWORDS
nitrogen, peach, quality, volatiles

INTRODUCTION

Nitrogen is a fundamental nutrient for plants and plays a primary role in peach tree physiology.[1,2] Peaches take up N from the soil in the form of nitrate (NO_3) and ammonium (NH_4). Nitrogen is stored in the roots, bark, and in the parenchyma tissue of shoots as protein.[1–5] Nitrogen fertilization affects tree vegetative growth, flower bud production, and fruit compositional attributes in peach.[6–11] As a key component of the amino acids that are the building blocks of enzyme and proteins, N is also a necessary requirement for all plant metabolism. That includes synthesis of the sugars, acids, and volatile aroma compounds that determine the flavor of peaches. However, fruit composition is also influenced by the genetic background of the crop, environmental conditions (rain, growing degree hours, spring freezes, chilling accumulation, and light interception), cultural practices, maturity stage at harvest, and postharvest handling.[12,13]

The nutritional value of peach is an important component of fruit quality, since consumption of fruits and vegetables is beneficial for our health.[14] Peaches are rich in vitamin C, provitamin A and other carotenoids, and several phenolic compounds such as flavonoids and anthocyanins, all of which have antioxidative, cardioprotective, and chemopreventive properties.[15–17] The phytochemical content of peaches is affected by harvest maturity and cultural practices. As peach fruit matures, an increase in phenolics, carotenoids, and ascorbic acid is observed.[18] The enzyme phenylalanine ammonia-lyase (PAL), which controls the synthesis of phenolic compounds and flavonoids, is affected by N fertilization.[19] Under low and medium N fertilization, the PAL activity is low, and thus phenolic compounds could also be reduced by inadequate N fertilization. As well as being responsible for some beneficial health properties, phenolic compounds are also related to sensory attributes such as astringency in peach fruit.[20]

The antioxidant capacity of peach fruit does not seem to be affected by mineral and organic fertilization, since peach trees grown with 120 kg/ha of conventional N fertilizer had the same antioxidant capacity as peach trees grown with 10 tons DW/ha of compost.[21] However, other factors may be involved. Vashisth[22] reported higher amounts of phenolic compounds and higher antioxidant activity on the low-chill cultivars TropicBeauty (TB) and UFSharp (UFS) receiving zero N (and thus probably experiencing some stress) than trees grown with 269 kg/ha N.[23]

Volatile aroma compounds are found in fruits in low trace amounts, and each type of fruit produces a unique set of volatiles.[24] For peach fruit, more than 80 aroma compounds have been identified, but only about 12 to 20 compounds are important components of the peach aroma profile.[25–27] Volatile compounds and sensory attributes may also be affected by N rates, with peach trees grown under high N reported to produce sour and bitter fruit.[28] Those fruit had lower levels of the aroma compound ϒ-decalactone and were less liked by sensory panelists. In contrast, peach puree from non-fertilized peach trees was judged to be sourer than puree from fertilized trees that received N at 45 or 90 kg/ha.[29] The amount of volatile compounds was affected by fertilizer source, with fruit from peach trees receiving N chemical fertilization having lower amounts of volatile compounds than fruit from trees fertilized with compost.[21]

Thus, there is not a clear understanding of how N fertilization affects nutritional value and sensory properties in peach fruit, especially in a subtropical environment. Therefore, the objective of this research was to study the importance of different N fertilization rates on peach trees grown under subtropical conditions in order to provide consumers with peach fruit that possess adequate nutritional value and the highest edible quality.

MATERIALS AND METHODS

Plant material and nitrogen treatments

Two-Year-Old 'TropicBeauty' (TB) and 'UFSharp' (UFS) trees on 'Flordaguard' rootstock were planted in 2010 at the UF-IFAS Plant Science Research and Education Unit (PSREU) at Citra, Florida. These two peach varieties differ in their texture characteristics, with TB being a wild type melting flesh (MF) peach and UFS expressing the mutant non-melting flesh (NMF) trait.[30,31] Melting flesh peaches soften rapidly and have a smooth texture, non-melting flesh peaches on the contrary have a rubbery or crispy texture and soften gradually. The experimental plot had 10 rows and each row had 20 trees, half UFS and half TB, randomly distributed in each row. The trees were spaced 6.09 m between rows and 1.82 m between trees. Trees were established under five nitrogen (N) treatments with 0 (N1), 45 (N1), 90 (N2 – the commercially recommended rate), 179 (N3), and 269 (N4) kg/ha applied each year, with each N treatment replicated twice (i.e., on two rows of trees). The annual application rates for phosphorus and potassium remained constant from tree establishment through the course of the project, at 37 and 74 kg/ha (33 and 66 lbs/acre), respectively. The fertilizers used were urea ammonium nitrate, phosphoric acid, and potassium chloride. Fertilizers were applied daily, through a micro irrigation system, using a micro sprinkler for each tree. Fertilizer applications were started each year in mid-March and continued for about 26 weeks. Trees were trained in a perpendicular "V" shape,[32] summer and winter pruned in the same manner every year, and the pruning weights recorded. Fruit were thinned before pit hardening to a 6-inch (15-cm) spacing on branches. The experimental peach orchard was managed according to standard cultural practices as performed in commercial orchards.[33]

Starting 5 years after crop establishment, peach fruit were harvested three times in each of three consecutive seasons (2015, 2016, and 2017). Fruit were harvested based on subjective evaluation of ground color change in the first two seasons. In the third year, fruit were harvested based on firmness (∼10 lbs) measured using a Magness-Taylor handheld penetrometer with an 8-mm diameter tip. Fruit used for measurements of phytochemical compounds, antioxidant capacity, and volatiles were stored for 7 days at 0°C then transferred to 20°C to ripen and were analyzed at the ripe stage. In the 2015 and 2016 seasons, fruit from all harvests were analyzed. In 2017, only fruit from the second harvest of each variety were analyzed since that harvest provided the vast majority of the fruit yield for the season.

For phytochemical analyses, five groups of five fruit of each variety. from each replicate of each N treatment were pitted and the skin and flesh blended to produce a smooth slurry. A portion of the resulting homogenate was weighed, according to the amount needed for each analysis. Samples for each phytochemical compound and for antioxidant analyses were stored at −20°C until needed. All the steps in the phytochemical analyses were performed under yellow light to avoid deterioration of double bonds and hydroxyl groups.

Volatile collection: each N treatment had three replicates and each replicate was composed of three sets of five fruit. This was done for both varieties.

Sensory evaluation: About 15 fruit from each treatment per variety were randomly selected from among the treatment replicates.

Phytochemical measurements

Total anthocyanins

A 2.0-g aliquot of peach mesocarp and epicarp tissue (flesh and skin), homogenized as previously described, was weighed then stored at −20°C until the date of analysis. The anthocyanins were extracted using 15 mL of a 95% ethanol:1.5 N HCl solution (85:15). The mixture was blended (GLH, Omni International, Kennesaw, GA, USA) and stored at 4°C overnight. The mixture of the homogenized tissue and ethanol:HCl solution was then centrifuged for 15 min at 29,000 × g_n at 2°C (Sorvall LYNX 4000). The supernatant was decanted and filtered through cheesecloth. A 5.0-mL aliquot of clear supernatant was taken and the volume was adjusted to 15 mL using deionized (DI) water. A PowerWave XS microplate reader spectrophotometer (Biotek Winooski, VT, USA) was zeroed with the extraction solvent as a blank and the samples were read at 535 nm. Results were expressed as total anthocyanins (mg/100 g FW). This protocol was based on Vizzotto.[34]

Total carotenoids

A 2.0-g aliquot of homogenized peach mesocarp and epicarp tissue (flesh and skin) was weighed and stored at −20°C until the date of analysis. Ethanol (95%) and hexane (HPLC Grade, 98.5%) were mixed in a 1:1 proportion and 200 mg of butylated hydroxytoluene (BHT) was added to create the solvent mixture. The solvent mixture was shaken vigorously for 20 s, then 20.0 mL was added to a 50-mL centrifuge tube containing the blended tissue sample. Tissue and solvent were homogenized (GLH) and left overnight at 4°C. The solution was then centrifuged for 20 min at 29,000 × g_n at 2°C. The supernatant (hexane with carotenoids) was next transferred to a different tube (extraction pool). The pellet was resuspended by adding additional solvent mixture and re-homogenizing. This step was repeated three times. For the last extraction, 20.0 mL of DI water was added to the tissue, the pellet was resuspended, and the mixture was centrifuged. The resulting supernatant was recovered and transferred to the extraction pool. A second 20.0-mL aliquot of DI water was added to the extraction pool, and the mixture was vortexed before being placed in a −20°C freezer for 1 h or overnight. Samples in tubes were placed in crushed ice after taking them out of the freezer. The upper phase of washed hexane was transferred to a clean tube and 10.0 mL additional hexane was added. Absorbance of carotenoids was read at 470 nm. Hexane was used as a blank. Total carotenoids were calculated using the formula (A*V × 106)/ (A1% × 100G) where A = absorbance, V = total volume used, A1% = 2500 Talcott and Howard,[35] and G = tissue samples in grams. Results were expressed as mg/100 g FW. This protocol was based on Vizzotto.[34]

Ascorbic acid

The total amount of ascorbic acid was measured using the method of Terada.[36] A 2.0-g aliquot of homogenized peach mesocarp and epicarp tissue (flesh and skin) was weighed and immersed in a mixture of 6% metaphosphoric acid in 2 N acetic acid (20.0 mL). Samples were stored at −20°C until analyzed. On the day of analysis, samples were thawed and centrifuged at 29,000 × g_n for 20 min at 2°C (Sorvall LYNX 4000). The supernatant was recovered and filtered through cheesecloth. Each sample was analyzed using 1.0 mL of 2% thiourea and 0.5 mL of 2% dinitrophenylhydrazine (DNPH) were added to each sample test tube. The blank did not receive DNPH. Tubes were vortexed, covered with marbles and incubated for 3 h at 60°C in a water bath. The blank was left at room temperature. After incubation, sample test tubes were chilled in ice, then 2.5 mL of cold 90% sulfuric acid was added. At this moment, 0.5 mL 2% DNPH was added to the blank followed by 2.5 mL of cold 90% sulfuric acid. An aliquot of 250 μL from each sample was placed in a microplate. Absorbance was read at 540 nm using a microplate reader (PowerWave XS). The concentration of total ascorbic was calculated using a standard curve. Results were expressed as mg of ascorbic acid/100 g FW.

Total phenolics

Total phenolics in peach juice were determined using the Folin–Ciocalteu (FC) method.[37] Different concentrations of gallic acid were used to develop a standard curve using a stock solution of 5 mg/mL concentration. Water was used as a blank. Peach juice (0.5 mL) was diluted in 4.5 mL of DI water. Samples and standards were replicated three times. An aliquot of 0.5 mL of each dilution was pipetted into a test tube, and 2.5 mL of 0.2 N FC reagent was added. Between 30 s after addition of FC, but before 8 minutes elapsed, 2 mL of 7.5% sodium carbonate were added. Test tubes were incubated for 1 h at 30°C and then transferred at 0°C for approximately 1 h. An aliquot of 250 μL of each sample was pipetted into a 96-well plate and absorbance was read at 765 nm (PowerWave XS). Results were expressed as mg of gallic acid equivalents per 100 g FW.

Flavonoids

Flavonoids were determined using 5.0 g of homogenized mesocarp and epicarp tissue (flesh and skin). The protocol used for flavonoid determination was based on Cantin.[15] Tissue was homogenized (GLH) in 10.0 mL of a 0.5 N HCl in methanol solution. The mixture was centrifuged at 20,000 × g_n for 20 min at 2°C (Sorvall LYNX 4000). The recovered supernatant was filtered through cheesecloth. In a test tube, 1.0 mL of the supernatant was diluted in 2.0 mL of DI water, followed by the addition of 0.3 mL of 5% $NaNO_2$. After 5 min, 0.3 mL of 10% $ALCl_3$ were added. After 1 min, 2.0 mL of 1 N NaOH was added and the solution was mixed by vortexing. An aliquot of 250 μL of each sample was pipetted into a 96-well plate and absorbance was read at 510 nm (PowerWave XS). Different concentrations of catechin were used for the standard curve. Results were expressed as mg of catechin equivalents per 100 g FW.

Antioxidant capacity

Antioxidant capacity was determined using the Oxygen Radical Absorbance Capacity (ORAC) method described by Huang.[38] A 25.0-g aliquot of homogenized mesocarp and epicarp tissue (flesh and skin) was weighed and stored at −20°C until analyzed. On the day of analysis, tissue was mixed (GLH) and centrifuged at 29,000 × g_n for 20 min at 2°C. The supernatant was recovered and filtered through cheesecloth. The supernatant was diluted through a serial dilution to obtain the appropriate amount of sample to be used for the analysis. Different concentrations of Trolox® (6-hydroxy-2,-5,7,8-tetramethylchromane-2- carboxylic acid) were used to develop a standard curve. A 96-well polystyrene plate was used; outside wells were not used and were each was filled with 250 μL of water. The sample wells were filled with 150 μL of 4.196 ×10-3 mM sodium fluorescein and 25 μL supernatant samples or Trolox®. The plate was incubated for 15 min at 37°C. The kinetic reaction was initiated by the addition of 25 μL of 153 mM 2, 2′-azobis (2-amidinopropane) dihydrochloride (AAPH). Fluorescence was monitored kinetically every minute for a total of 60 min. A synergy TM HT Multi-Detection Microplate Reader (Biotek, Winooski, VT USA) with an excitation filter of 485 nm and an emission filter of 528 nm was used. Fluorescence of each of the wells was measured from the bottom. The net area under the curve (AUC) for standards and samples was calculated using the formula from Cao and Prior (1999). The standard curve was obtained by plotting Trolox® concentration against AUC values. Sample antioxidant capacity values were obtained using the standard curve. Results were expressed as Trolox® equivalents per g FW.

Volatiles measurement

Volatiles were collected and quantified using the protocol of Tieman.[39] The edible portion (mesocarp and epicarp tissue) of five peach fruit was diced into approximately 1-cm cubes and mixed. Approximately 100 g of the mixture was weighed (exact weight was recorded). Each sample was inserted into a glass tube and stoppers placed in both ends. Each glass tube was connected to the house air flow at one end and a trapping divinylbenzene resin column (SuperQ; Agilent, Palo Alto, CA) was inserted in the other end. Air flow (55 mL min^{-1}) was allowed to continue for 1 h. Methanol chloride (150 μL) containing a known amount of nonylacetate as internal standard was introduced onto the divinylbenzene resin column. Volatiles were then eluted from the resin columns by flushing with nitrogen gas and the methanol chloride containing the volatiles was collected into vials. Vials were placed at −80°C until analyzed. Samples were separated using a DB-5 column (Agilent, www.agilent.com) and analyzed on an Agilent 6890 N gas chromatograph with FID detector. Retention times were compared with known standards, and the identities of the volatile peaks were confirmed by mass spectrometry using a NSIT 2005 library. Volatile levels were calculated as ng per g FW per h of collection.

Sensory evaluation

Fruit from each of the peach varieties and N treatments were subjected to a consumer sensory panel. In 2015 and 2016, three sensory panel sessions were conducted. In the first session, panelists compared all the N treatments for TB (Tables 2 and 6); in the second session, the extreme treatments (0 N and 249 N) and the recommended commercial N rate (90 N) applied to TB and UFS were compared (Tables 3 and 7). In the third session, all the N treatments for UFS were evaluated (Tables 4 and 8). In 2017, only two sensory panel sessions were performed. In the first one, panelists compared all the N treatments in TB (Table 9), and in the second, the UFS N treatments N0, N1, N2, and N3, plus N2 and N4 from TB were compared (Table 10).

Then 30–35 peaches of each variety from each N treatment were designated for sensory evaluation. Each fruit was sliced longitudinally, and about six to eight slices were obtained from each peach. All slices from each treatment were combined to create a random mixture. Each panelist was provided with two randomly selected peach slices from each treatment being evaluated. Samples were presented to panelists labeled with a three-digit random number, and the order of presentation of the samples was set using the Williams design.[40] An average of 80 panelists were used for each evaluation.

Panelists used the Global Hedonic Intensity Scale (GHIS), the Global Sensory Intensity Scale (GSIS), and the hedonic just-right scale to rate each of the peach attributes.[41] Texture, overall liking, and flavor were rated using the GHIS scale from −100 to 100, where 100 is the strongest liking ever experienced by the panelist and −100 is the strongest disliking ever experienced. Firmness and juiciness were rated using the hedonic just-right scale (JRS) from 1 to 5, where 1 was much too soft and dry and 5 was much too hard and juicy. Sweetness, sourness, bitterness, and overall peach flavor intensity were rated using the GSIS from 0 to 100, where 100 is the strongest sensation of any kind the panelist has ever experienced and zero is no sensation at all.

The sensory evaluation was performed at University of Florida Sensory laboratory. The laboratory focuses on providing sensory services using quantitative and qualitative testing methods. The laboratory is regulated by The Internal Review Board at the University of Florida, and panelist signed a consent agreement before their participation in the consumer sensory evaluation.

Statistical analysis

Data were analyzed using JMP. A one-way ANOVA at $\alpha = 0.05$ was performed to measure the effect of each of the N treatments on fruit nutritional value and volatile compounds. Each variety was analyzed separately. Mean separation was performed using Tukey's test at $\alpha = 0.05$. Sensory data were analyzed using COMPUSENSE using a two-way ANOVA, and means were separated by Tukey's test at $\alpha = 0.05$.

RESULTS

2015 Season

For the phytochemical compounds investigated in 2015, treatment differences were only found for anthocyanin accumulation in the MF

TABLE 1 Total phenolics, total flavonoids, total carotenoids, total anthocyanins, ascorbic acid, and antioxidant capacity in 'TropicBeauty' peaches under different nitrogen fertilization rates.

Year	N treatment (kg/ha)	Total phenolics (mg of gallic acid/100 g FW)	Total flavonoids (mg of catechin/100 g FW)	Total carotenoids (mg/ 100 g of FW)	Total anthocyanins (mg/100 g FW)	Ascorbic acid (mg/100 g FW)	Antioxidant capacity (μM Trolox equivalents/g FW)
2015	N0-0	47.7	13.5	9.6	1.5b[a]	11.7	143.5
	N1-45	68.3	21.1	13.0	1.3b	13.2	149.8
	N2-90	57.1	20.6	9.6	1.7ab	11.2	112.6
	N3-179	60.8	19.6	12.5	1.7ab	12.9	136.2
	N4-269	68.7	19.4	14.2	2.6a	12.7	216.2
	p-value	*0.6214*	*0.4152*	*0.225*	*0.0262*	*0.8655*	*0.0517*
2016	N0-0	57.6b	13.7b	15.7a	0.1b	14.4	200.7b
	N1-45	60.5b	16.5b	13.3ab	0.1b	14.8	295.1a
	N2-90	55.6b	16.8b	14.9a	0.1b	14.7	303.9a
	N3-179	64.7b	17.8b	10.5ab	0.1b	14.4	288.2a
	N4-269	78.7a	32.4a	8.9b	0.3a	15.6	349.6a
	p-value	*0.0001*	*0.0001*	*0.0075*	*0.0001*	*0.6357*	*0.0001*
2017	N0-0	40.2ab	12.4	8.7b	0.1ab	8.9	201.3b
	N1-45	30.9b	11.8	8.9b	0.13a	9.3	280.ab
	N2-90	35.8ab	12.0	9.9ab	0.1ab	9.50	374.0a
	N3-179	45.9a	10.6	9.1b	0.08b	8.6	236.7b
	N4-269	33.1b	12.2	10.5a	0.1a	9.4	226.9b
	p-value	*0.0028*	*0.6367*	*0.0028*	*0.0025*	*0.3847*	*0.008*

[a]Means not followed by the same letter are significantly different at $p \leq 0.05$ according to Tukey's test.

variety TB. In that case, tripling the recommended N rate yielded fruit with higher anthocyanin concentration compared with zero N or half the recommended rate (N1, 45 kg/ha) (Table 1). No differences were observed in UFS (Table 5). In the same year, the amounts of the volatiles trans-2-hexanal and isopentyl acetate in UFS fruit were significantly affected by N (Figure 1). Fruit from trees treated with the recommended N rate in 2015 had the highest amount of trans-2-hexanal and the zero N treatment had the lowest. Fruit from N0 had the highest amount of isopentyl acetate and this was significantly different from the other treatments (Figure 1).

For the 2015 sensory evaluation in which TB fruit from all N treatments were compared, fruit from trees treated with three times the recommended N rate (269 kg/ha) had the highest overall liking score and were significantly different from N1, half the recommended rate (45 kg/ha) (Table 2). In addition, fruit from N4 were judged by the panelists to have good texture and flavor. Differences in firmness were found in which fruit from trees treated with the commercial N rate (N2–90 kg/ha), double the recommended N rate (N3, 180 kg/ha) and three times the recommended N rate (N4–269 kg/ha) were judged to be significantly different from the reduced N rate of 45 kg/ha; for this attribute, N4 was rated the best, meaning the firmness of the fruit was considered just right by the panelists. Fruit from trees in which the N was reduced or zero N was applied were judged to be a little too soft. Fruit from TB trees treated with half of the recommended N rate (N1, 45 kg/ha) were rated as the juiciest, and those fruit were also less firm and their texture was less liked. Fruit from the highest N rate (N4, 269 kg/ha) also received higher sweetness scores than the other treatments, but those were significantly different only from N3 (179 kg/ha). No differences were found in sourness, bitterness, or overall peach flavor. In 2015, the sensory evaluation in which fruit from the melting flesh variety TB and the non-melting flesh variety UFS from different N treatments were compared, the treatment with the highest N rate (N4, 269 kg/ha) of TB was the most liked by the panelists, more than N4 from UFS (Table 3). Fruit from the NMF variety UFS treated with triple the recommended N rate (264 kg/ha) had the lowest rating for flavor. In addition, fruit from this treatment were rated by the panelists as a little too dry, less sweet, and with lower overall peach flavor. In the third 2015 sensory panel (Table 4), UFS from N4 was rated the lowest for flavor, juiciness, sweetness, and overall peach flavor.

2016 Season

In 2016, N treatment had a significant effect on TB phytochemical accumulation. In that case, the N4 treatment was significantly higher than the other treatments for phenolics, flavonoids, and anthocyanin content (Table 1). In the same manner, N4 had higher antioxidant capacity, but was significantly different only from N0. Carotenoid content was lower in TB fruit from N4 (highest N rate) in 2016, which

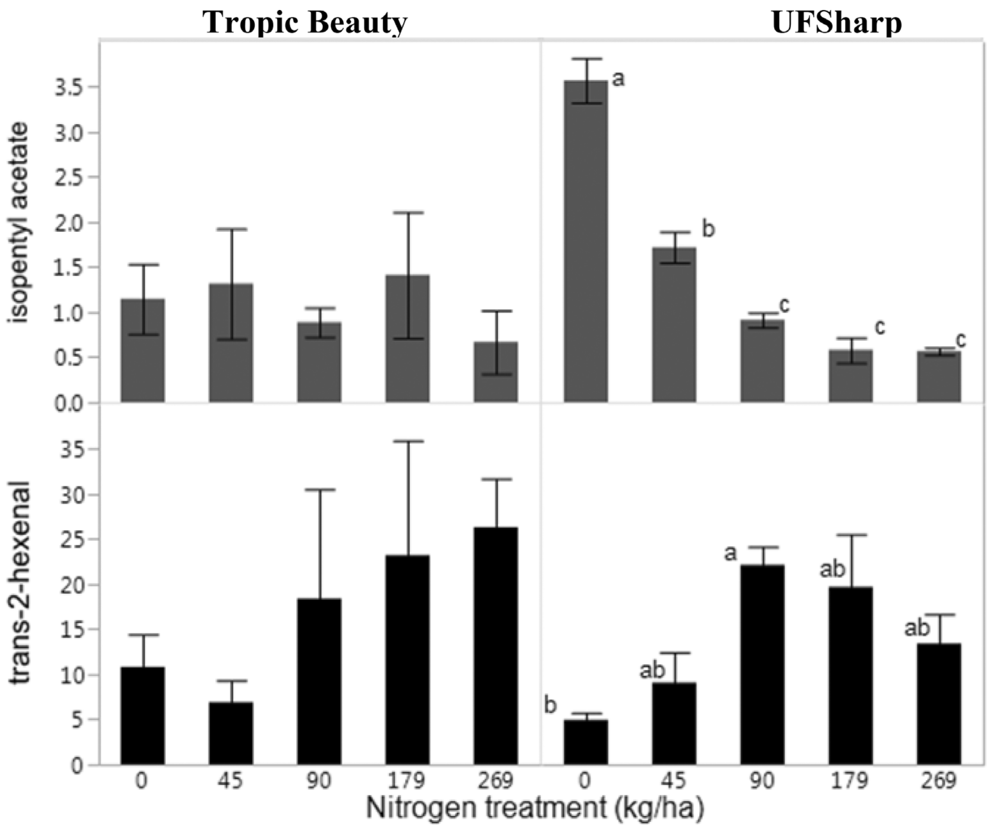

FIGURE 1 Volatile compounds affected by nitrogen fertilizations rates in 2015 (TB – Tropic Beauty; UFS – UFSharp).

TABLE 2 Sensory evaluation results for 2015, harvest I– TropicBeauty.

Nitrogen treatments (kg/ha)	Overall liking[a] (−100 to 100)	Texture[a] (−100 to 100)	Flavor[a] (−100 to 100)	Firmnes[b] (1 to 5)	Juiciness[b] (1 to 5)	Sweetness[c] (0 to 100)	Sourness[c] (0 to 100)	Bitterness[c] (0 to 100)	Overall peach flavor intensity[c] (0 to 100)
N0-0	30.83ab	25.15ab	29.10ab	2.35ab	2.79ab	31.20ab	13.48	9.55	31.8
N1-45	27.28b	17.11b	31.34ab	2.14b	3.00a	32.41ab	13.93	7.75	33.97
N2-90	31.55ab	28.10a	34.01a	2.54a	2.83ab	31.28ab	14.11	8.34	33.65
N3–179	27.94ab	24.58ab	25.89b	2.52a	2.76b	27.83b	17.89	7.68	30.94
N4-269	35.49a	27.87a	34.25a	2.59a	2.79ab	33.85a	12.65	6.69	35.66
p-value	0.0416	0.0121	0.0313	0.0001	0.0431	0.0184	0.0748	0.37	0.1226

Note: Overall liking, texture, and flavor were rated using GHIS (Global Hedonic Intensity Scale), firmness and juiciness rated using just-right scale (JRS), sourness, bitterness and overall peach flavor intensity rated using GSIS (Global Sensory Intensity Scale).
[a]GHIS −100 to 100: −100 is the strongest dislike and 100 is the strongest liking ever experience by the panelist.
[b]JRS 1 to 5: 1: too soft or dry and 5: was much too hard and juice.
[c]GSIS 0 to 100: 0 is no sensation at all and 100 is the strongest sensation of any kind ever experience by the panelist.

was significantly different than N0 and N2 (commercial N rate). No differences were obtained in ascorbic acid content. In the case of UFS, differences among N treatments were obtained for flavonoids, anthocyanins, and antioxidant capacity. The N4 treatment had higher antioxidant capacity and anthocyanin content but was only different from N0 and N1. The N2 treatment had higher flavonoid content that was significantly different from N0 and N3 (Table 5).

Differences in volatile composition in 2016 were found in TB only for 2-pentanone (Figure 2). TropicBeauty fruit from N4 (269 kg/ha) had the highest amount of this compound and were significantly different from fruit in the other treatments. UFSharp fruit had differences among N treatments for isobutyl acetate and 1-hexanol. Fruit from UFS treated with the recommended N rate (90 kg/ha) had the highest amount of isobutyl acetate and were significantly different

TABLE 3 Sensory evaluation results for 2015 harvest II—TropicBeauty (TB) and UFSharp (UFS).

Nitrogen treatments (kg/ha)	Overall liking[a] (−100 to 100)	Texture[a] (−100 to 100)	Flavor[a] (−100 to 100)	Firmness[b] (1 to 5)	Juiciness[b] (1 to 5)	Sweetness[c] (0 to 100)	Sourness[c] (0 to 100)	Bitterness[c] (0 to 100)	Overall peach flavor intensity[c] (0 to 100)
N0–0-TB	29.20abc	14.89	29.7ab	2.13d	3.10a	31.48a	11.67ab	4.03	31.7a
N2-90-TB	29.74ab	22.52	31.41a	2.30 cd	3.10a	30.08ab	12.13ab	5.82	30.25ab
N4-269-TB	30.25a	23.41	30.23a	2.51c	2.98a	30.30ab	14.48a	5.48	31.54a
N0-0-UFS	28.54abc	20.87	26.33ab	3.51b	2.56b	26.92ab	11.95ab	5.95	27.51abc
N2-90-UFS	21.89bc	20.51	22.1bc	3.46b	2.49bc	25.74bc	8.49b	5.54	25.16bc
N4-269-UFS	21.59c	20.26	17.26c	3.05a	2.23c	20.87c	9.8ab	5.82	23.07c
p-value	0.0053	0.2469	<0.001	<0.001	<0.001	<0.001	0.0073	0.5655	<0.0001

Note: Consumer sensory evaluation in which panelist compared TB fruit from N0, N45, and N269 to UFS fruit from N0, N45, and N269 treatments. Overall liking, texture, and flavor were rated using GHIS (Global Hedonic Intensity Scale), firmness and juiciness rated using just-right scale (JRS), sourness, bitterness, and overall peach flavor intensity rated using GSIS (Global Sensory Intensity Scale).
[a]GHIS −100 to +100: −100 is the strongest dislike and +100 is the strongest liking ever experience by the panelist.
[b]JRS 1 to 5: 1: too soft or dry and 5: was much too ha.
[c]GSIS 0 to +100: 0 is no sensation at all and +100 is the strongest sensation of any kind ever experience by the panelist.

TABLE 4 Sensory evaluation results for 2015 for harvest III—UFSharp.

Nitrogen treatments (kg/ha)	Overall liking[a] (−100 to 100)	Texture[a] (−100 to 100)	Flavor[a] (−100 to 100)	Firmness[b] (1 to 5)	Juiciness[b] (1 to 5)	Sweetness[c] (0 to 100)	Sourness[c] (0 to 100)	Bitterness[c] (0 to 100)	Overall peach flavor intensity[c] (0 to 100)
N0-0	25.4	24.1	23.49ab	3.4	2.46ab	24.90ab	10.46	5.03	26.55ab
N1-45	25.36	23.55	26.24a	3.54	2.51a	26.60a	14.3	5.67	28.73ab
N2-90	28.64	25.97	29.18a	3.46	2.54a	28.19a	11.72	4.96	30.18a
N3–179	23.34	23.6	21.31ab	3.49	2.34ab	25.36ab	12.93	6.31	27.39ab
N4-269	20.42	20.34	16.37b	3.52	2.22b	20.88b	12.24	5.12	23.82b
p-value	0.0786	0.2864	0.0011	0.6204	0.0022	0.0034	0.2519	0.7411	0.0188

Note: Consumer sensory evaluation in which panelist compared UFS fruit from all the N treatments. Overall liking, texture, and flavor were rated using GHIS (Global Hedonic Intensity Scale), firmness and juiciness rated using just-right scale (JRS), sourness, bitterness and overall peach flavor intensity rated using GSIS (Global Sensory Intensity Scale).
[a]GHIS −100 to +100: −100 is the strongest dislike and +100 is the strongest liking ever experience by the panelist.
[b]JRS 1 to 5: 1: too soft or dry and 5: was much too hard and juice.
[c]GSIS 0 to +100: 0 is no sensation at all and +100 is the strongest sensation of any kind ever experience by the panelist.

from the other N treatments (Figure 2). Different results were obtained for 1-hexanol, for which UFS fruit from N0 had the highest content.

For the sensory evaluation in 2016 in which all N treatments applied to TB trees were compared, TB fruit from N0 were judged to be the lowest in overall liking, sweetness, and overall peach flavor compared with fruit from all the other treatments (Table 6). These results were similar to 2015 when the sensory attributes of TB N0 fruit were also rated the lowest by the panelists. In the taste panel in which MF TB and NMF UFS were compared (Table 7), the UFS fruit received lower scores compared with TB fruit. In addition, UFS fruit from the N2 (recommended N rate) treatment were least liked by the panelists, with its texture and flavor least preferred. Non-melting flesh UFSharp fruit from N0, N2, and N4 were judged less sweet and the scores were significantly lower than N0 TB. UFSharp fruit from the N2 and N4 treatments received the lowest scores for sourness but were only significantly different from N2 TB. UFSharp fruit from the N2 (recommended rate) treatment were judged to have lower overall peach flavor intensity than fruit from the other treatments. The results from the 2016 taste panel in which UFS fruit from all the N treatments were compared (Table 8) had different results than the taste panel in 2015, in which fruit from N4 were less liked. In 2016, the fruit from the reduced N rate (N1, 45 kg/ha) were least liked and were significantly different from fruit from trees treated with the commercial rate and double the commercial rate (N2 and N3). However, fruit from N0 received the lowest scores for firmness and the highest for juiciness, scores which were judged to be significantly different from the other N treatments. UFSharp fruit from N0, N1, and N4 treatments also were judged to have higher sourness intensity compared with N3.

TABLE 5 Total phenolics, total flavonoids, total carotenoids, total anthocyanins, ascorbic acid, and antioxidant capacity in 'UFSharp' peaches under different nitrogen fertilization rates.

Year	N treatment (kg/ha)	Total phenolics (mg gallic acid/100 g FW)	Total flavonoids (mg catechin/ 100 g FW)	Total carotenoids (mg/100 g FW)	Total anthocyanins (mg/100 g FW)	Ascorbic acid (mg/100 g FW)	Antioxidant capacity (µM Trolox equivalents/g FW)
2015	0	78.1	18.5	11.9	1.1	7.6	78.2
	45	92.8	16.7	10.4	0.1	7.9	106.4
	90	92.2	14.6	10.9	1.1	8.9	96.4
	179	63.8	18.1	12.0	1.6	12.5	149.3
	269	100.4	21.3	11.3	1.1	11.4	138.7
	p-value	*0.5131*	*0.5431*	*0.8691*	*0.0757*	*0.34*	*0.3378*
2016	0	64.9	11.9b[Y]	18.1	0.05b	20.5	289.7b
	45	69.2	16.9ab	16.0	0.05b	19.7	268.0b
	90	59.8	34.2a	17.7	0.08ab	21.3	328.1ab
	179	59.1	14.8b	15.5	0.08ab	17.8	334.7ab
	269	73.7	25.2ab	14.6	0.1a	19.9	393.9a
	p-value	*0.1047*	*0.0129*	*0.1065*	*0.0006*	*0.1028*	*0.0003*
2017	0	71.7	10.3	7.6a	0.07	8.4	287.6a
	45	67.0	10.1	6.1b	0.08	8.4	172.6c
	90	63.9	11.4	7.9a	0.10	8.3	261.9ab
	179	63.1	9.6	7.0ab	0.10	7.4	209.2bc
	269						
	p-value	*0.7636*	*0.5676*	*0.0005*	*0.2315*	*0.099*	*0.0004*

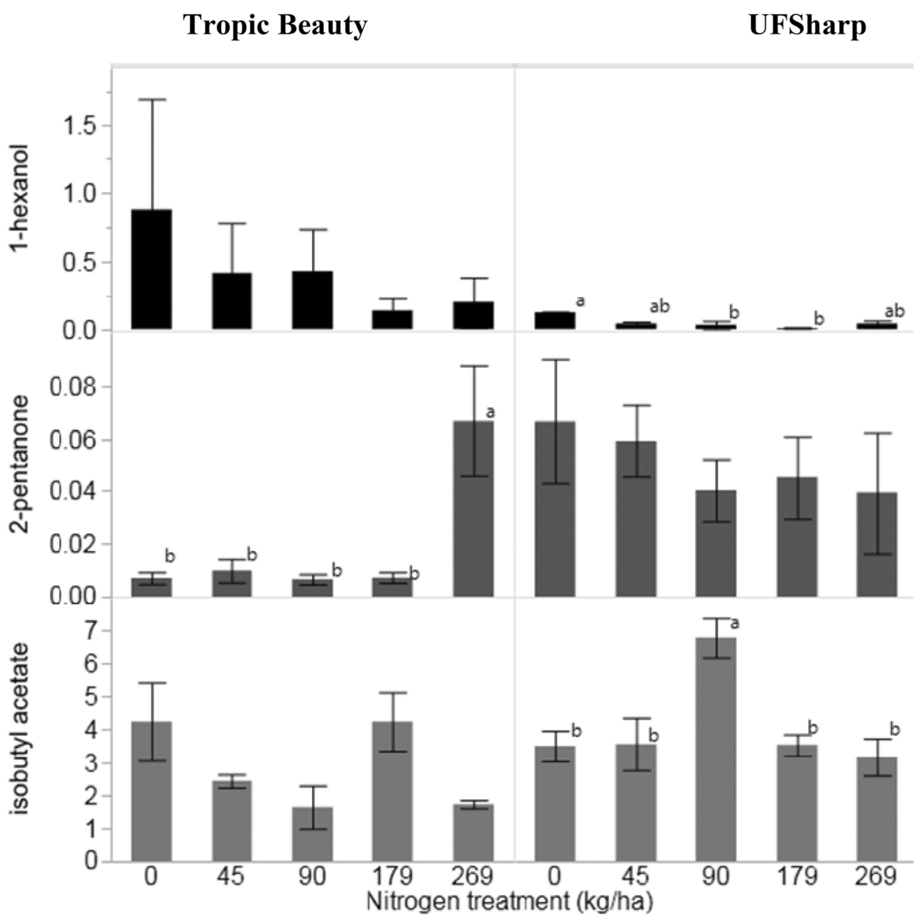

FIGURE 2 Volatile compounds affected by nitrogen fertilizations rates in 2016 (TB – Tropic Beauty; UFS – UFSharp).

TABLE 6 Sensory evaluation results for 2016, harvest I—TropicBeauty.

Nitrogen treatments (kg/ha)	Overall liking[a] (−100 to 100)	Texture[a] (−100 to 100)	Flavor[a] (−100 to 100)	Firmness[b] (1 to 5)	Juiciness[b] (1 to 5)	Sweetness[c] (0 to 100)	Sourness[c] (0 to 100)	Bitterness[c] (0 to 100)	Overall peach flavor intensity[c] (0 to 100)
N0-0	27.53b	26.16	26.17b	2.35	2.98	28.06b	18.09	10.17	31.96b
N1-45	28.4ab	23.03	27.34ab	2.43	2.88	31.06ab	16.16	8.84.	34.21ab
N2-90	34.31ab	27.46	34.74a	2.34	3	35.17a	17.29	7.2	37.2a
N3–179	35.37a	29.56	34.44a	2.4	2.96	34.19a	17.29	7.51	37.96a
N4-269	31.93ab	27.25	31.64ab	2.33	2.94	32.84a	16.12	8.66	34.83ab
p-value	0.02	0.0711	0.0135	0.7168	0.3479	0.0003	0.6727	0.2305	0.0018

Note: Consumer sensory evaluation in which panelist compared TB fruit from all the N treatments. Overall liking, texture, and flavor were rated using GHIS (Global Hedonic Intensity Scale); firmness and juiciness rated using just-right scale (JRS); sourness, bitterness and overall peach flavor intensity rated using GSIS (Global Sensory Intensity Scale).

[a]GHIS −100 to +100: −100 is the strongest dislike and +100 is the strongest liking ever experience by the panelist.

[b]JRS 1 to 5: 1: too soft or dry and 5: was much too hard and juice.

[c]GSIS 0 to +100: 0 is no sensation at all and + 100 is the strongest sensation of any kind ever experience by the panelist.

TABLE 7 Sensory evaluation results for 2016 for harvest II—TropicBeauty (TB) and UFSharp (UFS).

Nitrogen treatments (kg/ha)	Overall liking[a] (−100 to 100)	Texture[a] (−100 to 100)	Flavor[a] (−100 to 100)	Firmness[b] (1 to 5)	Juiciness[b] (1 to 5)	Sweetness[c] (0 to 100)	Sourness[c] (0 to 100)	Bitterness[c] (0 to 100)	Overall peach flavor intensity[c] (0 to 100)
N0-0-TB	34.68a	25.95ab	33.83a	2.26b	3.03a	37.26a	17.51ab	7.03a	38.88a
N2-90-TB	32.7ab	29.75a	31.23ab	2.33b	2.86a	34.21abc	19.2ab	7.91a	36.14ab
N4-269-TB	32.6ab	27.3ab	32.23ab	2.3b	2.9a	34.88ab	16.64a	8.94a	37.31a
N0-0-UFS	27.9ab	21.63ab	29.64ab	3.74a	2.29b	31.21bcd	16.76ab	6.59a	32.39bc
N2-90-UFS	26.46b	19.75b	24.75b	3.79a	2.23b	28.7d	15.7b	8.08a	29.89c
N4-269-UFS	27.06b	20.44b	25.23b	3.8a	2.39b	28.7 cd	15.45b	7.65a	31.74bc
p-value	*0.0073*	*<0.0068*	*0.005*	*<0.001*	*<0.001*	*<0.000*	*0.017*	*0.2205*	*<0.0001*

Note: Consumer sensory evaluation in which panelist compared TB fruit from N0, N90, and N269 to UFS fruit from N0, N45, and N269 treatments. Overall liking, texture, and flavor were rated using GHIS (Global Hedonic Intensity Scale), firmness and juiciness rated using just-right scale (JRS), sourness, bitterness and overall peach flavor intensity rated using GSIS (Global Sensory Intensity Scale).

[a]GHIS −100 to +100: −100 is the strongest dislike and +100 is the strongest liking ever experience by the panelist.

[b]JRS 1 to 5: 1: too soft or dry and 5: was much too hard and juice.

[c]GSIS 0 to +100: 0 is no sensation at all and +100 is the strongest sensation of any kind ever experience by the panelist.

TABLE 8 Sensory evaluation results for 2016 for harvest III—UFSharp.

Nitrogen treatments (kg/ha)	Overall liking[a] (−100 to 100)	Texture[a] (−100 to 100)	Flavor[a] (−100 to 100)	Firmness[b] (1 to 5)	Juiciness[b] (1 to 5)	Sweetness[c] (0 to 100)	Sourness[c] (0 to 100)	Bitterness[c] (0 to 100)	Overall peach flavor intensity[c] (0 to 100)
N0-0	26.63ab	20.35a	25.35a	2.17b	2.85a	30.81a	17.5a	8.85a	33.33a
N1-45	21.99b	22.77a	21.78a	3.47a	2.44b	27.67a	18.74a	8.72a	30.04a
N2-90	29.85a	25.94a	28.15a	3.38a	2.54b	30.28a	15.79ab	8.05a	31.88a
N3–179	28.62a	25.23a	26.45a	3.46a	2.47b	27.01a	12.72b	8.12a	30.14a
N4-269	27.65ab	25.08a	25.81a	3.53a	2.49b	27.63a	16.19a	8.49a	31.32a
p-value	*0.0144*	*0.1694*	*0.2350*	*<0.0001*	*<0.0001*	*0.0576*	*<0.0001*	*0.9592*	*0.3252*

Note: Consumer sensory evaluation in which panelist compared UFS fruit from all the N treatments. Overall liking, texture, and flavor were rated using GHIS (Global Hedonic Intensity Scale); firmness and juiciness rated using just-right scale (JRS); sourness, bitterness, and overall peach flavor intensity rated using GSIS (Global Sensory Intensity Scale).

[a]GHIS −100 to +100: −100 is the strongest dislike and +100 is the strongest liking ever experience by the panelist.

[b]JRS 1 to 5: 1: too soft or dry and 5: was much too hard and juice.

[c]GSIS 0 to +100: 0 is no sensation at all and +100 is the strongest sensation of any kind ever experience by the panelist.

2017 Season

In 2017, TB fruit from the N3 treatment had high phenolic concentration and low anthocyanin content, which were significantly different from N4 and N1. Antioxidant capacity and carotenoid content of TB fruit were significantly lower in N0 than in the other treatments (Table 1). In the NMF variety (UFS), N0 fruit had higher antioxidant capacity than N1 and N3 (Table 5). In 2017, differences were found in the volatile compound benzaldehyde for MF TB in that the fruit from N0 had the highest amount (Figure 3). The quantities of each volatile analyzed in the 3 years of data collection are shown in Appendix A tables A-1 through A-6.

For the first sensory evaluation in 2017, TB fruit from all N treatments were found to have no differences in overall liking, flavor, juiciness, sweetness, bitterness, and overall peach flavor (Table 9). However, panelists found differences in texture, firmness, and sourness. For texture and sourness, TB N1 was significantly different from N3, which was judged the highest for texture and sourness intensity. In the second taste panel (Table 10), in which NMF UFS fruit from N0, N1, N2, and N3 were compared with MF TB fruit from treatments N0 and N3, UFS fruit from the N2 treatment were the least liked by the panelists and were significantly different from N3 TB. In the same manner, UFS N2 scored lowest in texture and flavor. TropicBeauty fruit from treatments N0 and N3 were scored the lowest for firmness and higher for juiciness. This was somewhat expected based on the textural differences between the varieties. For sweetness and overall peach flavor, fruit from NMF UFS treated with the commercial recommended rate (90 kg/ha) scored the lowest. In this sensory evaluation, the results confirmed again the importance of sweetness for consumers since the treatments rated lowest in sweetness were also

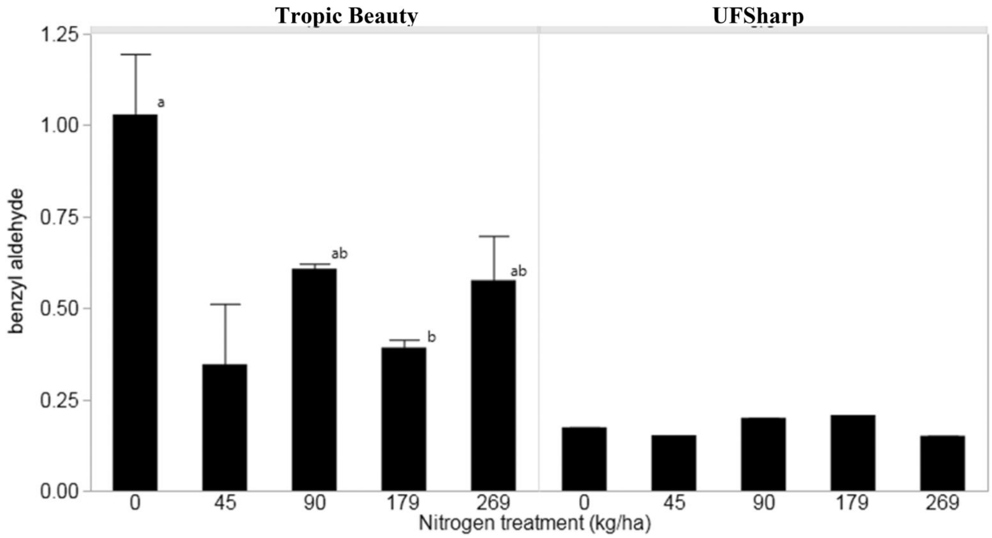

FIGURE 3 Volatile compounds affected by nitrogen fertilizations rates in 2017 (TB – 'Tropic Beauty'; UFS – 'UFSharp').

TABLE 9 Sensory evaluation results for 2017, harvest I—TropicBeauty.

Nitrogen treatments (kg/ha)	Overall liking[a] (−100 to 100)	Texture[a] (−100 to 100)	Flavor[a] (−100 to 100)	Firmness[b] (1 to 5)	Juiciness[b] (1 to 5)	Sweetness[c] (0 to 100)	Sourness[c] (0 to 100)	Bitterness[c] (0 to 100)	Overall peach flavor intensity[c] (0 to 100)
N0-0	33.76	27.74b	33.58	2.28b	3.09	29.79	18.25ab	7.31	34.79
N1-45	28.14	27.59b	27.65	2.44ab	2.96	26.12	17.76b	8.41	34.68
N2-90	31.99	29.6ab	33.18	2.39ab	2.95	27.48	19.71ab	8.59	33.94
N3–179	34.41	32.72a	32.98	2.52a	2.93	28.33	22.64a	7.78	33.8
N4-269	33.25	32.25a	31.31	2.56a	2.93	26.95	20.12ab	8.82	33.11
p-value	0.0835	0.013	0.19836	0.0074	0.0501	0.2731	0.0347	0.7724	0.8059

Note: Consumer sensory evaluation in which panelist compared TB fruit from all the N treatments. Overall liking, texture, and flavor were rated using GHIS (Global Hedonic Intensity Scale), firmness and juiciness rated using just-right scale (JRS), sourness, bitterness and overall peach flavor intensity rated using GSIS (Global Sensory Intensity Scale).

[a]GHIS −100 to +100: −100 is the strongest dislike and +100 is the strongest liking ever experience by the panelist.

[b]JRS 1 to 5: 1: too soft or dry and 5: was much too hard and juice.

[c]GSIS 0 to +100: 0 is no sensation at all and +100 is the strongest sensation of any kind ever experience by the panelist.

TABLE 10 Sensory evaluation results for 2017 harvest II—TropicBeauty (TB) and UFSharp (UFS).

Nitrogen treatments (kg/ha)	Overall liking[a] (−100 to 100)	Texture[a] (−100 to 100)	Flavor[a] (−100 to 100)	Firmness[b] (1 to 5)	Juiciness[b] (1 to 5)	Sweetness[c] (0 to 100)	Sourness[c] (0 to 100)	Bitterness[c] (0 to 100)	Overall peach flavor intensity[c] (0 to 100)
N0-0-UFS	20.10bc	19.04b	18.29bc	3.96a	2.12c	19.29bc	17.49a	11.43a	23.55bc
N1-45-UFS	25.61ab	25.17ab	23.36abc	3.48b	2.49b	23.57ab	16.36a	7.23a	29.56ab
N2-90-UFS	12.51c	16.75b	12.34c	3.95a	2.18c	15.95c	22.12a	11.34a	22.38c
N3-179-UFS	17.69bc	17.29b	18.66bc	4.00a	2.18c	16.26c	21.74a	12.51a	23.82bc
N0-0-TB	27.82ab	27.99ab	26.82ab	2.30c	2.92a	24.25ab	19.55a	11.97a	30.96a
N3-169-TB	33.79a	31.35a	32.36a	2.30c	3.08a	29.18a	17.81a	8.90a	34.29a
p-value	<0.000	0.0004	<0.0001	<0.0001	0.0001	0.0001	0.0334	0.0458	<0.0001

Note: Consumer sensory evaluation in which panelist compared fruit from UFS N0, N45, N90, and N179 to TB fruit from N0 and N169. Overall liking, texture, and flavor were rated using GHIS (Global Hedonic Intensity Scale); firmness and juiciness rated using just-right scale (JRS); sourness, bitterness, and overall peach flavor intensity rated using GSIS (Global Sensory Intensity Scale).

[a]GHIS −100 to +100: −100 is the strongest dislike and +100 is the strongest liking ever experience by the panelist.

[b]JRS 1 to 5: 1: too soft or dry and 5: was much too hard and juice.

[c]GSIS 0 to +100: 0 is no sensation at all and +100 is the strongest sensation of any kind ever experience by the panelist.

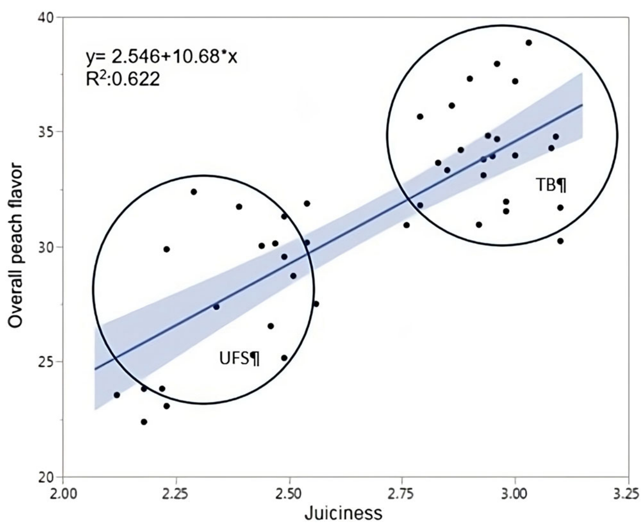

FIGURE 4 Overall peach flavor data from the 3 years of data collection related to juiciness for both varieties, 'TropicBeauty' (TB) and 'UFSharp' (UFS).

rated lowest in overall peach flavor, overall liking, and flavor. In addition, these results are an example of the halo effect of sweetness over other attributes.

The results obtained in the 3-year period of this study indicate that N did not have a consistent effect on the phytochemical composition of the peach fruit. Even though the differences in sensory evaluation results and volatile compound measurements were not striking, some trends in consumer preferences were observed when data from the 3 years of this study were plotted. It could be observed that the overall liking of both varieties increased as juiciness increased (Figure 4), while the opposite was observed for firmness, for which overall liking decreased with increasing firmness (Figure 5). When data were separated by variety, varietal differences in texture and juiciness were observed (circles on Figures 4 and 5). Panelist overall liking was higher for MF TB fruit and lower for NMF UFS.

DISCUSSION

The results obtained in the phytochemical evaluation did not show a clear effect of N on phytochemical composition in either TB or UFS. Furthermore, reducing N fertilization or even the lack of N fertilization did not greatly affect the fruit quality of TB and UFS varieties, although the phytochemical content of TB appeared to be more affected by N fertilization than UFS (Tables 2 and 5). Thus, it can be assumed that environmental conditions influenced phytochemical composition more than N, which was previously reported by Kader.[18] In addition, Claypool[42] reported changes in peach fruit composition based on temperature during fruit development. It can be noted that PAL, the main enzyme regulating the synthesis of phenolic compounds, is activated by light and temperature. Thus, environmental conditions can affect PAL activity, masking the effect of N on fruit phenolic composition.[43,44]

Anthocyanins in this study increased as N rates increased, in contrast to the results of Jia.[28] Even though the trees grown under N4 had more vegetative growth, which can cause fruit shading, anthocyanin content was not reduced by increasing N. This could be due to the training system; the trees were trained under the "V" system, which produces fruit with better color than trees under other systems.[45] Also, the trees in N1 (lowest N rate) through N4 (highest N rate) were pruned to approximately equal size (N0 trees were smaller). Thus, the training system and pruning practices could have reduced the effect of shading on the fruit. In addition, anthocyanin in the flesh is synthesized even when fruit are not exposed to light. Rumainum[46] reported no differences in the anthocyanin content in the flesh of covered versus uncovered peach fruit. Since the tissue samples for this research

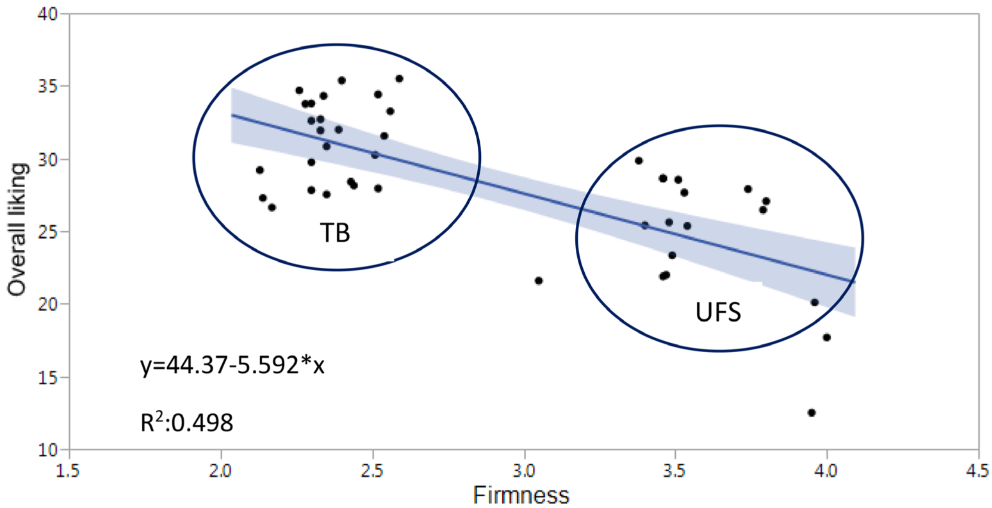

FIGURE 5 Overall liking data from the 3 years of data collection related to firmness for both varieties, 'TropicBeauty' (TB) and 'UFSharp' (UFS).

were a mix of skin and flesh, even if the skin had a lower amount of anthocyanins, the flesh could have increased the total anthocyanin content of the sample.

Even though our results were not consistent among years, fruit from the highest N rate (269 kg/ ha) produced fruit with higher amounts of phenolics, flavonoids, and antioxidant capacity than the control (zero N). These results differed from the results reported by Vashisth[22] and Pande,[47] in which peach trees grown either under zero N or low N rates had high phenolic and flavonoid contents and antioxidant capacity. The discrepancy between the results in this investigation and previous research can be due to sampling time. Pande[47] and Vashisth[22] processed the fruit for each analysis right after harvest, while for this research, the fruit were harvested, stored for 7 days at 0°C, and then transferred to 20°C to ripen, which was done to simulate typical commercial handling. Thus, it is possible that phytochemical differences in peaches at harvest, as affected by N fertilization, may be largely lost by the time fruit are consumed.

Another possible reason for the discrepancy in results for N effect on phenolic composition can be that fruit from the N4 treatment were less mature than fruit from the control treatment (N0). High N fertilization rates delay fruit maturation by increasing the length of the fruit developmental period (FDP). Thus, fruit from high N trees take longer to ripen, and less mature fruit have higher amounts of phenolic compounds.[20,48,49] This hypothesis can be supported by the low carotenoid content in fruit from N4 trees since peach fruit carotenoid content increases with maturation and ripening.

In the same manner, volatiles synthesis was little affected by N. It could be possible that, since volatiles increase as fruit ripen, and fruit volatile composition was measured at the ready-to-eat stage, (firmness between 2 and 10 lbs-force depending on variety), this could have masked the effect of N on volatile composition.

An important result from the volatile measurements made with the two varieties analyzed in this research is that esters such as hexyl acetate, cis-3-hexenyl acetate, and trans-2-hexenyl acetate were the volatiles that were present in the highest quantities in all three seasons of data collection. This result is contrary to what has previously been reported for peach aroma profiles, which is that lactones are the compounds present in higher quantities in peach fruit.[50–52] Furthermore, the higher quantities of volatiles esters in the two peach varieties analyzed in this study resembles what was previously reported by Visai and Valoni[52] for nectarines as well as for the NMF Oro, a peach variety.[25,53] Another possible explanation for the results obtained is that the technique used in this study to collect the volatiles using a 'purge and trap' approach may have allowed a larger quantity of ester volatile compounds to be collected compared with the more commonly used headspace analysis of frozen tissue homogenates after heating. The 1-week storage at 0°C probably did not affect the synthesis of lactones. It has been shown that lactones start to decrease only by the second week of such storage.[51,54,55]

Linking the consumer results to the volatile results, the increase in the three ester compounds previously mentioned appear to be highly related to the overall liking by the panelists (Figure 6). In same context, in 2016, low overall liking of non-melting flesh UFS fruit from the N0 and N1 (half commercial N rate) treatments could be due to the observed increase of 1-hexanol. This compound is an alcohol that is usually related to a "green note aroma."[26,50,56,57] In 2015, N affected the volatile concentration of UFS fruit, with fruit from N0 having the highest quantity of isopentyl acetate (an ester) and fruit from N2 having the highest amount of trans-2-hexanal (an aldehyde). However, panelists did not appear to notice those differences. In the same manner, consumers did not detect the increase of benzaldehyde in TB fruit that accompanied the increase in N fertilization rate.

In the taste panels in which the MF variety TB was compared with NMF variety UFS, TB was liked more than UFS. These results could be due to the NMF texture of UFS, since, as reported by Rubio Ames,[58] consumers prefer a juicy and fully ripe peach. The NMF texture of UFS fruit could have been perceived by the panelists as unripe. Therefore, consumers may have rated softer and apparently riper TB

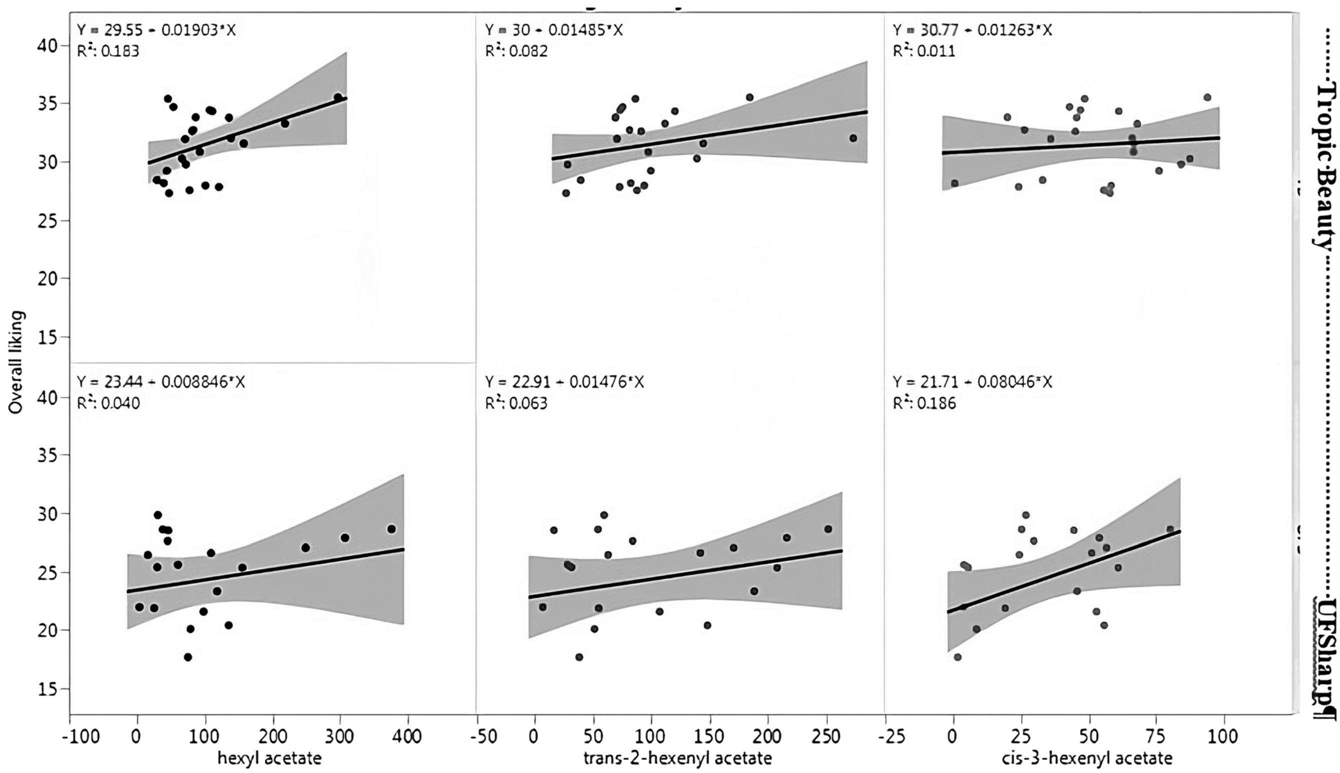

FIGURE 6 Relationship between overall liking and ester compounds for TropicBeauty (TB) and UFSharp (UFS). Data points from the 3 years of data collection. Volatile quantities are expressed as ng/g FW/h.

higher when compared with UFS. Furthermore, since N extended the FDP, fruit receiving higher amounts of N took longer to ripen, resulting in fruit that were firmer and the texture was less liked. Therefore, it is possible that the combination of both higher N and longer FDP affected the sensory attributes of UFS, resulting in it being less liked by the panelists. Our results are different than those reported by Williamson and Sargent[59] in which NMF 'UFGold' peach fruit were preferred by panelists even when the fruit were firmer than MF 'Flordaprince' fruit.

Thus, while it could be concluded that N fertilization rate had little effect on peach fruit flavor or consumer acceptability, and data from this research do not allow the effect on peach nutritional value to be clearly discerned, it seems that N affected the two varieties differently. It is important to consider that volatile contents and nutritional value are influenced by the environment and the genetic background of each variety as well as by the cultural practices used, such as the training system. Yield was only affected by N treatments in year 2017, and physical and compositional attributes were inconsistently affected by N as previously reported.[10]

CONCLUSIONS

The data from this research do not allow the effect of N on peach nutritional values to be clearly discerned. Indeed, it could be concluded that N fertilization rate had little effect on peach fruit flavor or consumer acceptability. However, it seems that N affected the two varieties differently, and environmental conditions and cultural practices such as the training system may have played an important role in the response of the peach trees to N fertilization.

ACKNOWLEDGMENTS

This research was supported by the Florida Department of Agriculture and Consumer Service, Specialty Crop Block grant. FEID-59-6002052.

CONFLICT OF INTEREST STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this article.

ORCID

Jeffrey K. Brecht https://orcid.org/0000-0003-0102-7128

REFERENCES

1. Millard P. Internal cycling of nitrogen in trees. Min Nutr Deciduous Fruit Plants. Acta Hortic. 1995;383:3–14. https://doi.org/10.17660/ActaHortic.1995.383.1
2. Tromp J. Nutrient reserves in roots of fruit trees, in particular carbohydrates and nitrogen. Plant Soil. 1983;71:401–13.
3. Gomez L, Faurobert M. Contribution of vegetative storage proteins to seasonal nitrogen variations in the young shoots of peach trees (*Prunus persica* L. Batsch). J Expt Bot. 2022;53:2431–9. https://doi.org/10.1093/jxb/erf098

4. Taylor B, May L. The nitrogen nutrition of the peach tree II. Storage and mobilization of nitrogen in young trees. Aust J Biol Sci. 1967;20: 389–412. https://doi.org/10.1071/BI9670389
5. Taylor B, Van DEB. The nitrogen nutrition of the peach tree. IV. Storage and mobilization of nitrogen in mature trees. Aust J Agric Res. 1968;20:869–81. https://doi.org/10.1071/AR9690869
6. Jordan MO, Vercambre G, Gomez L, Pagès L. The early spring N uptake of young peach trees (*Prunus persica*) is affected by past and current fertilizations and levels of C and N stores. Tree Physiol. 2013;34:61–72. https://doi.org/10.1093/treephys/tpt109
7. Jordan MO, Vercambre G, Le Bot J, Adamowicz S, Gomez L, Pagès L. Autumnal nitrogen nutrition affects the C and N storage and architecture of young peach trees. Trees. 2011;25:333–44.
8. Jordan MO, Wendler R, Millard P. The effect of autunm N supply on the architecture of young peach (Prunus persica) trees. Trees, Bilaspur, India; 2009. pp. 3–14. https://doi.org/10.1007/s00468-011-0600-8
9. Munoz N, Guerri J, Legaz F, Primomillo E. Seasonal uptake of N-15-nitrate and distribution of absorbed nitrogen in peach trees. Plant Soil. 1993;150:263–9.
10. Rubio Ames Z, Brecht JK, Olmstead MA. Nitrogen fertilization rates in a subtropical peach orchard: effects on tree vigor and fruit quality. J Sci Food Agric. 2020;100(2):527–39.
11. Tagliavini M, Millard P, Quartieri M, Marangoni B. Timing of nitrogen uptake affects winter storage and spring remobilisation of nitrogen in nectarine (*Prunus persica* var. nectarina) trees. Plant Soil. 1999;211:149–53.
12. Baldwin EA. Fruit and Vegetable Flavor. Handling, Transportation and Storage of Fruits, Vegetables, and Florist and Nursery Stock. US Dept of Agri- Agri ResSer, Washington, DC; 2016. p. 66.
13. Fallik E, Ilic Z. Pre-and postharvest treatments affecting flavor quality of fruits and vegetables. In: Siddiqui MW, editor. Preharvest modulation of postharvest fruit and vegetable quality. London: Academic Press; 2018. p. 139–68. Elsevier. https://doi.org/10.1016/B978-0-12-809807-3.00006-8
14. Kader AA. Fruit maturity, ripening, and quality relationships. Acta Hort. 1999;485:203–8. https://doi.org/10.17660/ActaHortic.485.27
15. Cantin CM, Gogorcena Y, Moreno MA. Analysis of phenotypic variation of sugar profile in different peach and nectarine (*Prunus persica* (L.) Batsch) breeding progenies. J Sci Food Agric. 2009;89:1909–17. https://doi.org/10.1002/jsfa.3672
16. Lea MA, Ibeh C, Vizzotto M, Cisneros-Zevallos L, Byrne DH, Okie WR, et al. Inhibition of growth and induction of differentiation of colon cancer cells by peach and plum phenolic compounds. Anticancer Res. 2008;28:2067–76.
17. Noratto G, Porter W, Byrne D, Cisneros-Zevallos L. Identifying peach and plum polyphenols with chemopreventive potential against estrogen-independent breast cancer cells. J Agric Food Chem. 2009; 57:5219–26. https://doi.org/10.1021/jf900259m
18. Kader AA, Heintz CM, Chordas A. Postharvest quality of fresh and canned clingstone peaches as influenced by genotypes and maturity at harvest. J Am Soc Hort Sci. 1982;107:947–51. https://doi.org/10.21273/JASHS.107.6.947
19. Hernández-Fuentes A, Colinas M, Pinedo-Espinoza J. Effect of fertilization on the concentration of N, P, K, CA, MG, FE, MN, CU, ZN AND phenylalanine ammonia-lyase activity in fruit of 'zacatecas' type peach (*Prunus persica* (L.) Batsch). Acta Hort. 2002;636:521–5. https://doi.org/10.17660/ActaHortic.2004.636.65
20. Kubota N, Mimura H, Shimamura K. Differences in phenolic levels among mature peach and nectarine cultivars and their relation to astringency. J Jpn Soc Hort Sci. 2000;69:35–9. https://doi.org/10.2503/jjshs.69.35
21. Toselli M, Baldi E, Marangoni B, Noferini M, Fiori G, Bregoli A, et al. Effects of mineral and organic fertilization and ripening stage on the emission of volatile organic compounds and antioxidant activity of 'Stark RedGold' nectarine. Acta Hort. 2010;868:381–8.
22. Vashisth T, Olmstead MA, Olmstead JW, Colquhoun TA. Effects of nitrogen fertilization on subtropical peach fruit quality: organic acids, phytochemical content, and total antioxidant capacity. J Am Soc Hort Sci. 2017;142:393–404. https://doi.org/10.21273/JASHS04011-16
23. Cao G, Prior RL. Measurement of oxygen radical absorbance capacity in biological samples. Meth Enzymol. 1999;299:50–62. https://doi.org/10.1016/S0076-6879(99)99008-0
24. Jiang Y, Song J. Fruits and fruit flavor: classification and biological characterization. In: Hui YH, editor. Handbook of fruit and vegetable flavors. New York: Wiley; 2010. p. 1–23.
25. Eduardo I, Chietera G, Bassi D, Rossini L, Vecchietti A. Identification of key odor volatile compounds in the essential oil of nine peach accessions. J Sci Food Agr. 2010;90:1146–54. https://doi.org/10.1002/jsfa.3932
26. Horvat RJ, Chapman GW, Robertson JA, Meredith FI, Scorza R, Callahan AM, et al. Comparison of the volatile compounds from several commercial peach cultivars. J Agric Food Chem. 1990;38:234–7.
27. Wang Y, Yang C, Li S, Yang L, Wang Y, Zhao J, et al. Volatile characteristics of 50 peaches and nectarines evaluated by HP–SPME with GC–MS. Food Chem. 2009;116:356–64. https://doi.org/10.1016/j.foodchem.2009.02.004
28. Jia H, Hirano K, Okamoto G. Effects of fertilizer levels on tree growth and fruit quality of'Hakuho'peaches (Prunus persica). J Jpn Soc Hort Sci. 1999;68:487–93.
29. Olienyk P, Gonzalez A, Mauromoustakos A, Patterson W, Rom C, Clark J. Nitrogen fertilization affects quality of peach puree. Hort Sci. 1997;32:284–7. https://doi.org/10.21273/HORTSCI.32.2.284
30. Chaparro J, Sherman W. 'UFSharp'peach. J Am Pom Soc. 2006; 60:95.
31. Okie WR. Handbook of peach and nectarine varieties: performance in the southeastern. United States and index of names. US Dept of Agri- Agri ResSer, Washington, DC; 1998 Hdbk. No. 714.
32. DeJong TM, Day KR, Doyle JF, Johnson R. The Kearney agricultural center perpendicular "V" (KAC-V) orchard system for peaches and nectarines. Hort Technol. 1994;4:362–7.
33. Olmstead MA, Chaparro J, Williamson J, Rouse R, Mizell R, Harmon P, et al. Florida subtropical peaches: production practices. Vol 2013. Univ Florida Inst Food Agri Sci Ext Publ, Florida; 2013. p. HS1109.
34. Vizzotto M, Cisneros-Zevallos L, Byrne DH, Ramming DW, Okie W. Large variation found in the phytochemical and antioxidant activity of peach and plum germplasm. J Am Soc Hort Sci. 2007;132:334–40. https://doi.org/10.21273/JASHS.132.3.334
35. Talcott ST, Howard LR. Phenolic autoxidation is responsible for color degradation in processed carrot puree. J Agric Food Chem. 1999;47: 2109–15.
36. Terada M, Watanabe Y, Kunitomo M, Hayashi E. Differential rapid analysis of ascorbic acid and ascorbic acid 2-sulfate by dinitrophenylhydrazine method. Anal Biochem. 1978;84:604–8.
37. Singleton VL, Rossi JA. Colorimetry of total phenolics with phosphomolybdic-phosphotungstic acid reagents. Am J Enol Viticult. 1965;16:144–58.
38. Huang D, Ou B, Hampsch-Woodill M, Flanagan JA, Prior RL. High-throughput assay of oxygen radical absorbance capacity (ORAC) using a multichannel liquid handling system coupled with a microplate fluorescence reader in 96-well format. J Agric Food Chem. 2002;50:4437–44.
39. Tieman DM, Zeigler M, Schmelz EA, Taylor MG, Bliss P, Kirst M, et al. Identification of loci affecting flavour volatile emissions in tomato fruits. J Exp Bot. 2006;57:887–96. https://doi.org/10.1093/jxb/erj074
40. Meilgaard MC, Carr BT, Civille GV. Sensory evaluation techniques. Boca Raton, FL: CRC Press; 1999.

41. Snyder DJ, Sims CA, Bartoshuk LM. Psychophysical measures of human oral sensation. In: Doty RL, editor. Handbook of olfaction and gustation. New York: Wiley; 2015. p. 774–94. https://doi.org/10.1002/9781118971758.ch34
42. Claypool L, Uriu K, Leonard S, Lasker P. The influence of cultural practices on the quality of "Dixon" cling peaches. Davis, Res. Prog. Rpt: University of California; 1971.
43. Kubota N. Phenolic content and L-phenylalanine ammonia-lyase activity in peach fruit. In: Linsken HF, Jackson JF, editors. Modern methods of plant analysis: fruit analysis. Springer: New York; 1996. p. 81–95.
44. Olsen KM, Slimestad R, Lea US, Brede C, Lovdal T, Ruoff P, et al. Temperature and nitrogen effects on regulators and products of the flavonoid pathway: experimental and kinetic model studies. Plant Cell Environ. 2009;32:286–99. https://doi.org/10.1111/j.1365-3040.2008.01920.x
45. Sharma Y, Singh H, Thakur A. Effect of training system and in row spacing on yield and fruit quality of peach in the sub-tropical regions. Hort Soc India (Regd). 2017;74:440–3. https://doi.org/10.5958/0974-0112.2017.00085.8
46. Rumainum IM, Worarad K, Yamaki Y, Yamane K. Effects of developmental stages, light, and an auxin polar transport inhibitor on the skin and flesh pigmentation of red-fleshed peach fruit. Hort J. 2016;85:141–7. https://doi.org/10.2503/hortj.MI-077
47. Pande KK, Dimri D, Rao V, Lal S, Uniyal S, Pal R. Response of different nitrogen regimes through neem coated urea and calcium sprays on bio-chemical attributes and antioxidant activities of peach. Intl J Chem Stud. 2017;5:1528–34.
48. Saenz J, DeJong TM, Weinbaum S. Nitrogen stimulated increases in peach yields are associated with extended fruit development period and increased fruit sink capacity. J Am Soc Hort Sci. 1997;122:772–7. https://doi.org/10.21273/JASHS.122.6.772
49. Wert TW, Williamson JG, Chaparro JX, Miller EP, Rouse RE. The influence of climate on fruit development and quality of four low-chill peach cultivars. Hort Sci. 2009;44:666–70. https://doi.org/10.21273/HORTSCI.44.3.666
50. Kakiuchi N, Ohmiya A. Changes in the composition and content of volatile constituents in peach fruits in relation to maturity at harvest and artificial ripening. J Jpn Soc Hort Sci. 1991;60:209–16. https://doi.org/10.2503/jjshs.60.209
51. Robertson J, Meredith F, Forbus W. Changes in quality characteristics during peach (CV. 'Majestic') maturation. J Food Qual. 1991;14:197–207. https://doi.org/10.1111/j.1745-4557.1991.tb00061.x
52. Visai C, Vanoli M. Volatile compound production during growth and ripening of peaches and nectarines. Sci Hort. 1997;70:15–24. https://doi.org/10.1016/S0304-4238(97)000320
53. Pirona R, Vecchietti A, Lazzari B, Caprera A, Malinverni R, Consolandi C, et al. Expression profiling of genes involved in the formation of aroma in two peach genotypes. Plant Biol. 2013;15:443–51. https://doi.org/10.1111/j.1438-8677.2012.00666.x
54. Cano-Salazar J, López ML, Crisosto CH, Echeverría G. Volatile compound emissions and sensory attributes of 'big top' nectarine and 'early rich' peach fruit in response to a pre-storage treatment before cold storage and subsequent shelf-life. Postharvest Biol Tech. 2013;76:152–62. https://doi.org/10.1016/j.postharvbio.2012.10.001
55. Raffo A, Nardo N, Tabilio MR, Paoletti F. Effects of cold storage on aroma compounds of white- and yellow-fleshed peaches. Eur Food Res Technol. 2008;226:1503–12.
56. El Hadi MAM, Zhang FJ, Wu FF, Zhou CH, Tao J. Advances in fruit aroma volatile research. Molecules. 2013;18:82008229. https://doi.org/10.3390/molecules18078200
57. Klee HJ. Improving the flavor of fresh fruits: genomics, biochemistry, and biotechnology. New Phytol. 2010;187:44–56. https://doi.org/10.1111/j.1469-8137.2010.03281.x
58. Rubio Ames Z, Brecht JK, Olmstead MA, Colquhoun TA, Keene SA. Using conjoint-based experimental design to assess willingness to purchase Florida peaches. Hort Sci. 2022;57:1110–9. https://doi.org/10.21273/HORTSCI16588-22
59. Williamson J, Sargent S. Postharvest characteristics and consumeracceptance of non-melting peaches. Proc Fla State Hort Soc. 1999;112:241–2.

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

How to cite this article: Ames ZR, Brecht JK, Olmstead MA, Tieman D, Sims CA. Nitrogen fertilization rates in a subtropical peach orchard: Effect on fruit nutritional value and flavor. JSFA Reports. 2024;4(3):148–62. https://doi.org/10.1002/jsf2.183