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ORIGINAL PAPER

Cold storage of six nectarine cultivars: consequences for volatile compounds emissions, physicochemical parameters, and consumer acceptance

Jaime Cano-Salazar · Luisa López · Carlos H. Crisosto · Gemma Echeverría

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Abstract The effects of cold storage and shelf life of 'Big Top,' 'Honey Blaze^{cov},' 'Honey Royale^{cov},' 'Venus,' 'August Red,' and 'Nectagala^{cov}' nectarines were evaluated. Volatile compounds, firmness, soluble solids content, titratable acidity, color, and degree of consumer acceptance of the fruit were determined at harvest, after storage at −0.5 °C for 10, 20, or 40 days and following 3 days at 20 °C. Ten days cold storage plus 3 days at 20 °C produced the highest total ester emission for 'Nectagala^{cov}' and 'August Red,' while similar results were obtained after 10 days cold storage for the 'Big Top' and 'Honey Blaze^{cov}' and 20 days cold storage for 'Honey Royale^{cov}' and 'Venus.' For 'Nectagala^{cov},' this higher total ester emission coincided with the greatest percentage of satisfied consumers. Increased consumer acceptance was associated with the cultivars and storage time that resulted in firmer fruits and greater concentrations of specific volatile compounds.

Keywords Nectarines · Cold storage · Physicochemical parameters · Volatile compounds · Consumer acceptance

J. Cano-Salazar · L. López · G. Echeverría (✉)
Àrea de Post-Collita, XaRTA, UdL-IRTA,
Alcalde Rovira Roure 191, 25198 Lleida, Spain
e-mail: gemma.echeverria@irta.es

J. Cano-Salazar
e-mail: jaime.cano@irta.cat

L. López
e-mail: mluisa@tecal.udl.cat

C. H. Crisosto
Department of Plant Sciences, University of Davis,
One Shields Avenue, Davis, CA 95616, USA
e-mail: chcrisosto@ucdavis.edu

Introduction

Nectarine (*Prunus persica* (L.) Batsch, var. *nectarina*) is an important commercial crop in Spain, the world's third largest producer of peaches and nectarines [1]. The increased stone fruit production in recent years has included new cultivars with different flesh colors, flavors, soluble solids concentrations, and titratable acidities. In spite of this renewal of cultivar assortment, peach/nectarine consumption in Spain is continuously decreasing from close to 8–4.3 kg/capita-year in the period 1989–2012 [2]. Similar trend is registered in other EU countries (France, Italy, Greece, etc.) and USA. Several reports from Italy [3], France [4], Spain [5], and USA [6] evidenced that the main causes of this low consumption are the inconsistent quality of the product (hard or soft texture and the lack of flavor). Since there is a high production and relatively low consumption, this means that a larger part of the fruits will have to be stored for longer periods in order to regulate commercial availability. Unfortunately, nectarine fruit is characterized by high perishability caused by rapid softening during shelf life, which restricts drastically storage potential [7]. Low-temperature storage is the primary tool used to reduce postharvest deterioration and maintain overall fruit quality, since reducing metabolic activity and respiration rates effectively slows ripening [8]. However, storage potential depends on cultivar. For instance, some early maturing, white-fleshed nectarine cultivars tended to maintain quality under controlled atmosphere storage better than later maturing cultivars [9].

Nectarine flavor is the result of a complex combination of taste and odor. Aroma is an essential factor for evaluating nectarine quality [10]. Only volatile compounds present in concentrations above their odor thresholds contribute to overall nectarine aroma [11]. Volatile composition is also cultivar dependent; the volatile profile of nectarine includes alcohols, aldehydes, esters, ketones, terpenes, and lactones, mainly γ- and δ-decalactones [12–17]. Since flavor is a key attribute for sensory quality and consumer acceptance in stone fruit [18], its absence is often associated with unsatisfactory eating quality regardless of firmness and external appearance. Improving volatile production has therefore become an important challenge for the fruit industry.

Intensive research has focused on changes in the physicochemical characteristics and volatile composition of nectarines during maturation and ripening [10, 19–23]. Ester and lactone compounds provide fruity notes, and C_6 aldehyde and alcohol compounds contribute green sensory notes to the aroma of the ripening fruit, respectively [17]. Benzaldehyde and linalool increase significantly during maturation [19]. Although the first comprehensive studies of nectarine volatile production were performed about 40 years ago [12], to the best of our knowledge, no previous studies on the relationships between volatile production, quality, and sensory evaluation in cold-stored fruit have appeared in the literature.

The objectives of this study were the evaluation of the relationships between volatile compounds, physicochemical measurements, and consumer acceptance of 'Big Top,' 'Honey Blaze^{cov},' 'Honey Royale^{cov},' 'Venus,' 'August Red,' and 'Nectagala^{cov}' nectarines and the assessment of the ability of post-storage exposure of fruit to air at 20 °C to stimulate volatile production after cold storage. These varieties were selected in order to cover all the season maturity periods, and they represent the most produced nectarine varieties in Europe.

Materials and methods

Plant material and storage conditions

Nectarine fruits (*P. persica* (L.) Batsch, var. *nectarina*) of early season varieties 'Big Top' and 'Honey Blaze^{cov}' were harvested on June 30, 2009, at 97 and 100 days after full bloom (DAFB), respectively. Fruits of mid-season varieties 'Honey Royale^{cov}' and 'Venus' were harvested on July 31, 2009, at 122 and 125 DAFB, respectively, and fruits of late season varieties 'August Red' and 'Nectagala^{cov}' were harvested on August 31, 2009, at 160 and 166 DAFB, respectively. The six nectarine varieties were grown in commercial orchards at Alcarràs, Lleida, Catalonia (northeastern Spain). Immediately after harvest, four 50 kg lots from each cultivar were selected on the basis of uniformity and the absence of defects. One lot was analyzed at harvest (H) and the other three lots were stored for 10 (S10), 20 (S20), or 40 (S40) days at −0.5 °C and 92–93 % relative humidity in a 22 m^3 cold air storage chamber (21 kPa O_2/0.03 kPa CO_2). Analyses were carried out just after removal from each cold storage (SL0) and following 3 days at 20 °C (SL3).

Chemicals

All the standards for the volatile compounds studied in this work were analytical grade or the highest quality available. Ethyl acetate, 2,3-butanodione, eucalyptol, butyl acetate, pentyl acetate, acetophenone, and γ-hexalactone were obtained from Fluka (Buchs, Switzerland). 2-Methylpropyl acetate was obtained from Avocado Research Chemicals, Ltd. (Madrid, Spain). 2-Ethyl-1-hexenal, Z-3-hexenyl acetate, methyl octanoate, and decanoic acid were obtained from SAFC Supply Solutions (St. Louis, MO, USA). The rest of the compounds (up to 43) were supplied by Sigma-Aldrich (Steinheim, Germany).

Analysis of volatile compounds

The measurement of volatile compounds was carried out as described [24]. Six kilograms of fruit per cultivar (2 kg per replicate × 3) at harvest and after each cold storage period were selected for analysis of volatile compounds. Intact fruits were placed in an 8-L Pyrex container through which an air stream (150 mL/min) was passed for 60 min. The resulting effluent was passed through an adsorption tube filled with 350 mg Tenax TA/Carbograph 1TD at 20 °C. The volatile compounds were desorbed at 275 °C for 15 min, using an automated UNITY Markes thermal desorption system (Markes International Ltd., Llantrisant, United Kingdom). The identification and quantification of volatile compounds were performed on an Agilent 7890A gas chromatograph (Hewlett-Packard Co., Barcelona, Spain) equipped with a flame ionization detector (GC-FID), using a capillary column with cross-linked free fatty acid as the stationary phase (FFAP; 50 m × 0.2 mm × f0.33 μm). Helium was used as the carrier gas, at a linear velocity of 42 cm/s, with a split ratio of 60:1. Both the injector and the detector were kept at 240 °C. The analysis was conducted according to the following program: 40 °C (1 min); 40–115 °C (2.5 °C/min); 115–225 °C (8 °C/min); 225 °C (10 min). Compound identification was performed in an Agilent 6890 N gas chromatograph/mass spectrometer (Agilent Technologies, Inc.), using the same capillary column and chromatographic conditions as for GC analyses. Mass spectrometric data were collected in full scan. Scan ranged from 30 to 500 amu. The scan rate was 3.1 scans/s. Mass spectra were obtained by electron impact ionization at 70 eV. Helium was used as the carrier gas (42 cm/s), following the same temperature gradient program described above. Spectrometric data were recorded

(Hewlett-Packard 3398 GC Chemstation) and compared with those from the original NIST HP59943C library mass spectra. Compounds were confirmed by comparing their respective Kovats retention indices with those of accepted standards and by enriching peach extracts with authentic standards. Quantification was performed using individual calibration curves for each identified compound. Standard concentrations were prepared by dilution in diethyl ether (ACS >99.8 %, Fluka, Barcelona, Spain) and ranged between 0.01 and 100 μg/kg. They were freshly prepared at calibration. The concentrations were expressed as ng/kg.

Analysis of physicochemical parameters

Twenty fruits either at harvest or after each combination of factors (storage period × shelf life period) were individually assessed for flesh firmness, soluble solids content (SSC), titratable acidity (TA), and skin color. Flesh firmness was measured on opposite sides of each fruit with a digital penetrometer (Model. 53205; TR, Forlí, Italy) equipped with an 8 mm diameter plunger tip; the results were expressed in N. SSC and TA were measured in juice pressed from each fruit. SSC was determined with a Palette-10 hand refractometer (Atago PR-32, Tokyo, Japan), and the results were expressed as percent sucrose in an equivalent solution. TA was determined by titrating 10-mL juice with 0.1 M of NaOH to pH 8.1, and the results were given as grams of malic acid per liter. Fruit epidermis color was determined with a portable tri-stimulus colorimeter (Chroma Meter CR-400, Konica Minolta Sensing, Inc. Osaka, Japan) using CIE illuminant D_{65} and with an 8-mm measuring aperture diameter. The skin color was measured at two points on the equator of each fruit that were 180° apart: one was on the side exposed to sunlight (ES) and the other was on the shaded side (SS). Hue angle was determined on both sides, and the resulting values were used as measurements of superficial (ES) and background (SS) color.

Sensory analyses

Common fruits were used for consumer evaluation and physicochemical analysis but different to that used for volatile analysis.

Twenty nectarines per cultivar at harvest and after each cold storage period were kept in a room at 20 °C for 3 days and used for consumer evaluation. Prior to this evaluation, color and flesh firmness were measured on each fruit, and two longitudinal wedges were instrumentally analyzed in relation to its SSC and TA values, as explained above; the rest of the fruit was divided into pieces and used for consumer evaluation. A piece of nectarine of each cultivar was placed on a white plate and immediately presented to a tasting panel of 111 consumers, straight after each harvest and after each storage period. The consumers were all volunteers and were either staff members at the UdL-IRTA research institute or students at the University of Lleida. All test participants were habitual nectarine consumers. Each piece was identified by a random three-digit code. Two cultivars were harvested at the same time. Thus, two pieces of fruit (one per each cultivar) were presented on the white plate. The order of tasting of each cultivar was randomized for each consumer. Mineral water was used as palate cleansers between samples. To score the degree of consumer preference, each consumer tasted all samples and was asked to indicate his/her degree of like/dislike using a 9-point hedonic scale (1—dislike extremely to 9—like extremely). The percentage of satisfied consumers was defined as the percentage of participating consumers who scored a particular sample with a mark of 6 or higher. Samples could be re-tasted as often as the tasters wanted to ensure that they were confident about the different scores. The same consumers participated in all the different evaluations.

Statistical analyses

A multifactor design was used for statistical analysis of the results. The factors considered were cultivar, storage time, and shelf life time. All data were tested using analysis of variance (GLM/ANOVA procedure) with the SAS program package [25]. Means were separated by the least significant difference (LSD) test at $p \leq 0.05$. Unscrambler version 9.1.2 software [26] was used to develop a partial least square regression model (PLSR). This PLSR was used as a predictive method to relate consumer acceptance (Y) to a set of explanatory variables (X) which contains the volatile compounds and physicochemical measures. As a pretreatment, data were centered and weighted using the inverse of the standard deviation of each variable in order to avoid the influence of the different scales used for the variables [27]. Full cross-validation was run as a validation procedure.

Results and discussion

Physicochemical measures at harvest and after cold storage

At harvest (Table 1), cultivars showed statistically similar average firmness except 'Big Top' and 'August Red,' which were firmer than the others. Firmness measurements were between 38.14 and 47.09 N, consistent with the recommended harvest firmness for nectarine fruits intended for cold storage [8]. The SSC and TA exhibited varietal differences; sugar and acid concentrations are cultivar dependent [28]. As expected, the 'Honey Royale^{cov}' variety had the highest SSC. However, in our study, 'Big Top' and 'Honey Blaze^{cov},' which are typically sweet varieties, exhibited lower SSC values as a particular year behavior. The variety with the highest TA was 'August Red,' followed by 'Venus,' 'Big Top,' 'Honey Blaze^{cov},' 'Honey Royale^{cov},' and 'Nectagala^{cov}.' All the varieties studied here were selected because they typically exhibit high coloration [28]; consequently, statistical differences were not detected, except for 'Honey Blaze^{cov}' which presented significant differences for the hue angle measured on the shaded side.

In general, after each cold storage period, the loss of firmness during shelf life was one of the most important changes among the physicochemical measures (Table 1), the only variety that maintained firmness was 'Nectagala^{cov}.' The negative effect of shelf life temperature on nectarine firmness has also been reported by other authors [8]. However, 'Nectagala^{cov}' firmness was not affected by shelf life, probably due to the denser pulp of this slow melting cultivar. Along cold storage plus 0 days at 20 °C, all the varieties presented a quite stable firmness, except 'Honey Royale^{cov}' variety which showed a significant softening. This unusual softening was not observed in 2010 and 2011 and could be due to the high temperatures and rainfall raised during July 2009. After 3 days at 20 °C after cold storage, firmness ranged from 7.0 N for 'Venus' to 32.1 N for 'Big Top.' The extreme firmness for 'Big Top,' even after 3 days of storage at 20 °C, agrees with previous results of its special texture [6, 29–31].

Shelf life at 20 °C did not generally affect SSC, which remained constant. The only exception was in 'Honey Royale^{cov}' fruits cold stored for 20 days, which exhibited a slight decrease in SSC. A slight increase in SSC during shelf life after removal from cold storage has been reported [32]. In general, in this study, the storage period did not influence SSC (Table 1). These results indicate that even though nectarines are climacteric fruits, postharvest variations in SSC should be relatively unimportant [33].

In general, after cold storage and the subsequent shelf-life period, TA was lower than the corresponding harvest value for all varieties, except 'August Red' and 'Nectagala^{cov}' cultivars which showed an almost constant TA. The decrease in TA with cold storage is attributable to the oxidation of organic acids [7, 32].

The SSC/TA ratio tended to show a slight increase along cold storage as can be deduced from the slight decrease in TA, while SSC tended to keep constant. Similar results were previously reported for 'Harvester' peaches [34]. A closer relationship has been reported between the SSC/TA ratio and eating quality than between TA and SSC considered separately [32]. However, the establishment of a minimum quality index based on SSC or SSC/TA must be evaluated for each stone fruit cultivar [35].

No significant differences in hue were detected during cold storage for 'August Red,' 'Big Top,' or 'Venus.' Over recent decades, new cultivars have been released which develop a full, intense red color at an early stage of maturity [36–38]. As seen here, this full red color makes these cultivars more uniform and means that they undergo fewer changes during cold storage.

Volatile compounds emitted by nectarines at harvest and after cold storage

Differences in volatile profiles before and after cold storage were found among the different cultivars (Table 2), up to 23 out of 43 volatile compounds emitted by the analysed cultivars were detected for the first time after cold storage. In early season cultivars 'Big Top' and 'Honey Blaze^{cov},' eight new compounds were identified after cold storage. In mid-season cultivars 'Venus' and 'Honey Royale^{cov},' five and nine new compounds were identified after cold storage, respectively, while ten new compounds were detected after cold storage in the two late season cultivars 'August Red' and 'Nectagala^{cov}.' For instance, ethyl 2-methylbutanoate was not detected at harvest but appeared during cold storage in one early cultivar ('Big Top'), two mid-season varieties ('Venus' and 'Honey Royale^{cov}'), and one late season cultivar ('Nectagala^{cov}'). In contrast, 2-methylpropyl hexanoate was only detected at harvest in 'Big Top' nectarines.

Most of these volatile compounds were esters, and since esters and lactones are the most important contributors to nectarine aroma [39], particular attention was placed on these compounds. Emissions of eight straight-chain esters (ethyl acetate, butyl propanoate, pentyl acetate, hexyl propanoate, methyl octanoate, ethyl octanoate, pentyl hexanoate, and hexyl hexanoate), five branched-chain esters (ethyl 2-methylbutanoate, 2-methylbutyl-2-methylpropanoate, butyl 2-methylbutanoate, Z-3-hexenyl acetate, and hexyl 2-methylbutanoate), and four cyclic esters (γ-hexalactone, γ-octalactone, δ-decalactone, and γ-dodecalactone) were detected in nectarines after cold storage. As a consequence, increased fruity and floral notes [17] were observed in the volatile profiles of 'Big Top,' 'Honey Blaze^{cov},' 'Venus,' 'Honey Royale^{cov},' 'August Red,' and 'Nectagala^{cov}' nectarines after cold storage (Table 2).

The same aldehydes, ketones, terpenes, and acetic acid that were present at harvest were identified and quantified in the volatile fractions emitted by these six cultivars after cold storage (Table 2).

The effects of cold storage on early season varieties were mainly characterized by opposing changes in two major groups of volatile compounds, esters and acids

Table 1 Physicochemical measures of nectarine fruits at harvest and after storage at −0.5 °C for 10, 20, or 40 days with or without 3 days at 20 °C

Days at −0.5 °C	Harvest	10		20		30	
Days at 20 °C		0	3	0	3	0	3
Big Top							
SSC	11.3 a	11.6 a	11.0 a	11.4 a	12.2 a	11.5 a	10.6 a
TA	8.1 a	5.9 b	5.9 b	5.1 b	4.9 b	5.2 b	5.8 b
SSC/TA	14.1 c	19.7 bc	18.8 bc	22.6 ab	25.3 a	22.8 a	17.7 bc
Firmness	47.1 a	43.6 a	32.1 b	43.0 a	29.5 bc	40.1 ab	28.8 c
Hue skin (ES)	24.5 a	19.6 a	23.1 a	19.1 a	23.6 a	22.2 a	25.3 a
Hue skin (SS)	70.5 a	53.9 a	58.3 a	66.4 a	54.9 a	59.3 a	55.0 a
Honey Blaze[cov]							
SSC	11.2 a	11.8 a	11.9 a	11.3 a	11.1 a	10.2 b	11.0 a
TA	5.6 a	4.7 ab	4.9 ab	3.4 c	4.5 ab	3.3 c	4.0 bc
SSC/TA	21.0 d	25.4 bc	24.7 c	34.3 a	25.3 bc	31.6 a	27.5 b
Firmness	38.1 a	36.8 a	29.6 ab	33.6 ab	24.4 b	35.5 a	13.6 c
Hue skin (ES)	17.3 a	16.7 a	20.5 a	21.8 a	24.0 a	22.6 a	23.0 a
Hue skin (SS)	40.2 b	40.7 b	48.1 ab	52.5 a	51.0 ab	55.4 a	47.1 ab
Venus							
SSC	11.6 a	11.5 a	12.2 a	11.9 a	12.1 a	11.4 a	11.8 a
TA	9.9 a	10.0 a	10.1 a	8.3 b	6.9 b	7.9 b	7.0 b
SSC/TA	11.7 c	11.4 c	12.2 bc	14.3 b	17.5 a	14.4 b	16.8 a
Firmness	39.2 a	25.2 b	7.0 d	20.0 b	7.3 d	18.0 bc	15.0 c
Hue skin (ES)	23.5 a	19.7 a	18.5 a	24.3 a	21.6 a	23.6 a	18.7 a
Hue skin (SS)	60.5 a	54.9 a	52.9 a	68.4 a	57.3 a	69.9 a	61.7 a
Honey Royale[cov]							
SSC	13.2 b	13.6 b	12.9 b	14.9 a	11.1 c	11.5 c	14.0 ab
TA	5.5 a	3.2 b	2.8 b	2.5 b	3.0 b	3.0 b	2.7 b
SSC/TA	26.4 d	45.3 b	43.0 b	59.9 a	37.0 c	38.3 c	53.0 a
Firmness	39.6 a	36.4 a	8.4 d	28.3 b	7.9 e	16.8 c	28.1 bc
Hue skin (ES)	19.4 b	18.3 bc	18.3 bc	41.7 a	16.8 c	23.6 b	13.7 d
Hue skin (SS)	44.8 b	39.8 b	37.3 b	36.0 b	44.9 b	69.9 a	39.4 b
August Red							
SSC	12.5 a	12.8 a	13.0 a	12.4 a	12.5 a	12.9 a	12.5 a
TA	11.2 a	9.6 a	8.5 a	10.5 a	9.7 a	9.4 a	8.0 a
SSC/TA	11.2 d	13.4 bc	15.3 a	11.8 cd	13.2 bc	13.9 b	15.7 a
Firmness	47.0 a	30.2 b	17.4 d	27.8 b	20.6 cd	22.1 bc	17.5 d
Hue skin (ES)	28.3 a	30.2 a	29.5 a	29.2 a	27.7 a	31.1 a	31.2 a
Hue skin (SS)	79.4 a	82.9 a	84.1 a	87.2 a	82.7 a	86.7 a	82.1 a
Nectagala[cov]							
SSC	11.5 a	11.6 a	11.4 a	11.2 a	12.4 a	12.7 a	12.3 a
TA	4.3 a	3.8 a	3.8 a	3.1 a	3.2 a	2.7 a	2.6 a
SSC/TA	27.1 a	30.8 a	30.7 a	36.5 a	39.0 a	49.5 a	47.4 a
Firmness	40.4 a	21.0 b	17.2 b	19.1 b	17.8 b	19.7 b	17.2 b
Hue skin (ES)	23.1 a	23.6 a	27.9 a	20.4 a	20.6 a	20.8 a	20.4 a
Hue skin (SS)	70.9 a	66.6 b	83.8 a	71.7 a	63.0 b	70.2 a	65.1 b

Means followed by different small letters for each quality measure are significantly different at $p \leq 0.05$ (LSD test)

SSC Soluble solids content, *TA* titratable acidity, *ES* exposed side, *SS* shaded side

Table 2 Volatile compounds detected in six nectarine cultivars (labeled as X)

Volatile compounds	Code[a]	RI[b]	RI[c]	OTH[d]	CAS registry no.	Big top		Honey blaze[cov]		Venus	
						Harvest	Cold storage	Harvest	Cold storage	Harvest	Cold storage
Ethyl acetate	ea	911	–	13,500	141-78-6	nd	X	nd	nd	nd	X
Propyl acetate	pra	995	766	2,000	109-60-4	X	X	X	X	X	X
2,3-Butanodione	23bone	999	1,067	1	431-03-8	X	X	X	X	X	X
Eucalyptol	euOH	1,032	–	1	470-82-6	X	X	X	X	X	X
2-Methylpropyl acetate	2mpra	1,052	789	65	110-19-0	X	X	X	X	X	X
Hexanal	hnal	1,082	807	2.4	66-25-1	X	X	X	X	X	X
Ethyl 2-methylbutanoate	e2mb	1,127	847	0.006	7452-79-1	nd	X	nd	nd	nd	X
Butyl acetate	ba	1,183	816	66	123-86-4	X	X	X	X	X	X
2-Methylbutyl acetate	2mba	1,240	879	11	123-92-2	X	X	X	X	X	X
Butyl propanoate	bpr	1,257	912	25	590-01-2	X	X	X	X	nd	X
2-Ethyl-1-hexenal	2e1hal	1,293	1,033	Not found	123-05-7	X	X	X	X	X	X
Pentyl acetate	pa	1,307	917	43	628-63-7	X	X	X	X	X	X
2-Methylbutyl 2-methylpropanoate	2mb2mpr	1,310	1,043	14	2445-78-5	nd	X	X	X	X	X
2-Methyl-1-butanol	2mbOH	1,329	776	250	137-32-6	X	X	nd	X	nd	X
Butyl 2-methylbutanoate	b2mb	1,348	1,017	17	15706-73-7	X	X	X	X	nd	nd
1-Pentanol	pOH	1,375	788	4,000	71-41-0	X	X	nd	X	X	X
Hexyl acetate	ha	1,393	1,016	2	142-92-7	X	X	X	X	X	X
2-Methylbuyl 2-methylbutanoate	2mb2mb	1,397	1,123	Not found	2445-78-5	X	X	nd	nd	nd	nd
Acetic acid	aac	1,432	–	99,000	64-19-7	X	X	X	X	X	X
Hexyl propanoate	hp	1,435	1,110	Not found	2445-76-3	nd	X	nd	nd	nd	X
Propyl hexanoate	prh	1,440	1,099	Not found	626-77-7	X	X	X	X	nd	nd
2-Methylpropyl hexanoate	2mprh	1,444	1,293	Not found	105-79-3	X	nd	nd	nd	nd	nd
Z-3-Hexenyl acetate	Z3hxea	1,457	1,020	13	3681-71-8	X	X	X	X	X	X
1-Hexanol	hOH	1,480	873	500	111-27-3	X	X	X	X	X	X
Methyl octanoate	mo	1,511	1,128	200	111-11-5	X	X	X	X	X	X
Z-3-hexen-1-ol	Z3henOH	1,513	857	70	928-96-2	nd	X	nd	X	X	X
Benzaldehyde	byde	1,521	971	350	100-52-7	X	X	X	X	X	X
Butyl hexanoate	bh	1,533	1,014	700	626-82-4	X	X	nd	nd	X	X
Hexyl 2-methylbutanoate	h2mb	1,546	1,239	22	10032-12-0	X	X	X	X	X	X
Ethyl octanoate	eo	1,555	1,003	Not found	106-32-1	X	X	X	X	X	X
Benzoic acid	bac	1,560	1,193	85,000	65-85-0	X	X	X	X	X	X
2-Ethyl-1-hexanol	2ehOH	1,619	1,033	Not found	104-76-4	X	X	X	X	X	X
Pentyl hexanoate	ph	1,637	1,293	Not found	540-07-8	nd	X	nd	nd	nd	nd
(R)-Linalool	liOH	1,679	1,105	0.087	126-91-0	X	X	X	X	X	X

Table 2 continued

Volatile compounds	Code[a]	RI[b]	RI[c]	OTH[d]	CAS registry no.	Big top		Honey blaze[cov]		Venus	
						Harvest	Cold storage	Harvest	Cold storage	Harvest	Cold storage
Hexyl hexanoate	hh	1,736	1,392	6,400	6378-65-0	X	X	nd	X	X	X
Acetophenone	aone	1,736	1,076	65	98-86-2	X	X	X	X	X	X
Butyl octanoate	bo	1,740	1,394	Not found	589-75-3	X	X	X	X	X	X
Benzyl alcohol	beOH	1,869	1,046	Not found	10-51-6	X	X	X	X	X	X
γ-Hexalactone	hlac	1,880	1,266	1,600	695-02-7	X	X	X	X	X	X
γ-Octalactone	olac	2,111	1,270	7	104-50-7	X	X	nd	X	X	X
Decanoic acid	deac	2,407	1,390	2,200	334-48-5	nd	X	nd	X	X	X
δ-Decalactone	dlac	2,417	1,507	31	211-889-1	X	X	nd	X	X	X
γ-Dodecalactone	dolac	2,587	1,697	0.43	2305-05-7	nd	X	nd	X	nd	nd

Volatile compounds	Code[a]	RI[b]	RI[c]	OTH[d]	CAS registry no.	Honey royale[cov]		August red		Nectagala[cov]	
						Harvest	Cold storage	Harvest	Cold storage	Harvest	Cold storage
Ethyl acetate	ea	911	–	13,500	141-78-6	X	X	X	X	X	X
Propyl acetate	pra	995	766	2,000	109-60-4	X	X	X	X	X	X
2,3-Butanodione	23bone	999	1,067	1	431-03-8	X	X	X	X	X	X
Eucalyptol	euOH	1,032	–	1	470-82-6	X	X	X	X	X	X
2-Methylpropyl acetate	2mpra	1,052	789	65	110-19-0	X	X	X	X	X	X
Hexanal	hnal	1,082	807	2.4	66-25-1	X	X	X	X	X	X
Ethyl 2-methylbutanoate	e2mb	1,127	847	0.006	7452-79-1	nd	X	nd	nd	nd	X
Butyl acetate	ba	1,183	816	66	123-86-4	X	X	X	X	X	X
2-Methylbutyl acetate	2mba	1,240	879	11	123-92-2	X	X	X	X	X	X
Butyl propanoate	bpr	1,257	912	25	590-01-2	nd	X	nd	nd	nd	nd
2-Ethyl-1-hexenal	2e1hal	1,293	1,033	Not found	123-05-7	X	X	X	X	X	X
Pentyl acetate	pa	1,307	917	43	628-63-7	nd	X	nd	X	nd	X
2-Methylbutyl 2-methylpropanoate	2mb2mpr	1,310	1,043	14	2445-78-5	X	X	nd	nd	X	X
2-Methyl-1-butanol	2mbOH	1,329	776	250	137-32-6	X	X	X	X	nd	X
Butyl 2-methylbutanoate	b2mb	1,348	1,017	17	15706-73-7	nd	nd	nd	nd	nd	X
1-Pentanol	pOH	1,375	788	4,000	71-41-0	nd	X	nd	X	nd	X
Hexyl acetate	ha	1,393	1,016	2	142-92-7	X	X	X	X	X	X
2-Methylbuyl 2-methylbutanoate	2mb2mb	1,397	1,123	Not found	2445-78-5	nd	nd	nd	nd	nd	nd
Acetic acid	aac	1,432	–	99,000	64-19-7	X	X	X	X	X	X
Hexyl propanoate	hp	1,435	1,110	Not found	2445-76-3	nd	X	nd	nd	nd	nd
Propyl hexanoate	prh	1,440	1,099	Not found	626-77-7	nd	nd	nd	nd	nd	nd
2-Methylpropyl hexanoate	2mprh	1,444	1,293	Not found	105-79-3	nd	nd	nd	nd	nd	nd

Table 2 continued

Volatile compounds	Code[a]	RI[b]	RI[c]	OTH[d]	CAS registry no.	Honey royale[cov]		August red		Nectagala[cov]	
						Harvest	Cold storage	Harvest	Cold storage	Harvest	Cold storage
Z-3-Hexenyl acetate	Z3hxea	1,457	1,020	13	3681-71-8	nd	X	nd	nd	nd	X
1-Hexanol	hOH	1,480	873	500	111-27-3	X	X	X	X	nd	X
Methyl octanoate	mo	1,511	1,128	200	111-11-5	X	X	nd	X	nd	X
Z-3-hexen-1-ol	Z3henOH	1,513	857	70	928-96-2	nd	X	X	X	nd	nd
Benzaldehyde	byde	1,521	971	350	100-52-7	X	X	X	X	X	X
Butyl hexanoate	bh	1,533	1,014	700	626-82-4	nd	nd	nd	nd	nd	nd
Hexyl 2-methylbutanoate	h2mb	1,546	1,239	22	10032-12-0	X	X	nd	X	X	X
Ethyl octanoate	eo	1,555	1,003	Not found	106-32-1	X	X	nd	X	nd	X
Benzoic acid	bac	1,560	1,193	85,000	65-85-0	X	X	X	X	X	X
2-Ethyl-1-hexanol	2ehOH	1,619	1,033	Not found	104-76-4	X	X	X	X	X	X
Pentyl hexanoate	ph	1,637	1,293	Not found	540-07-8	nd	nd	nd	nd	nd	nd
(R)-Linalool	liOH	1,679	1,105	0.087	126-91-0	X	X	X	X	X	X
Hexyl hexanoate	hh	1,736	1,392	6,400	6378-65-0	X	X	nd	X	X	X
Acetophenone	aone	1,736	1,076	65	98-86-2	X	X	X	X	X	X
Butyl octanoate	bo	1,740	1,394	Not found	589-75-3	X	X	nd	nd	nd	nd
Benzyl alcohol	beOH	1,869	1,046	Not found	10-51-6	X	X	X	X	nd	X
γ-Hexalactone	hlac	1,880	1,266	1,600	695-02-7	X	X	nd	X	X	X
γ-Octalactone	olac	2,111	1,270	7	104-50-7	nd	X	nd	X	nd	nd
Decanoic acid	deac	2,407	1,390	2,200	334-48-5	X	X	X	X	X	X
δ-Decalactone	dlac	2,417	1,507	31	211-889-1	nd	X	nd	X	nd	nd
γ-Dodecalactone	dolac	2,587	1,697	0.43	2305-05-7	nd	nd	nd	X	nd	nd

[a] Codes used for principal component analysis

[b] *RI* Retention index in a FFAP column

[c] *RI* Retention index in a BPX5 column. Volatile compounds not detected: nd

[d] Odor threshold (μg kg^{-1}) in water as reviewed in Ref. [23]

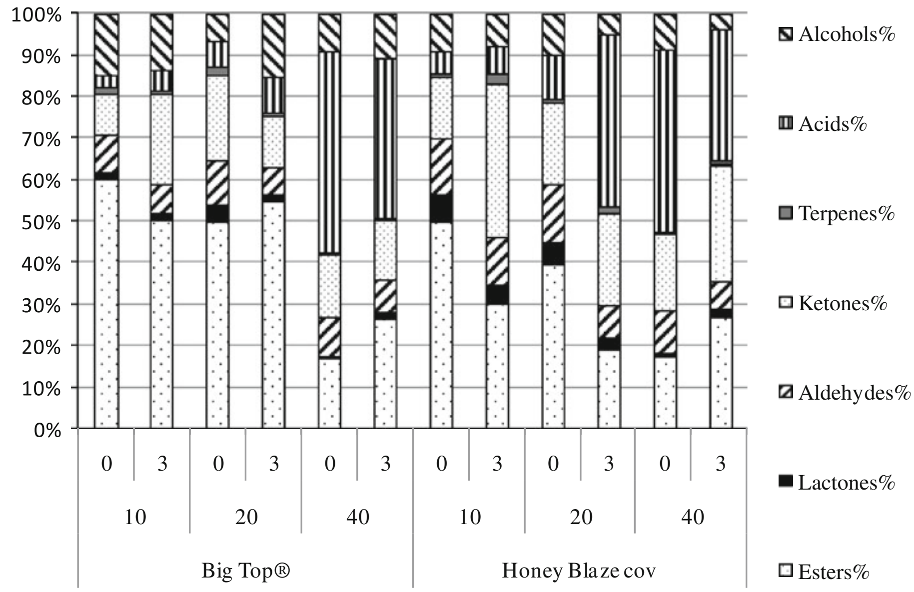

Fig. 1 Relative proportions (%) of the main classes of volatile compounds in 'Big Top®' and 'Honey Blaze^{cov}' nectarines after 10, 20, or 40 days storage at −0.5 °C with or without 3 days at 20 °C

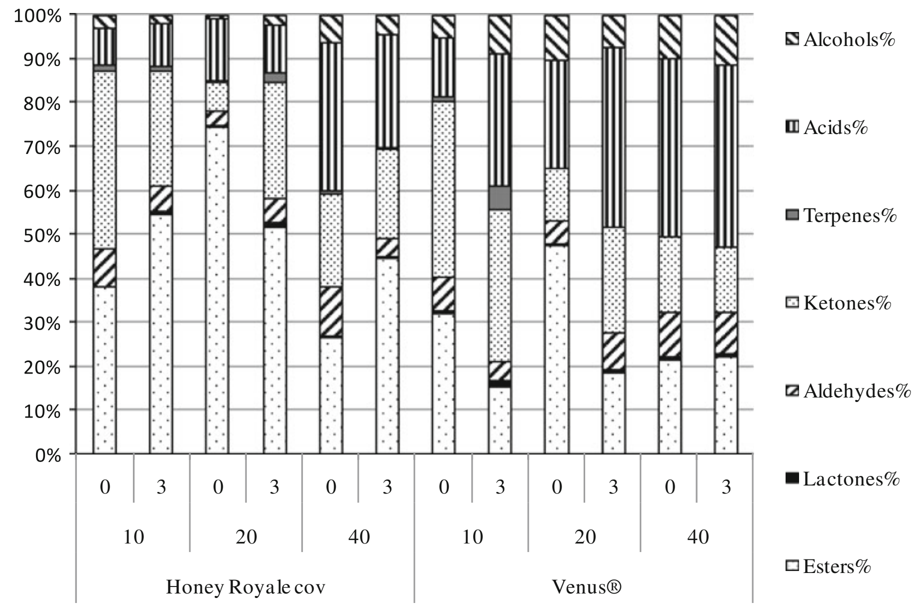

Fig. 2 Relative proportions (%) of the main classes of volatile compounds in 'Honey Royale^{cov}' and 'Venus®' nectarines after 10, 20, or 40 days storage at −0.5 °C with or without 3 days at 20 °C

(Fig. 1). Esters were the main compounds isolated from 'Big Top' and 'Honey Blaze^{cov},' representing ≥50 % of total volatile compounds in fruit kept in cold storage for 10 days without shelf life. The relative proportion of esters decreased by up to 17 % in early season varieties after 40 days cold storage. An increase in the relative proportion of acids was observed during cold storage: ≥39 % in 'Big Top' and ≥30 % in 'Honey Blaze^{cov}' nectarines after 40 days cold storage, depending on shelf life.

In mid-season cultivars like 'Venus' and 'Honey Royale^{cov},' the volatile profile was dominated by esters (75–15 %), acids (42–8 %), and ketones (40–7 %). These three organic families represented more than 78 % of total volatile compounds in samples kept in cold storage. During cold storage and/or shelf life at 20 °C, the relative proportions of ester and ketone compounds decreased by up to 37 % in 'Venus' after 40 days cold storage. With the relative proportion of esters decreasing after 40 days cold storage, the proportion of acids increased during the same period. Acids became the most abundant compounds in 'Venus' (41 % of total volatile compounds) and the second most abundant compounds in 'Honey Royale^{cov}' (26 % of total volatile compounds) after 40 days cold storage (Fig. 2).

During cold storage and shelf life of two late season varieties, the volatile profile was dominated by acids (65–17 %), ketones (55–8.5 %), and esters (52–3.5 %). The relative proportion of acids was higher than that of

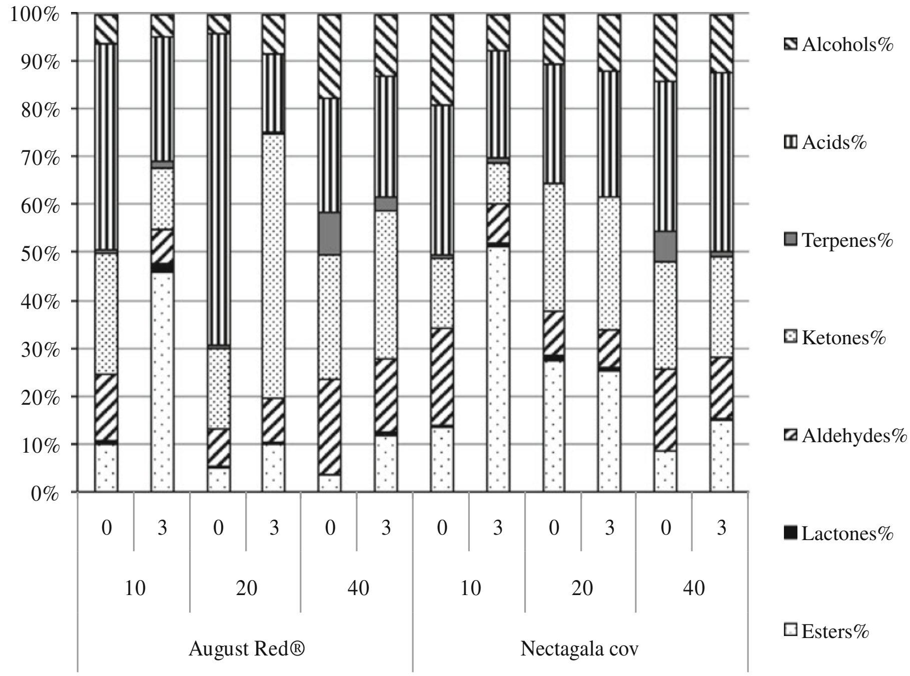

Fig. 3 Relative proportions (%) of the main classes of volatile compounds in 'August Red®' and 'Nectagala^cov' nectarines after 10, 20, or 40 days storage at −0.5 °C with or without 3 days at 20 °C

esters in fruits kept in cold storage for 10 or 40 days plus 0 days of shelf life. There was an increase in the relative proportion of esters during shelf life in both 'August Red' and 'Nectagala^cov' nectarines, particularly after 10 days cold storage (Fig. 3).

Differences among cultivars in volatile emissions were found both before and after cold storage (Tables 3, 4, and 5). At harvest, the total volatiles emitted by 'Venus' were triple those emitted by 'Big Top,' 'Honey Royale^cov,' 'August Red,' 'Honey Blaze^cov,' or 'Nectagala^cov,' whose emissions ranged from 2,275 to 3,710 ng/kg. After 10 days cold storage plus 3 days at 20 °C, the total volatiles of 'Honey Royale^cov' were 12,565 ng/kg; this was more than those of 'Big Top,' 'Venus,' or 'August Red' (5,360, 5,350, or 4,987 ng/kg, respectively) and about four times higher than 'Nectagala^cov' and 'Honey Blaze^cov' (2,991 and 2,523 ng/kg, respectively).

Cold storage and shelf life affected total volatile emissions in early and late season cultivars (Tables 3, 5). The greatest increases in total volatile compounds emitted by 'Honey Blaze^cov' and 'August Red' were obtained after 40 days cold storage plus 3 days at 20 °C. In contrast, a significant decrease in total volatile emissions was noted in 'Honey Royale^cov' after 40 days cold storage plus 0 days at 20 °C (Table 4).

'Big Top,' 'Venus,' 'Honey Royale^cov,' and 'Nectagala^cov' cultivars cold stored after 20 or 40 days showed ethyl 2-methylbutanoate concentrations higher than for fruit stored for 10 days. Ethyl 2-methylbutanoate directly affected nectarine flavor because it has a very low odor threshold (6 ng/kg; Table 2) and plays an important role in the characteristic aroma of many fresh fruits such as apple [40], blackberry [41], orange [42], and pineapple [43].

The emission of acetate esters, and especially of 2-methylpropyl, pentyl, and hexyl acetates, increased with cold storage in 'Big Top' and 'Honey Blaze^cov' nectarines. In fruits kept for 40 days cold storage plus 3 days at 20 °C, a large increase was observed (Table 3).

Four lactones were found, although not all were detected in all nectarines (Tables 3, 4, and 5). Lactones accounted for 0.5–3.5 % of total volatiles (Figs. 1, 2, and 3). These low proportions were consistent with previous observations of mature nectarines [17]. In our study, the most abundant and stable lactone during cold storage followed by shelf life was γ-hexalactone. Lactones are prominent volatiles in nectarine aroma [10], and concentrations of γ-hexalactone and γ- and δ-decalactones are generally low at harvest and increase during shelf life [44]. In early season cultivars, γ-dodecalactone was first detected after 10 days cold storage. This lactone has the lowest odor threshold (430 ng/kg; Table 2) and could therefore influence nectarine aroma [20]. Furthermore, γ-octalactone and δ-decalactone were identified in 'Honey Blaze^cov' after 10 days cold storage. In contrast, γ-dodecalactone was not detected in the two mid-season cultivars or in 'Nectagala^cov.' This influence of cultivar on lactone compounds has been previously noted: 10 lactones were found in the essential oil of three nectarine accessions, but none lactones were detected in 'Romagna Big' nectarines [23].

Significant differences in lactone concentrations were found among the six cultivars and different cold storage times. In early season and 'Nectagala' cultivars, there was

Table 3 Volatile compounds emitted (ng/kg) by 'Big Top' and 'Honey Blaze[cov]' nectarines after cold storage at −0.5 °C with or without 3 days at 20 °C

Early season varieties	Big Top							Honey Blaze[cov]						
Days at −0.5 °C	Harvest	10		20		40		Harvest	10		20		40	
Days at 20 °C		0	3	0	3	0	3		0	3	0	3	0	3
Ethyl acetate	nd	17.5 a	22.8 a	nd	21.4 a	nd	nd	nd	nd	nd	nd	nd	nd	nd
Propyl acetate	<10	488.2 a	516.1 a	171.9 b	601. a	nd	nd	20.3	432.2 a	23.4 b	407.2 a	22.9 b	nd	nd
2-Methylpropyl acetate	21.5	40.7 c	42.7 c	55.0 b	50.2 bc	nd	116.1 a	213.1	30.9 b	62.7 b	29.7 b	61.9 b	46.9 b	219.0 a
Ethyl 2-methylbutanoate	nd	<10	<10	18.3 b	<10	37.0 a	nd	nd	nd	nd	nd	nd	nd	nd
Butyl acetate	42.1	97.7 b	103.9 a	30.6 c	120.4 a	nd	36.1 c	55.1	119.1 a	21.5 b	113.3 a	20.8 a	25.8 b	88.5 a
2-Methylbutyl acetate	29.7	109.5 b	117.9 b	261.1 a	134.9 b	231.2 a	273.4 a	71.3	143.3 a	133.0 a	139.0 a	126.6 a	205.4 a	185.3 a
Butyl propanoate	113.1	17.9 a	19.3 a	28.2 a	22.0 a	nd	nd	99.3	nd	12.5 a	nd	11.7 a	nd	nd
Pentyl acetate	10	<10	<10	<10	<10	<10	12.1 a	87.5	<10	11.2 b	<10	10.8 b	11.4 b	24.5 a
2-Methylbutyl 2-methylpropanoate	153.9	51.8 a	53.7 a	36.0 b	63.9 a	32.4 b	50.3 a	368.4	35.5 a	50.6 a	37.1 a	49.7 a	27.1 a	43.2 a
Butyl 2-methylbutanoate	24.5	41.5 a	44.8 a	nd	51.2 a	nd	nd	48.8	24.3 a	nd	20.8 a	nd	nd	nd
Hexyl acetate	45.1	73.2 b	79.5 b	37.3 c	90.2 a	43.6 c	95.5 a	93.3	34.0 b	54.8 b	34.6 b	52.7 b	36.5 b	109.4 a
2-Methylbuyl 2-methylbutanoate	nd	25.4 a	26.7 a	nd	31.4 a	nd	nd	nd	nd	nd	nd	nd	nd	nd
Propyl hexanoate	32	12.0 a	11.1 a	<10	14.9 a	nd	nd	36.3	66.6 b	148.4 a	57.1 b	140.6 a	nd	nd
Z-3-hexenylacetate	58.4	70.6 a	92.1 a	43.6 b	86.5 a	nd	nd	51.4	72.4 a	68.0 a	81.3 a	67.8 a	nd	nd
Hexyl propanoate	nd	100.2 a	92.6 a	nd	124.0 a	16.3 b	nd	nd	nd	nd	nd	nd	nd	nd
2-Methylpropyl hexanoate	<10	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Methyl octanoate	33	<10	<10	<10	11.0 a	<10	13.2 a	35.5	24.7 a	<10	39.4 a	<10	28.4 a	13.7 b
Butyl hexanoate	<10	179.8 b	185.7 b	nd	221.9 a	nd	56.7 c	nd	nd	nd	nd	nd	nd	nd
Hexyl 2-methylbutanoate	11.6	716.3 a	737.7 a	12.5 c	883.7 a	17.9 c	175.3 b	10.4	18.7 a	11.4 a	16.0 a	11.3 a	10.2 a	12.1 a
Ethyl octanoate	229	81.1 b	84.3 b	329.0 a	100.1 b	26.8 c	86.5 b	82.5	79.0 b	98.3 b	69.5 b	97.3 b	144.2 b	506.8 a
Pentyl hexanoate	nd	34.9 a	36.2 a	<10	43.1 a	nd	11.4 b	nd	nd	nd	nd	nd	nd	nd
Hexyl hexanoate	22	314.5 a	331.4 a	19.3 b	387.8 a	13.4 b	146.8 b	nd	38.7 a	36.6 a	48.0 a	38.1 a	11.0 b	41.3 a
Butyl octanoate	25.4	56.2 a	59.9 a	11.4 b	69.3 a	nd	21.4 b	<10	18.9 a	15.4 a	21.8 a	16.4 a	nd	nd
γ-Hexalactone	26.5	30.7 c	34.1 b	28.7 c	37.8 b	12.7 d	49.7 a	36.3	44.4 a	41.4 a	48.8 a	41.3 a	30.3 a	67.4 a
γ-Octalactone	<10	12.8 a	14.1 a	13.2 a	15.7 a	nd	nd	nd	24.6 a	18.4 a	26.5 a	18.3 a	nd	nd
δ-Decalactone	<10	16.8 b	20.6 b	51.9 a	20.6 b	nd	12.8 b	nd	73.1 a	41.0 a	68.3 a	41.0 a	nd	24.5 b
γ-Dodecalactone	nd	<10	<10	nd	<10	nd	nd	nd	13.3 a	<10	14.2 a	<10	nd	nd
2-Ethyl-1-hexenal	133.7	115.2 a	127.7 a	77.2 b	141.8 a	82.1 a	116.2 a	11.8	68.3 a	94.0 a	71.5 a	91.3 a	108.9 a	99.6 a
Hexanal	223.3	240.5 a	230.4 a	101.5 d	170.9 b	129.8 c	137.2 c	195.7	184.5 a	119.1 b	246.3 a	151.6 b	195.8 a	154.2 b
Benzaldehyde	112.0	26.2 b	18.4 b	51.3 a	63.7 a	34.4 b	71.8 a	97.5	63.3 a	85.9 a	78.1 a	63.8 a	26.4 b	64.0 a
2,3-Butanodione	419.8	364.6 c	1,030.8 a	340.6 c	660.2 b	333.2 c	542.4 b	740.1	270.4 c	900.8 a	460.9 b	784.5 b	525.0 b	1,221.7 a
Acetophenone	38.4	67.3 b	120.8 a	114.7 a	49.3 b	58.8 b	60.4 b	25.1	71.1 a	32.6 b	93.8 a	88.6 a	65.9 a	74.2 a

Table 3 continued

Early season varieties	Big Top							Honey Blaze^{cov}						
Days at −0.5 °C	Harvest	10		20		40		Harvest	10		20		40	
Days at 20 °C		0	3	0	3	0	3		0	3	0	3	0	3
Linalool	579.4	49.3 a	54.5 a	40.5 b	60.7 a	10.2 c	22.1 c	603.5	21.7 ab	59.5 a	22.8 ab	57.2 a	<10 c	22.3 ab
Eucalyptol	21.0	23.9 a	nd	nd	nd	nd	nd	<10	nd	nd	nd	nd	nd	16.9 a
Acetic acid	46.1	nd	88.7 b	nd	159.1 b	970.6 a	1,266.4 a	300.0	nd	nd	142.6 b	1,406.5 a	1,164.1 a	1,192.1 a
Decanoic acid	nd	nd	nd	nd	17.0 a	11.6 a	18.2 a	nd	nd	21.4 a	nd	26.0 a	nd	28.0 a
Benzoic acid	198.1	117.7 b	170.4 b	138.6 b	316.1 a	261.2 a	317.8 a	194.4	115.3 b	144.3 b	165.7 b	184.2 b	239.8 a	247.1 a
2-Methyl-1-butanol	24.8	34.7 a	37.3 a	nd	42.7 a	19.2 b	16.4 b	nd	nd	nd	nd	nd	35.8 a	10.9 b
1-Pentanol	12.3	13.2 a	15.4 a	nd	16.3 a	<10	nd	nd	14.3 a	10.3 a	12.2 a	<10	12.6 a	10.4 a
1-Hexanol	37.1	29.9 a	31.9 a	11.7 b	36.9 a	16.0 b	26.1 ab	30.3	19.9 a	20.4 a	20.7 a	19.8 a	16.0 a	21.7 a
Z-3-hexen-1-ol	nd	<10	<10	nd	<10	nd	nd	nd	nd	22.0 a	nd	20.6 a	nd	nd
2-Ethyl-1-hexanol	134.2	526.6 a	638.4 a	97.4 b	646.7 a	134.1 b	361.1 ab	169.5	150.0 a	108.5 a	170.3 a	108.2 a	170.6 a	124.6 a
Benzyl alcohol	99.3	24.2 b	34.4 b	40.0 b	130.9 a	58.7 b	57.9 b	17.2	33.3 b	39.0 b	81.5 a	41.5 b	52.2 b	23.0 c
Total esters	867.9	2,550.0 a	2,678.7 a	1,086.4 b	3,144.4 a	431.4 b	1,094.9 b	1,281.2	1,146.7 a	756.3 ab	1,122.2 a	736.2 ab	546.8 b	1,243.8 a
Total lactones	37.9	66.8 a	76.0 a	93.8 a	82.2 a	12.7 b	62.6 a	36.3	155.4 a	109.5 a	157.8 a	109.4 a	30.3 b	91.9 a
Total aldehydes	469.0	381.9 a	376.5 a	230.0 b	376.4 a	246.2 b	325.3 a	305.0	316.0 a	299.0 a	395.9 a	306.7 a	331.2 a	317.8 a
Total ketones	458.2	431.9 c	1,151.6 a	455.3 c	709.5 b	392.0 c	602.8 b	765.2	341.5 d	933.3 b	554.7 c	873.1 b	590.9 b	1,295.8 a
Total terpenes	600.4	73.2 a	54.5 b	40.5 c	60.7 a	10.2 e	22.1 d	611.6	21.7 b	59.5 a	22.8 b	57.2 a	8.4 c	39.2 ab
Total acids	244.2	117.7 b	259.1 b	138.6 b	492.3 b	1,243.4 a	1,602.4 a	494.4	115.3 b	165.7 b	308.3 b	1,616.6 a	1,404.0 a	1,467.3 a
Total alcohols	307.7	635.6 a	763.7 a	149.1 b	882.0 a	237.7 b	461.6 b	217.0	217.4 a	200.2 b	284.7 a	199.8 b	287.2 a	190.6 b
Total	2,985.3	4,257.1 b	5,360.1 a	2,193.6 c	5,747.5 a	2,573.7 c	4,171.7 b	3,710.7	2,314.0 b	2,523.4 b	2,846.3 b	3,899.0 b	3,198.7 b	4,646.4 a

Means within the variety followed by different small letters are significantly different at $p \leq 0.05$ (LSD test). Volatile compounds not detected are indicated by nd

Table 4 Volatile compounds emitted (ng/kg) by 'Venus' and 'Honey Royale[cov]' nectarines after cold storage at −0.5 °C with or without 3 days at 20 °C

Mid-season varieties	Venus							Honey Royale[cov]						
Days at −0.5 °C	Harvest	10		20		40		Harvest	10		20		40	
Days at 20 °C		0	3	0	3	0	3		0	3	0	3	0	3
Ethyl acetate	nd	478.1 ab	nd	910.9 a	nd	252.1 b	nd	352.7	2,509.1 b	5,605.5 a	3,795.3 ab	nd	nd	nd
Propyl acetate	30.4	16.1 b	20.4 b	132.6 a	39.1 b	17.0 b	75.5 ab	<10	61.9 c	49.4c	1,093.2 a	865.5 a	70.1 c	356.3 b
2-Methylpropyl acetate	24.2	22.2 b	60.3 a	23.5 b	89.6 a	23.0 b	99.2 a	<10	36.8 b	115.7 b	45.8 b	224.7 a	25.0 b	95.6 b
Ethyl 2-methylbutanoate	nd	nd	nd	114.4 a	nd	<10	<10	nd	13.3 b	nd	nd	nd	<10	85.9 a
Butyl acetate	55.1	24.0 b	15.3 b	205.9 a	34.5 b	15.0 b	46.6 b	<10	24.6 b	41.4 b	1,496.1 a	193.4 b	32.2 b	114.2 b
2-Methylbutyl acetate	120.3	45.6 ab	47.0 ab	99.2 a	29.3 b	33.0 b	nd	40.5	176.6 a	39.6 c	164.6 a	86.5 bc	53.4 c	103.5 b
Butyl propanoate	nd	168.3 a	97.2 a	<10	nd	nd	nd	nd	17.2 a	<10	20.3 a	nd	nd	nd
Pentyl acetate	26.6	nd	13.5 a	<10	nd	nd	12.6 a	nd	<10	21.8 b	10.6 b	70.2 a	<10	26.3 b
2-Methylbutyl 2-methylpropanoate	74.9	15.7 b	32.8 a	nd	nd	nd	nd	41.6	41.0 a	35.2 a	nd	17.6 b	nd	nd
Hexyl acetate	242.7	nd	nd	32.5 a	56.7 a	30.3 a	nd	25.5	54.2 c	173.2 b	64.4 c	316.3 a	42.0 c	214.7 b
Z-3-Hexenyl acetate	44.8	nd	nd	22.0 a	nd	17.4 a	nd	nd	nd	nd	nd	153.7 a	nd	nd
Hexyl propanoate	nd	nd	nd	23.7 a	nd	nd	nd	nd	nd	27.6 a	nd	nd	nd	nd
Methyl octanoate	20.2	41.9 b	82.8 a	13.7 c	18.2 c	17.4 c	<10	21.5	21.1 b	163.8 a	<10 b	153.2 a	nd	nd
Butyl hexanoate	18.7	40.7 a	nd	14.9 b	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Hexyl 2-methylbutanoate	206.4	150.9 a	166.9 a	150.3 a	13.7 b	27.9 b	111.0 a	112.8	<10	15.8 b	nd	nd	nd	34.3 a
Ethyl octanoate	401.5	49.5 b	206.3 a	20.6 b	78.4 ab	nd	157.2 a	36.2	56.4 b	423.0 b	35.0 b	3,207.5 a	252.8 b	1,626.6 a
Hexyl hexanoate	347	180.1 a	74.7 b	17.5 b	nd	12.3 b	46.5 b	137.6	nd	nd	nd	nd	13.5 b	21.7 a
Butyl octanoate	37	23.7 a	nd	nd	nd	nd	nd	15.3	nd	nd	<10	nd	nd	nd
γ-Hexalactone	101.3	20.8 a	25.7 a	15.6 a	13.0 a	14.8 a	22.1 a	12.1	16.3 bc	48.4 a	13.2 c	26.6 b	<10	14.9 bc
γ-Octalactone	<10	nd	32.2 a	nd	nd	nd	nd	nd	nd	nd	<10	nd	nd	nd
δ-Decalactone	33.5	nd	22.7 a	nd	nd	nd	nd	nd	nd	63.8 a	<10	77.9 a	nd	15.4 b
2-Ethyl-1-hexenal	683.5	71.6 a	nd	nd	25.4 a	18.1 a	15.8 a	58.8	229.3 a	369.8 a	36.2 b	34.7 b	19.6 b	25.9 b
Hexenal	813.5	165.8 a	149.4 a	138.8 ab	83.1 b	127.4 ab	152.5 a	74.4	339.7 a	236.9 b	177.9 bc	407.6 a	130.4 c	130.1 c
Benzaldehyde	74.6	61.8 a	76.9 a	44.5 b	50.0 a	72.2 a	75.4 a	45.5	119.0 a	93.0 ab	75.4 b	123.2 a	62.2 b	79.1 b
2,3-Butanodione	873	1,191.1 a	1,403.7 a	239.0 b	218.8 b	160.0 b	188.7 b	167.1	2,986.0 a	3,003.7 a	519.8 b	2,523.3 a	306.5 b	1,107.7 b
Acetophenone	252.1	379.5 b	435.3 a	206.4 c	245.1 c	201.6 c	192.7 c	309.1	222.9 ab	420.6 a	79.7 b	165.0 b	87.1 b	121.1 b
Linalool	2,878.5	18.7 a	30.6 a	nd	nd	nd	nd	<10	nd	117.0 a	<10	nd	nd	nd
Eucalyptol	21	27.4 b	266.5 a	nd	nd	nd	nd	59.0	97.7 ab	22.1 b	20.4 b	237.1 a	15.2 b	22.7 b
Acetic acid	932.9	307.2 b	1,221.5 a	685.5 ab	560.4 ab	594.8 ab	809.7 a	205.1	388.5 b	835.8 ab	1,099.9 a	778.6 ab	447.6 b	1,263.4 a
Decanoic acid	36.7	11.6 c	60.3 a	12.5 c	26.3 b	14.1 b	24.8 b	<10	32.2 b	66.2 a	<10	38.8 b	11.8 c	25.8 b
Benzoic acid	324.2	218.9 a	335.4 a	193.2 a	207.1 a	260.5 a	234.3 a	272.8	245.0 a	332.9 a	160.2 a	296.5 a	179.7 a	246.2 a
2-Methyl-1-butanol	nd	23.7 a	nd	nd	nd	nd	10.1 b	6.6	14.6 b	nd	nd	nd	nd	137.0 a
1-Pentanol	22.9	nd	141.2 a	nd	nd	nd	nd	nd	11.0 a	nd	nd	nd	nd	nd
1-Hexanol	27.3	45.7 a	29.1 a	10.3 ab	nd	15.6 ab	nd	<10	20.0 a	16.1 a	10.7 a	26.7 a	nd	25.2 a

Table 4 continued

Mid-season varieties	Venus							Honey Royale^{cov}						
Days at −0.5 °C	Harvest	10		20		40		Harvest	10		20		40	
Days at 20 °C		0	3	0	3	0	3		0	3	0	3	0	3
Z-3-hexen-1-ol	nd	nd	nd	nd	nd	nd	nd	nd	nd	28.7 a	<10	nd	nd	nd
2-Ethyl-1-hexanol	809.9	87.6 a	246.6 a	345.5 a	57.7 a	162.2 a	254.2 a	222.7	169.0 a	152.3 a	28.3 b	173.5 a	92.1 ab	90.1 ab
Benzyl alcohol	34	42.9 a	55.8 a	25.3 a	84.2 a	33.6 a	29.3 a	59.4	36.1 a	37.4 a	43.8 a	34.4 a	30.8 a	22.4 b
Total esters	1,649.8	1,256.9 a	817.1 a	1,797.4 a	359.5 a	454.4 a	567.8 a	804.6	3,029.5 ab	6,720.4 a	6,736.5 a	5,288.6 a	504.2 b	2,679.0 ab
Total lactones	142.7	20.8 b	80.6 a	15.6 b	13.0 b	14.8 b	22.1 b	12.1	16.3 b	112.2 a	22.5 b	104.5 a	<10 b	30.3 b
Total aldehydes	1,571.6	299.2 a	226.3 ab	183.3 ab	158.5 b	217.7 ab	243.7 a	178.7	688.0 a	699.7 a	289.5 b	565.6 a	212.2 b	235.1 b
Total ketones	1,125.1	1,570.6 a	1,839.0 a	445.4 b	463.8 b	361.6 b	381.5 b	476.2	3,208.8 a	3,424.2 a	599.5 bc	2,688.3 a	393.7 c	1,228.8 b
Total terpenes	2,899.5	46.1 b	297.1 a	nd	nd	nd	nd	65.8	97.7 b	139.1 b	25.6 b	237.1 a	15.2 b	22.7 b
Total acids	1,293.8	537.7 c	1,617.2 a	891.3 c	793.8 c	869.5 c	1,068.9 b	483.5	665.7 b	1,234.9 a	1,268.5 a	1,114.0 ab	639.1 b	1,535.5 a
Total alcohols	894.1	199.9 ab	472.7 a	381.1 a	141.9 b	211.4 ab	293.6 a	294.0	250.8 a	234.5 a	89.9 b	234.5 a	122.9 ab	274.7 a
Total	9,576.6	3,931.2 a	5,350.1 a	3,714.1 ab	1,930.4 b	2,129.3 ab	2,577.6 ab	2,314.9	7,956.9 ab	12,565.1 a	9,032.0 ab	10,232.5 a	1,895.4 c	6,006.2 bc

Means within the variety followed by different small letters are significantly different at $p \leq 0.05$ (LSD test). Volatile compounds not detected are indicated by nd

no decrease in total lactones after 40 days cold storage plus 3 days at 20 °C, while there was a decrease in mid-season and ‘August Red’ cultivars. Individual lactones did not contribute to these global changes in the same way. In general, γ-hexalactone concentrations were present in all the studied varieties after cold storage, excepting in late season cultivars cold stored for 40 days without shelf life.

Total aldehyde concentrations ranged from 3 to 20 % of the total volatile fraction collected after cold storage, at both 0 and 3 days of shelf life (Figs. 1, 2, and 3). This depends on the genetic background of the cultivar [17]. The concentrations of three C_6 aldehydes emitted by ‘Venus’ and ‘August Red’ increased after 40 days cold storage plus 3 days at 20 °C. Benzaldehyde is derived from cyanogenic glycoside, amygdalin, and prunasin, which are typical constituents of many *Prunus* species. Benzaldehyde was recognized as the almond aroma present in peach, but was present in quantities below its odor threshold of 350 μg/kg (Table 2).

Two ketones were detected in the six cultivars and accounted for 6–55 % of total volatiles after cold storage plus shelf life (Figs. 1, 2, and 3). During cold storage, total ketone concentrations decreased in ‘Big Top’ and the two mid-season varieties but increased in late season cultivars (Tables 3, 4, and 5). The predominant ketone was 2,3-butanodione. This is a compound with a low odor threshold (1 μg/kg, Table 2) that would have contributed buttery notes to the aroma of ‘Big Top,’ ‘Venus,’ and ‘Honey Royale^{cov}’ after 10 days cold storage followed by 3 days at 20 °C and in ‘August Red’ after 20 days cold storage plus 3 days at 20 °C. The cold storage period seems to delay synthesis of this ketone, except in ‘Honey Blaze®’ and ‘Nectagala^{cov}.’ Nevertheless, to the best of our knowledge, no data have previously been reported on the effect of cold storage on the concentration of this ketone in nectarine fruits.

Three organic acids accounted for 2–65 % of the total volatile fraction during cold storage followed by shelf life (Figs. 1, 2 and 3). The concentration of acetic acid emitted by all six cultivars increased or remained quite stable after 40 days cold storage plus 3 days at 20 °C compared to the rest of storage and shelf life periods (Tables 3, 4, and 5).

Terpenoids contribute the characteristic fruity aroma to nectarines and two compounds accounted for about 0.4–6 % of total volatiles depending on the cultivar, cold storage time, and shelf lifetime (Figs. 1, 2, and 3). The monoterpene linalool was the most abundant in early season varieties (Table 3); its predominance has also been noted in other nectarine cultivars such as ‘Romagna Big’ [23], ‘Fantasia,’ and ‘Early Red’ [17]. During cold storage, linalool concentrations decreased in all cultivars except ‘Honey Blaze^{cov}.’ In ‘Venus’ cultivar, the linalool and eucalyptol compounds were only detected at harvest and

Table 5 Volatile compounds emitted (ng/kg) by 'August Red' and 'Nectagala[cov]' nectarines after cold storage at −0.5 °C with or without 3 days at 20 °C

Late season varieties	August Red							Nectagala[cov]						
Days at −0.5 °C	Harvest	10		20		40		Harvest	10		20		40	
Days at 20 °C		0	3	0	3	0	3		0	3	0	3	0	3
Ethyl acetate	641.2	214.4 b	1,835.9 a	nd	nd	nd	nd	882.0	128.6 b	1,255.9 a	nd	nd	nd	nd
Propyl acetate	47.0	nd	28.7 c	27.0 c	60.5 b	<10	73.8 a	20.1	13.1 c	<10	72.9 b	77.9 b	<10	140.8 a
2-Methylpropyl acetate	62.2	21.1 c	40.5 bc	56.0 b	51.4 bc	22.8 bc	95.1 a	27.3	37.9 ab	38.9 ab	87.1 a	89.1 a	57.7 a	51.9 ab
Ethyl 2-methylbutanoate	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	21.7 a	21.0 a	nd	nd
Butyl acetate	30.5	nd	42.9 b	10.9 c	46.1 b	<10	72.0 a	32.5	14.8 b	16.6 b	50.3 a	52.3 a	22.6 b	54.9 a
2-Methylbutyl acetate	<10	30.5 a	38.8 a	12.5 b	19.8 b	nd	nd	21.7	55.8 ab	83.1 ab	186.4 a	189.7 a	nd	50.4 ab
Pentyl acetate	nd	nd	49.6 a	nd	10.0 b	nd	11.0 b	nd	nd	32.0 a	76.0 a	86.4 a	nd	nd
2-Methylbutyl-2-methylpropanoate	nd	nd	nd	nd	nd	nd	nd	<10		nd	nd	nd	10.6 b	15.8 a
Butyl 2-methylbutanoate	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	95.1 a	nd	nd	nd
Hexyl acetate	67.9	nd	83.4 a	20.9 c	60.9 ab	12.6 c	73.3 a	36.5	22.7 b	39.2 b	105.9 a	101.9 a	16.0 b	41.6 b
Hexyl propanoate	nd	nd	nd	nd	nd	nd	nd	nd	59.1 ab	nd	nd	nd	nd	38.1 a
Methyl octanoate	nd	nd	42.9 b	nd	nd	nd	189.6 a	nd	27.9 a	nd	nd	nd	nd	nd
Hexyl 2-methylbutanoate	nd	nd	nd	nd	nd	20.1 b	44.9 a	20.5	30.9 a	<10	25.5 a	25.7 a	32.2 a	36.1 a
Ethyl octanoate	nd	nd	99.6 a	nd	102.1 a	nd	74.5 b	nd	14.8 ab	48.5 ab	136.8 a	143.4 a	14.0 ab	105.7 a
Hexyl hexanoate	nd	nd	37.6 bc	nd	59.5 b	26.8 c	107.1 a	86.9	79.5 a	21.8 bc	40.4 b	45.0 b	14.4 bc	33.4 b
γ-Hexalactone	nd	21.3 b	34.4 a	<10	15.9 b	nd	42.0 a	15.2	13.5 a	23.8 a	29.1 a	26.5 a	nd	13.5 a
γ-Octalactone	nd	nd	21.3 a	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
δ-Decalactone	nd	nd	35.3 a	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
2-Ethyl-1-hexenal	32.2	25.4 a	48.1 a	nd	nd	27.2 a	37.5 a	69.4	82.6 a	30.8 a	nd	nd	53.8 a	14.6 a
Hexanal	140.5	204.4 d	189.0 d	141.1 e	325.8 c	489.2 b	826.9 a	224.3	523.4 a	188.5 d	257.1 c	225.8 c	237.5 c	400.0 b
Benzaldehyde	42.9	130.7 a	104.9 a	67.3 b	50.2 b	50.4 b	115.5 a	24.7	123.2 a	23.2 c	48.4 c	30.1 c	48.6 c	78.9 b
2,3-Butanodione	280.9	390.9 c	315.0 c	304.1 c	2,118.5 a	603.0 c	1,817.1 b	313.3	473.9 b	179.0 c	752.4 a	786.6 a	378.8 b	719.7 a
Acetophenone	114.1	272.8 a	324.7 a	124.7 b	131.1 b	123.0 b	144.9 b	100.6	53.6 ab	78.7 a	113.6 a	111.1 a	70.4 ab	82.4 a
Linalool	43.2	nd	43.8 a	nd	nd	nd	nd	233.5	nd	30.8 a	nd	nd	nd	nd
Eucalyptol	18.6	19.5 b	28.4 b	17.5 b	15.6 b	252.8 a	184.1 a	15.8	22.9 b	nd	nd	nd	123.5 a	40.6 b
Acetic acid	392.3	808.8 a	961.6 a	1,434.6 a	440.9 b	436.0 b	1,318.2 a	455.0	838.9 a	493.9 ab	682.2 ab	619.8 ab	423.1 ab	1,208.5 a
Decanoic acid	11.5	13.3 b	25.7 a	10.8 b	21.7 a	<10	15.4 b	16.7	15.7 a	11.1 a	14.9 a	11.9 a	nd	11.1 a
Benzoic acid	198.6	307.5 a	311.4 a	222.2 b	209.2 b	220.3 b	251.8 b	211.0	270.9 a	175.6 ab	123.3 ab	237.7 a	206.7 a	196.2 a
2-Methyl-1-butanol	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	<10	nd	nd
1-Pentanol	nd	nd	41.9 a	nd	nd	47.9 a	nd	nd	12.5 b	15.6 b	nd	41.0 a	nd	nd
1-Hexanol	<10	nd	42.9 a	nd	11.9 b	14.5 b	23.2 b	nd	14.2 a	nd	13.4 a	13.1 a	10.1 a	14.3 a
2-Ethyl-1-hexanol	117.7	135.2 c	139.5 c	90.5 d	294.7 b	412.8 b	777.3 a	331.9	627.8 a	185.4 d	299.2 c	302.0 c	270.4 c	438.0 b
Benzyl alcohol	22.2	29.0 a	20.2 a	17.5 b	34.3 a	18.9 a	27.8 a	nd	23.9 a	27.2 a	26.6 a	23.3 a	nd	18.0 a
Total esters	852.4	266.0 b	2,299.7 a	127.2 bc	410.0 b	99.2 bc	741.4 b	1,135.9	485.0 bc	1,551.7 a	898.1 b	832.5 b	175.2 bc	568.5 b
Total lactones	nd	21.3 c	91.0 a	<10	15.9 c	nd	42.0 b	15.2	13.5 a	23.8 a	29.1 a	26.5 a	nd	13.5 a

Table 5 continued

Late season varieties	August Red							Nectagala^{cov}						
Days at −0.5 °C	Harvest	10		20		40		Harvest	10		20		40	
Days at 20 °C		0	3	0	3	0	3		0	3	0	3	0	3
Total aldehydes	215.6	360.4 c	342.0 c	208.4 d	376.0 c	566.8 b	980.0 a	318.4	729.2 a	242.4 c	305.5 c	255.8 c	339.9 c	493.6 b
Total ketones	395.0	663.7 b	639.7 b	428.8 b	2,249.6 a	726.0 b	1,962.1 a	413.9	527.5 b	257.7 c	866.0 a	897.7 a	449.2 b	802.1 a
Total terpenes	61.8	19.5 c	72.2 c	17.5 c	15.6 c	252.8 a	184.1 b	249.3	22.9 b	30.8 b	nd	nd	123.5 a	40.6 b
Total acids	602.4	1,129.5 a	1,298.7 a	1,667.6 a	671.8 b	665.4 b	1,585.3 a	682.7	1,125.5 a	680.7 b	820.4 b	869.4 b	629.9 c	1,415.9 a
Total alcohols	147.8	164.2 c	244.5 bc	108.1 c	340.9 b	494.1 b	828.2 a	331.9	678.5 a	228.2 bc	339.2 bc	388.4 b	280.5 bc	470.3 b
Total	2,275.0	2,624.7 c	4,987.6 b	2,565.8 c	4,079.9	2,804.2 c	6,323.0 a	3,132.1	3,568.6 a	2,991.5 b	3,229.2 ab	3,243.8 ab	1,998.2 c	3,791.0 a

Means within the variety followed by different small letters are significantly different at $p \leq 0.05$ (LSD test). Volatile compounds not detected are indicated by nd

Table 6 Percentage of satisfied consumers of 'Big Top,' 'Honey Blaze^{cov},' 'Venus,' 'Honey Royale^{cov},' 'August Red,' and 'Nectagala^{cov}' nectarines at harvest and after cold storage for 10, 20, and 40 days at −0.5 °C plus 3 days ripening at 20 °C

Cultivars	Satisfied consumers (%)			
	Harvest	10 days	20 days	40 days
Big Top	71	79	86	80
Honey Blaze^{cov}	72	76	67	70
Venus	53	57	63	61
Honey Royale^{cov}	75	75	55	45
August Red	53	70	73	43
Nectagala^{cov}	70	97	93	53

after 10 days of cold storage. The concentration of eucalyptol increased after 40 days cold storage in 'August Red,' but always remained very low in early season varieties.

Six alcohols accounted for 4–18.5 % of total volatiles depending on the cultivar, cold storage time, and shelf lifetime (Figs. 1, 2, and 3). After 40 days cold storage, total alcohols decreased in 'Big Top' and 'Nectagala^{cov},' but increased in 'August Red' after 3 days at 20 °C (Tables 3, 4, and 5). 2-Ethyl-1-hexanol was the most abundant alcohol in all cultivars during cold storage. During cold storage, the concentration of 2-ethyl-1-hexanol remained constant in 'Big Top,' 'Honey Blaze' (early season cultivars), and 'Honey Royale' (mid-season cultivar), increased in 'August Red' and declined in 'Nectagala' (late season cultivars).

Consumer acceptance

Table 6 shows the percentage of satisfied consumers for each cultivar and storage time, including at harvest. At harvest, the highest percentages of satisfied consumers, ≥70 %, were associated with the sweet cultivars 'Honey Royale^{cov},' 'Honey Blaze^{cov},' 'Big Top,' and 'Nectagala^{cov}.' In contrast, acid cultivars such as 'Venus' and 'August Red' only satisfied about 50 % of consumers. These results agree with reported findings that among six nectarine cultivars, the sweet cultivars were better appreciated by consumers [28]. The six cultivars showed different changes in consumer acceptance from harvest through different lengths of cold storage. 'Big Top' became more acceptable to consumers after cold storage than at harvest. 'Venus' acceptability remained stable during cold storage. In comparison with harvest, consumer satisfaction provided for 'Honey Royale^{cov}' declined after 10 days cold storage. For 'Nectagala^{cov}' and 'August Red,' the percentage of consumer satisfaction increased at 10 and 20 days, respectively, but decreased at 40 days.

To determine the variables that most influenced consumer acceptance, a partial least square regression model

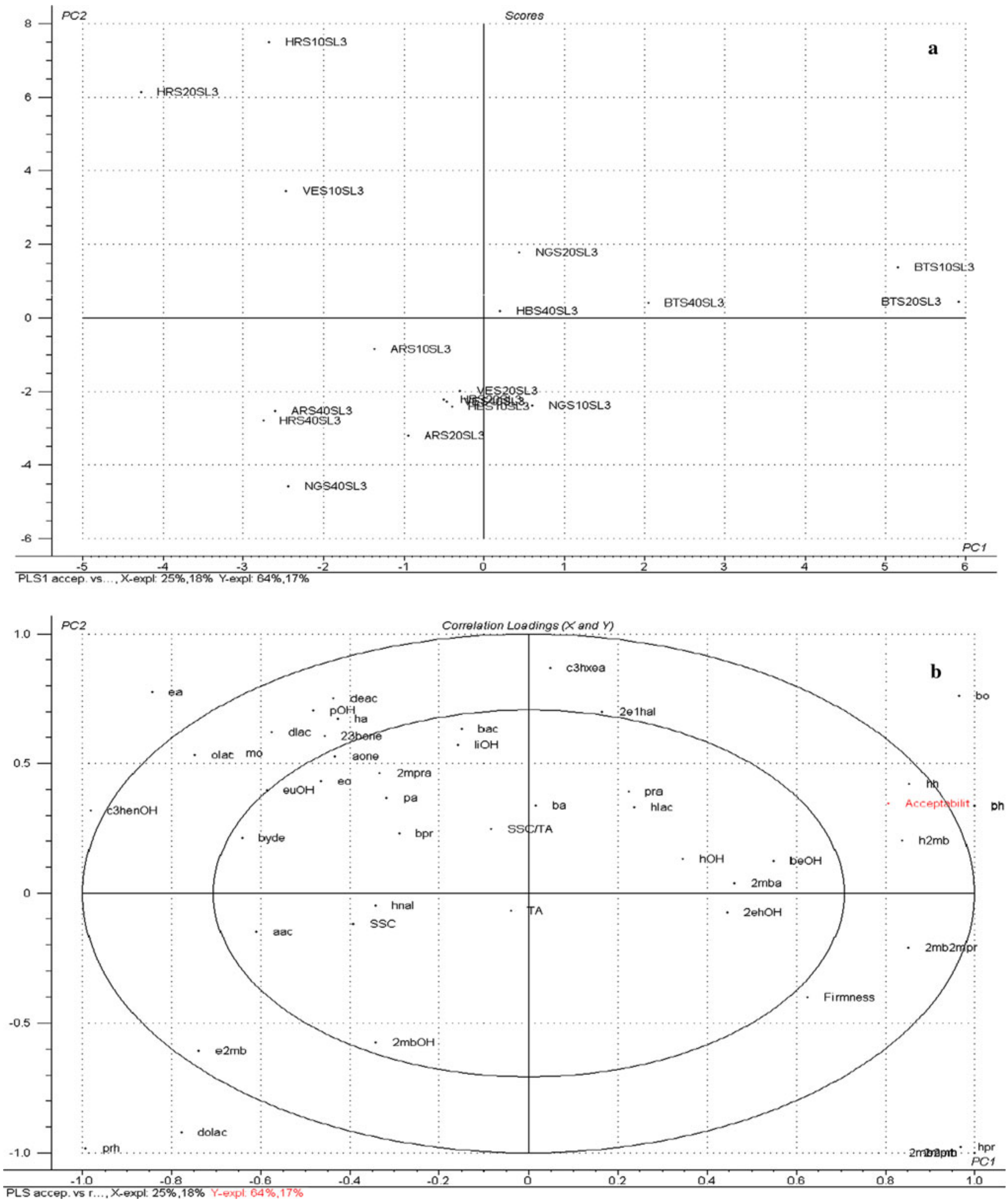

Fig. 4 PLS model using the data of the six nectarines cultivars after cold storage plus 3 days at 20 °C. **a** Scores; **b** correlation loadings; **c** regression coefficients from a PLS model of variable acceptance

(PLSR) was developed using physicochemical measures (SSC, TA, SSC/TA, and firmness) and volatile compound emissions as the *X* variables and the degree of consumer acceptance as the *Y* variable. The first two PLS factors built up by combinations of the physicochemical measures and volatile compound emissions accounted for up to 81 % of

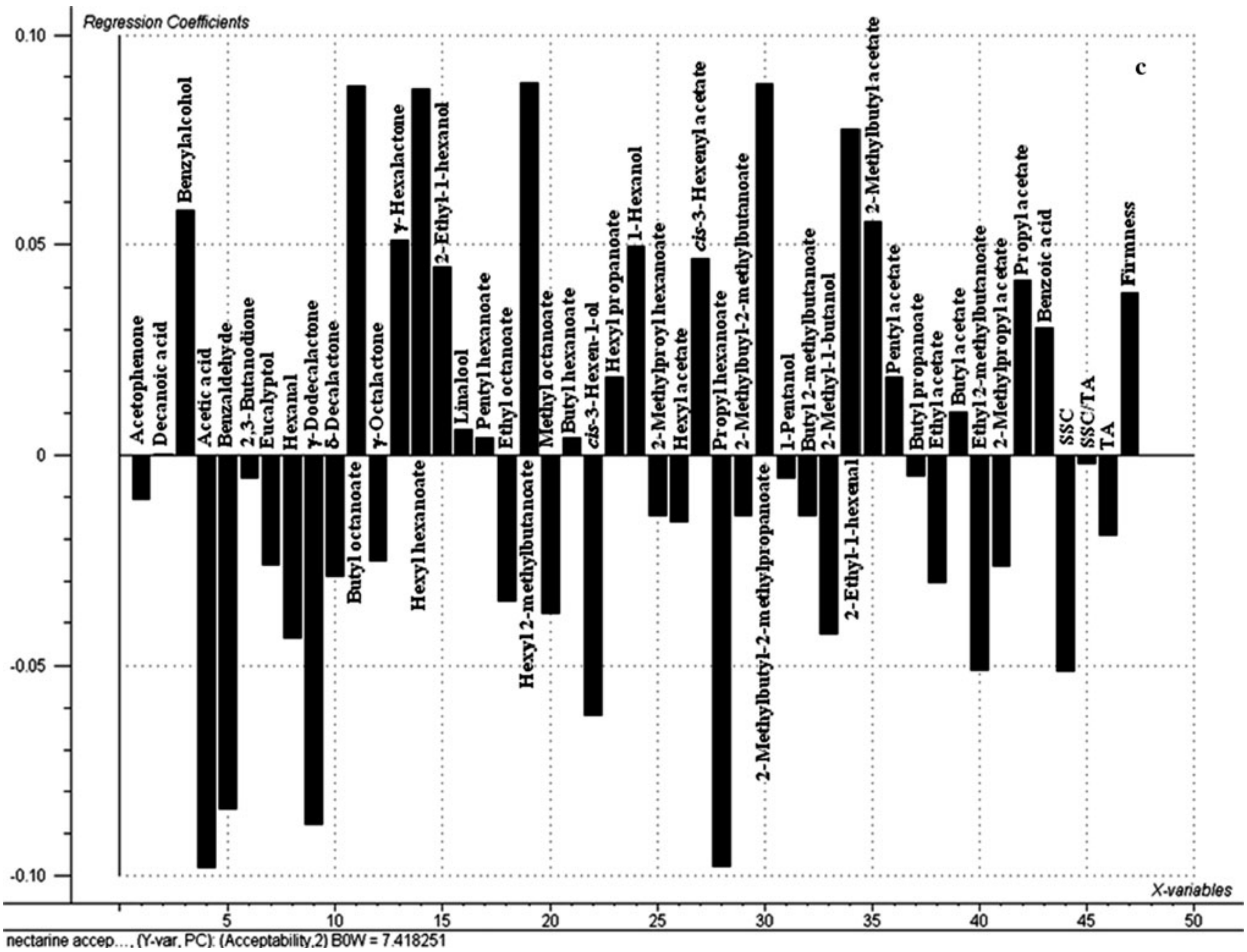

Fig. 4 continued

the total variability in consumer acceptance (Fig. 4a). Almost all the variance in the consumer acceptance is then collected in this figure. ‘Big Top’ (regardless cold storage time), ‘Nectagala’ (10 and 20 days cold storage), and ‘Honey Blaze’ (40 days cold storage) nectarines were located on the right side of the PC1 axis, which explained alone 64 % of total variance and, which in turn, were associated with higher consumer acceptance. In contrast, the rest of cultivars stored at different cold storage times on the left side of PC1, away from the first group (Fig. 4a, b). The Fig. 4c, which depicts the regression coefficient with respect the standardized variables, shows the influence of instrumental variables on consumer acceptance. While SSC did not have a significant regression coefficient with respect to acceptance due to the lack of variation of this property, a significant positive influence of flesh firmness on the acceptance was obtained. Additionally, the volatile compounds benzyl alcohol, butyl octanoate, γ-hexalactone, hexyl hexanoate, 2-ethyl-1-hexanol, hexyl 2-methylbutanoate, hexanol, 2-methylbutyl 2-methylpropanoate, 2-ethyl-1-hexenal, and 2-methylbutyl acetate (showing all of them positive relation to consumer acceptance) were the variables that most influenced consumer acceptance. Some of these volatiles (hexyl hexanoate and hexyl 2-methylbutanoate) were also found to have influence on consumer acceptance [45, 46] of cold-stored ‘Pink Lady’ apples. The importance of some volatile compounds on peach consumer acceptance has also been reported previously [47]. In addition to the influence of some volatile compounds, this work clearly shows a noticeable influence of the flesh firmness on the consumer acceptance so that for a SSC value in the range (11–13 °Brix), firmer fruits became more accepted.

Conclusion

A first aim of this study was the evaluation of the relationships between volatile compounds, physicochemical measurements, and consumer acceptance of ‘Big Top,’ 'Honey Blaze^cov^,' 'Honey Royale^cov^,' 'Venus,' 'August Red,' and 'Nectagala^cov^' nectarines after cold storage during three different periods. Results reported indicated that higher consumer acceptance score was associated with the cultivars and storage time that resulted in firmer fruits and greater concentrations of specific volatile compounds. After cold storage, fruit were exposed to air at 20 °C for different days to stimulate volatile production. This exposure produced an increase in total volatile compounds emission of 'Big Top' and 'August Red' cultivars after any analyzed cold storage period. Additionally, for 'Honey Blaze^cov^,' 'Honey Royale^cov^,' and 'Nectagala^cov^' nectarines, this exposure showed a positive effect on volatile production after 40 days of cold storage and had no effect in 'Venus' nectarines.

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Conflict of interest None.

Compliance with Ethics Requirements This article does not contain any studies with human or animal subjects.

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