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Cold-Storage Potential of Four Yellow-Fleshed Peach Cultivars Defined by Their Volatile Compounds Emissions, Standard Quality Parameters, and Consumer Acceptance

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ABSTRACT: 'Early Rich', 'Royal Glory', 'Sweet Dream[cov]', and 'Elegant Lady' peaches were stored at −0.5 °C for up to 40 days and then subjected to ripening at 20 °C for up to 3 days. Firmness, soluble solids content (SSC), titratable acidity (TA), color, consumer acceptance, and volatile compounds were then determined. The observed physicochemical changes included a significant decrease in firmness during both storage and commercialization periods. In contrast, the SSC, TA, and color remained constant during storage. Ten days of cold storage produced the highest total volatile emissions and the greatest consumer acceptance for 'Elegant Lady' and 'Sweet Dream[cov]', whereas similar results were obtained after 40 and 20 days for 'Royal Glory' and 'Early Rich', respectively. Volatile compounds that most consistently exhibited a positive correlation with consumer acceptance were dependent on the cultivar.

KEYWORDS: *cold storage, consumer acceptance, peach, partial least-squares regression model, volatile compounds*

INTRODUCTION

Peach (*Prunus persica* L. Batsch) is a climacteric stone fruit species that provides high nutrition and a pleasant flavor.[1] Catalonia is the main peach-growing region in Spain, the second largest producer of this fruit in the European Union. Catalonia has a total annual production of 206 816 t peaches, 23.4% of the total Spanish peach production in 2008, and 83.3% of Catalan production is from Lleida province.[2] The increasing peach production in Spain indicates that a larger percentage of total production will need to be stored for long periods to regulate commercial availability. Unfortunately, the peach fruit is characterized by high perishability due to its rapid loss of firmness during ripening. This favors spoilage and other physiological disorders and drastically restricts its storage potential and marketing possibilities.[3] Low-temperature storage is the primary technique for delaying ripening after harvest. Maintaining low temperatures (from −1 to 2 °C) during storage is one of the main tools used to reduce postharvest deterioration and to maintain the overall quality and nutritional value of fruits, because reducing their metabolic activity and respiration rate effectively slows ripening.[4] However, the storage potential depends on the cultivar in question. 'Royal Glory' peach maintains an acceptable appearance and eating quality even after 6 weeks of cold storage at 0 °C plus 5 days of ripening at 25 °C.[5]

Aroma is one of the essential components of fruit quality.[6] The relative contributions of specific volatile compounds to the flavor of peaches are cultivar-dependent.[6−9] 'Early Rich' is a peach with yellow flesh that produces hexyl acetate, *Z*-3-hexenyl acetate, γ-dodecalactone, linalool, γ-octalactone, *Z*-3-hexenol, δ-decalactone, and benzaldehyde, which are the key odorants in the essential oil of fruit at harvest date plus 24 h at 4 °C.[8] 'Royal Glory' is an early-season cultivar developed by Zaiger's, Inc. (Modesto, CA). It is a melting flesh variety. In this cultivar, the presence of γ-decalactone, δ-octalactone, γ-octalactone, ethyl butyrate, hexanal, and (*E*)-2-hexenol is a good indicator of maturity at harvest.[9] 'Elegant Lady' is a midseason, fresh, yellow-skinned, acidic cultivar, which originated from Merrillin in 1979.[10] Most postharvest studies on this variety have been concerned with the development of rot,[11−13] the effects of water stress on fruit quality,[14] or the quality of fresh-cut peach.[15,16] 'Sweet Dream' has red to dark maroon color skin and yellow with red blush flesh color. Fruit of this cultivar has relatively large size (average = 255.2 g) with over 12% soluble solids content.[17] 'Early Rich', 'Elegant Lady', 'Royal Glory', and 'Sweet Dream' have higher yield than many other cultivars. Although the first comprehensive studies of peach volatile production were performed about 50 years ago,[18] no studies on the relationships between volatile production, standard quality, and sensory evaluation in cold-stored peaches have been previously published in the literature to our knowledge.

The objectives of this study were to determine volatile compound emissions, standard quality measures, and consumer acceptance for 'Early Rich', 'Royal Glory', 'Elegant Lady', and 'Sweet Dream[cov]' peaches kept in cold storage for three different periods; to assess the relationships among sensory and instrumental qualities of cold-stored fruit using multivariate analysis; and to examine the efficacy of poststorage exposure of fruit to air at 20 °C to stimulate volatile production after long-term storage.

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■ MATERIALS AND METHODS

Plant Material and Storage Conditions. Peach fruits (*P. persica* L. Batsch) of 'Early Rich' (ER) and 'Royal Glory' (RG) were harvested on June 30, 2009 (115 and 125 days, respectively, after full bloom), and fruits of 'Sweet Dream[cov]' (SD) and 'Elegant Lady' (EL) were harvested on July 31, 2009 (140 and 145 days, respectively, after full bloom), when most of the fruits were ready to be harvested (turning from green to yellow and flesh firmness >33N). The four yellow-fleshed peach varieties were grown in commercial orchards at Alcarràs, Lleida, Catalonia (northeastern Spain). Immediately after harvest, four 50 kg lots of each peach cultivar were selected on the basis of uniformity and the absence of defects. Three of these lots were stored at −0.5 °C and 92−93% relative humidity in a cold-air storage chamber of 22 m^3 (21 kPa O_2/0.03 kPa CO_2). The other lot was analyzed at harvest (H). Samples were removed from storage after 10 (S10), 20 (S20), and 40 (S40) days and then transferred at 20 °C to simulate a commercialization period. Analyses were carried out at day 0 (SL0) and 3 (SL3) days thereafter.

Chemicals. All of the standards for the volatile compounds studied in this work were of 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). The rest of the compounds (up to 42) were supplied by Sigma-Aldrich (Steinheim, Germany).

Analysis of Volatile Compounds. The measurement of volatile compounds was carried out as described,[19] with slight modifications. Six kilograms of fruit (2 kg per replicate × 3) per storage period and cultivar were selected for analysis of volatile compounds, both at harvest and after removal from storage. Intact fruits were placed in an 8 L Pyrex container through which an air stream (150 mL min^{-1}) was passed for 60 min. The resulting effluent was passed through an adsorption tube filled with 350 mg of Tenax TA/Carbograph 1TD. The volatile compounds were desorbed into an Agilent 7890A gas chromatograph (Agilent Technologies, Inc., Barcelona, Spain) at 275 °C for 15 min, using an automated UNITY Markes thermal desorption system (Markes International Ltd., Llantrisant, U.K.). 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 × 0.33 μm). Helium was used as the carrier gas, at a flow rate of 42 cm s^{-1}, with a split ratio of 60:1. Both the injector and 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^{-1}); 115−225 °C (8 °C min^{-1}); 225 °C (10 min). A second capillary column (SGE, Milton Keynes, U.K.) with 5% phenyl polysilphenylene-siloxane as the stationary phase (BPX5; 30 m × 0.25 mm i.d. × 0.25 μm) was also used for compound identification under the same operating conditions as described above. Compounds were identified by comparing their respective retention indices with those of accepted standards and by enriching peach extract with authentic samples. Quantification was carried out using butyl benzene (assay >99.5%, Fluka) as an internal standard, whereas the concentrations of volatile compounds were expressed as nanograms per kilogram. Compound confirmation was performed in an Agilent 6890N gas chromatograph−mass spectrometer (Agilent Technologies, Inc.), using the same capillary column as in the GC analyses. Mass spectra were obtained by electron impact ionization at 70 eV. Helium was used as the carrier gas (42 cm s^{-1}), following the same temperature gradient program described previously. Spectrometric data were recorded (Hewlett-Packard 3398 GC Chemstation) and compared with those from the original NIST HP59943C library mass spectra.

Analysis of Standard Quality Parameters. Fifteen fruits at harvest (harvest × commercialization period) and from each combination of factors (storage period × commercialization 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 newtons. SSC and TA were measured in juice pressed from whole fruits. 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 of juice with 0.1 M 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 tristimulus colorimeter (chroma meter CR-400, Konica Minolta Sensing, Inc., Osaka, Japan) using CIE illuminant D_{65} with an 8 mm measuring aperture diameter. The skin color was measured at two points on the equator of each fruit, which were 180° apart: one on the side exposed to sunlight (ES) and the other on the shaded side (SS). Hue angle was determined on both the exposed and shaded sides, and the resulting values were used as measurements of superficial and background color, respectively.

Sensory Analyses. For the consumer evaluation test, fruit samples from each cultivar at harvest and after the different cold-storage periods were kept in a room at 20 °C for 3 days. Fifteen peaches from each treatment were used for sensory analysis. Prior to consumer evaluation, color and flesh firmness were measured on both sides of each fruit. Then, two longitudinal wedges were taken to measure standard quality parameters as explained in the previous section. The rest of the fruits were used for the consumer evaluation. Two pieces of peach (one per cultivar from each harvest season) were placed on white plates and immediately presented to a tasting panel of 111 consumers. The consumers were all volunteers from the members of the staff at the UdL-IRTA research institute and students at the University of Lleida. All test participants were habitual (daily) peach consumers. Each piece was identified with a random three-digit code. The order of presentation of the two pieces of fruit on the white plate was randomized for each consumer. Mineral water was used as a palate cleanser between samples. All evaluations were conducted in individual booths under white-light illumination and at room temperature. 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 (from 1 = dislike extremely to 9 = like extremely).

Statistical Analyses. A multifactorial design was used to statistically analyze the results. The factors considered were cultivar, storage period, and commercialization period. All data were tested using analysis of variance (GLM-ANOVA procedure) with the SAS program package.[20] Means were separated by the least significant difference (LSD) test at $P \leq 0.05$. Unscrambler version 9.1.2. software[21] was used to develop partial least-squares regression models (PLSR). These PLSR were run to correlate volatile compound emissions, as *X*-variables, to consumer acceptance, the *Y*-variable, to find the variables that had the most weight for discriminating among storage periods for each cultivar. The samples were coded as explained above under Plant Material and Storage Conditions. The volatile compound codes are in Table 2.

■ RESULTS AND DISCUSSION

Standard Quality Measures at Harvest and after Cold Storage. At harvest time, no statistical differences were detected among the analyzed cultivars. When firmness at harvest was compared to that after different lengths of cold storage, the only cultivar that maintained firmness was 'Early Rich'; the rest of the cultivars had decreased firmness. The loss of firmness during cold storage is one of the most important changes observed in the standard quality measures (Table 1). The firmness of peaches from the four cultivars after cold storage plus 3 days at 20 °C ranged from 7.9 to 22.6 N. These numbers are in line with those recommended by Crisosto[22] for peach consumption and peaches that are ready to buy,

Table 1. Standard Quality Parameters of 'Early Rich', 'Royal Glory', 'Elegant Lady', and 'Sweet Dream[cov]' Peaches at Harvest and after Storage at −0.5 °C for 10, 20, and 40 Days, plus 0 and 3 Days at 20 °C

		at harvest		10 days at −0.5 °C		20 days at −0.5 °C		40 days at −0.5 °C	
cultivar	quality parameter	0 days at 20 °C	3 days at 20 °C	0 days at 20 °C	3 days at 20 °C	0 days at 20 °C	3 days at 20 °C	0 days at 20 °C	3 days at 20 °C
Early Rich	SSC	10.4 b[a]	10.8 b	11.1 b	10.9 b	11.5 ab	11.1 b	12.1 a	11.1 b
	TA	9.8 a	9.7 a	8.3 ab	6.4 e	9.2 a	7.3 cd	8.2 bc	7.0 de
	SSC/TA	1.0 b	1.1 b	1.3 b	1.7 a	1.2 b	1.5 ab	1.5 ab	1.6 a
	firmness	40.8 a	42.7 a	23.0 bc	11.7 d	35.8 ab	19.3 cd	37.8 a	15.3 cd
	hue skin (ES[b])	87.9 a	91.1 a	17.8 b	18.4 b	22.1 b	21.6 b	37.6 b	20.3 b
	hue skin (SS[c])	90.2 a	92.5 a	46.5 b	37.8 b	45.5 b	40.1 b	20.4 b	37.8 b
Elegant Lady	SSC	10.7 c	11.4 c	10.6 c	12.1 bc	10.9 c	11.1 c	14.2 ab	11.5 c
	TA	9.1 a	6.8 c	8.4 a	6.7 c	7.1 bc	5.2 d	6.6 c	4.3 d
	SSC/TA	1.2 d	1.7 d	1.3 d	1.8 cd	1.5 c	2.3 bc	2.1 a	2.6 b
	firmness	37.4 a	14.7 bc	26.1 b	8.5 c	23.8 b	7.9 c	20.9 b	21.4 b
	hue skin (ES)	31.2 a	28.0 ab	31.9 a	26.9 bc	28.9 ab	30.0 ab	15.4 c	31.8 a
	hue skin (SS)	57.6 a	54.3 a	50.0 a	48.6 a	47.1 a	54.5 a	46.7 a	47.4 a
Royal Glory	SSC	8.9 a	9.6 a	9.9 a	9.0 a	9.3 a	9.2 a	9.9 a	9.6 a
	TA	3.9 a	4.1 a	2.8 a	3.1 a	3.2 a	2.7 a	2.6 a	3.3 a
	SSC/TA	2.3 b	2.3 b	3.5 a	2.9 b	2.9 b	3.4 ab	3.8 a	2.9 b
	firmness	35.6 ab	34.7 ab	36.1 ab	11.7 d	22.6 c	21.0 c	37.7 a	22.6 c
	hue skin (ES)	90.4 a	90.5 a	31.2 b	29.9 b	36.6 b	30.4 b	30.0 b	29.2 b
	hue skin (SS)	92.3 a	93.2 a	52.3 b	49.4 b	62.5 b	47.7 b	51.2 b	50.9 b
Sweet Dream[cov]	SSC	10.5 ab	10.4 ab	9.7 b	11.6 a	11.2 ab	10.6 ab	11.1 ab	11.5 ab
	TA	3.8 ab	3.9 ab	3.2 b	3.1 b	2.2 b	2.9 b	2.3 b	2.7 b
	SSC/TA	2.8 c	2.7 c	3.0 bc	3.7 b	5.1 a	3.6 b	4.8 a	4.2 b
	firmness	33.5 a	36.4 a	30.9 a	11.5 d	25.3 abc	17.2 cd	21.0 bcd	21.4 bcd
	hue skin (ES)	25.3 bc	28.1 bc	23.7 bc	47.8 a	30.1 bc	21.8 c	22.1 c	26.2 bc
	hue skin (SS)	51.8 a	54.0 a	53.1 a	45.9 ab	45.8 ab	41.1 b	51.4 ab	50.1 ab

[a]Means followed by different lower letters for each quality parameter are significantly different at $P \leq 0.05$ (LSD test). [b]ES, exposed side. [c]SS, shaded side.

respectively. They also coincide with recommendations for the consumption of white peaches such as 'Snow King' and 'September Snow'.[23] As expected, overall firmness decreased with days at 20 °C for all four peach cultivars. During cold storage, the firmness of 'Elegant Lady' and 'Sweet Dream[cov]' declined, whereas increased firmness was observed for 'Early Rich' and 'Royal Glory'. These results could be explained as symptoms of chilling injuries (CI); these symptoms cause uneven ripening and dry textures in the fruits, which are often referred to as leatheriness.[24] Ju and Duan[25] also reported that for 'Huangjin' peaches harvested at three different dates, the fruits that were picked earliest showed a greater tendency to be affected by leatheriness.

Generally speaking, days at 20 °C did not negatively affect SSC, which remained constant; the exceptions were 'Early Rich' and 'Elegant Lady' fruits stored for 40 days, which showed slight decreases in SSC. In contrast, Crisosto and Crisosto[26] reported a slight increase in SSC during ripening after removal from cold storage; this was probably attributable to fruit shrivelling. Here, the storage period did not seem to influence SSC (Table 1). These results are consistent with those previously reported by Robertson et al.,[3] Malakou and Nanos,[27] and Raffo et al.[28]

TA generally decreased significantly during days at 20 °C in acid cultivars ('Early Rich' and 'Elegant Lady'), but no significant differences were noted for sweet cultivars ('Royal Glory' and 'Sweet Dream[cov]'). Length of cold storage had no significant effect on TA after 1 day at 20 °C except for 'Elegant Lady', in which TA decreased with cold storage time. The decline in TA observed in 'Elegant Lady' has also been reported in other peach cultivars during cold storage[3,26,27] and could be due to oxidation of organic acids.[26]

The SSC/TA ratio was maintained through cold storage for 'Early Rich' and 'Royal Glory' but increased during longer cold storage times for 'Elegant Lady' and 'Sweet Dream[cov]', as previously reported in 'Harvester' peaches by Meredith et al.[29] Crisosto and Crisosto[26] reported a closer relationship between the SSC/TA ratio and eating quality than between TA or SSC considered separately.

No significant changes in skin hue were detected during storage. These results may be due to the fact that the studied cultivars are relatively new, released over the past several decades. This full red color provides more uniformity among the different cultivars and indicates that they undergo fewer changes during cold storage.

Volatile Compounds Emitted by Peaches at Harvest and after Cold Storage. Forty-two volatile compounds were identified and relatively quantified in both freshly harvested fruit (Table 2) and fruits after cold storage (Tables 3 and 4). These compounds included 22 esters, 4 lactones, 3 aldehydes, 2 ketones, 2 terpenes, 3 acids, and 6 alcohols. It has been reported that more esters can be obtained by using headspace

Table 2. Volatile Compounds Emitted (Nanograms per Kilogram) by Four Peach Cultivars after Harvest, plus 0 and 3 Days at 20 °C

				Early Rich		Royal Glory		Sweet Dream[COV]		Elegant Lady			
compound	RI[a]	RI[b]	code[c]	0 days at 20 °C	3 days at 20 °C	0 days at 20 °C	3 days at 20 °C	0 days at 20 °C	3 days at 20 °C	0 days at 20 °C	3 days at 20 °C	OTH[d]	CAS Registry No.
ethyl acetate	911		ea	nd	nd	599.0 Ba[e]	147.2 Ab	5049.2 Aa	nd	nd	nd	13500[d]	141-78-6
propyl acetate	995	766	pra	18.9 Ab	791.7 Aa	22.1 Aa	12.2 Ba	56.1 Aa	24.9 Ba	49.6 Aa	29.2 Ba	2000[d]	109-60-4
2,3-butanodione	999	1067	23bone	240.8 Ba	418.2 Ba	873.3 ABa	957.6 Aa	368.9 Ba	273.1 Ba	1114.2 Aa	863.6 Aa	1[f]	431-03-8
eucalyptol	1032	1105	euOH	nd	21.4 Ba	nd	1703.4 Ba	21.4 Ab	587.0 Ba	<10 Ab	3517.8 Aa	1[g]	470-82-6
2-methylpropyl acetate	1052	789	2mpra	25.7 Ab	173.7 Aa	21.7 Aa	24.9 Ba	15.7 Ab	50.7 Ba	27.8 Ab	116 ABa	65[d]	110-19-0
hexanal	1082	807	hnal	672.1 Aa	340.0 Ab	214.7 Ba	226.4 Aa	184.9 Ba	169.8 Aa	204.9 Ba	308.5 Aa	2.4[f]	66-25-1
ethyl 2-methyl-butanoate	1127	847	e2mb	<10 Aa	<10 Aa	nd	nd	nd	nd	nd	nd	0.006[d]	7452-79-1
butyl acetate	1183	816	ba	51.6 Aa	57.2 Aa	68.5 Aa	32.1 Aa	40.2 Aa	33.2 Aa	67.4 Aa	87.7 Aa	66[d]	123-86-4
2-methylbutyl acetate	1240	879	2mb a	96.4 Aa	147.1 Aa	30.3 Cb	78.5 Aa	69.8 BCa	21.9 Ab	86.4 ABa	47.8 Aa	11[d]	123-92-2
butyl propanoate	1257	912	bpr	37.1 Aa	<10 Aa	50.1 Aa	<10 Ab	nd	nd	nd	nd	25[d]	590-01-2
2-ethyl-1-hexenal	1293	1033	2elhal	240.7 Ba	179.9 ABa	109.0 Ca	94.8 Ba	256.8 Ba	148.6 Bb	839.9 A a	263.4 Ab	nf	123-05-7
pentyl acetate	1307	917	pa	15.9 Aa	17.0 Aa	15.1 Aa	9.8 Aa	14.7 Aa	<10 Aa	17.4 Aa	22.2 Aa	43[d]	628-63-7
2-methylbuty1 2-methylpropanoate	1310	1043	2mb2mpr	42.4 Ba	30.9 Aa	314.9 Aa	98.8 Ab	nd	18.0 Aa	105.0 Bb	51.1 Aa	14[g]	2445-78-5
2-methyl-1-butanol	1329	776	2mbOH	nd	10.2 Ba	12.5 Ab	44.9 Aa	nd	nd	nd	nd	250[d]	137-32-6
butyl 2-methyl-butanoate	1348	1017	b2mb	16.4 Aa	17.4 Ba	29.4 Ab	92.4 Aa	nd	nd	21.7 Aa	nd	17[d]	15706-73-7
1-pentanol	1375	788	pOH	27.2 Aa	23.3 Aa	13.9 Aa	11.9 Aa	nd	nd	nd	16.7 Aa	4000[j]	71-41-0
hexyl acetate	1393	1016	ha	127.9 Aa	127.7 Aa	108.1 Aa	68.1 Aa	79.7 Aa	70.0 Aa	126.2 Aa	193.4 Aa	2[d]	142-92-7
2-methylbuty1 2-methylbutanoate	1397	1123	2mb2mb	<10 Aa	<10 Aa	nd	<10 Aa	nd	nd	14.4 A a	<10 Aa	nf	2445-78-5
acetic acid	1432		aac	616.4 Bb	993.2 Aa	554.3 Ba	589.3 Aa	864.2 ABb	1309.9 Aa	1111.2 Aa	1325.7 Aa	99000[f]	64-19-7
propyl hexanoate	1440	1099	prh	39.1 Ab	186.1 Aa	51.2 Ab	184.4 Aa	nd	nd	nd	nd	nf	626-77-7
Z-3-hexenyl acetate	1457	1020	z3hxea	89.1 Aa	80.1 Aa	59.3 Aa	57.8 Aa	17.7 Aa	nd	47.0 Aa	nd	13[f]	3681-71-8
1-hexanol	1480	873	hOH	64.0 Aa	50.4 A a	27.7 Ba	<10 Ab	nd	19.4 Aa	18.9 Bb	41.1 Aa	500[d]	111-27-3
methyl octanoate	1511	1128	mo	38.5 Aa	13.1 Aa	33.5 Aa	41.3 Aa	16.5 Aa	nd	34.6 Aa	33.9 Aa	200[g]	111-11-5
Z-3-hexen-1-ol	1513	857	z3henOH	nd	15.9 Ba	nd	18.6 Ba	nd	26.1 Ba	19.5 Ab	77.6 Aa	70[i]	928-96-2
benzaldehyde	1521	971	byde	92.0 Aa	60.8 Ba	199.4 Aa	220.4 Aa	51.6 Aa	68.8 Ba	64.7 Aa	109.2 ABa	350[i]	100-52-7
butyl hexanoate	1533	1293	bh	53.8 Aa	73.0 Aa	<10 Ba	10.4 Ba	<10 Ba	<10 Ba	nd	nd	700[d]	626-82-4
hexyl 2-methyl-butanoate	1546	1239	h2mb	280.7 Aa	359.9 Aa	12.9 Bb	61.2 Ba	71.8 ABa	66.9 Ba	nd	56.4 Ba	22[g]	10032-12-0
ethyl octanoate	1555	1003	eo	376.7 Ab	8671.2 Aa	113.8 Ba	101.7 Ba	221.9 ABa	75.8 Bb	307.3 Aa	200.5 Ba	nf	106-32-1
benzoic acid	1560	1193	bac	246.8 Aa	132.1 Ba	286.2 Aa	294.2 Aa	311.5 Aa	295.4 Aa	245.8 Aa	365.5 Aa	85000[g]	65-85-0
2-ethyl-l-hexanol	1619	1033	2ehOH	583.9 Aa	661.7 Aa	167.0 Ba	147.5 Aa	262 Bb	312.9 Aa	134.5 Bb	456.1 Aa	nf	104-76-4
pentyl hexanoate	1637	1014	ph	26.6 Aa	33.4 Aa	nd	<10Aa	nd	nd	nd	nd	nf	540-07-8
(R)-linalool	1679		liOH	38.3 Da	nd	399.0 Ba	nd	220.7 Ca	nd	6058.5 Aa	84.9 Ab	0.087[f]	126-91-0
hexyl hexanoate	1736	1392	hh	330.3 Aa	338.2 Aa	40.6 Bb	132.2 ABa	108.7 ABa	68.0 Bb	nd	85.6 ABa	6400[g]	6378-65-0
acetophenone	1736	1076	aone	33.2 Bb	102.3 Ba	67.1 Ba	70.3 Ba	62.5 Bb	148.4 Ba	389.1 Ab	820.8 Aa	65[j]	98-86-2
butyl octanoate	1740	1394	bo	68.9 Aa	69.7 Aa	24.9 Ba	37.7 ABa	15.7 Ba	<10 Ba	nd	12.8 Ba	nf	589-75-3

Table 2. continued

compound	RI[a]	RI[b]	code[c]	Early Rich: 0 days at 20 °C	Early Rich: 3 days at 20 °C	Royal Glory: 0 days at 20 °C	Royal Glory: 3 days at 20 °C	Sweet Dream[COV]: 0 days at 20 °C	Sweet Dream[COV]: 3 days at 20 °C	Elegant Lady: 0 days at 20 °C	Elegant Lady: 3 days at 20 °C	OTH[d]	CAS Registry No.
benzyl alcohol	1869	1046	beOH	36.5 ABa	32.8 ABa	72.4 Aa	78.5 Aa	49.3 ABa	89.9 Aa	23.6 Ba	50.7 Aa	nf	10-51-6
γ-hexalactone	1880		hlac	99.0 Aa	110.7 Aa	43.2 Ba	42.5 Ba	32.7 Ba	35.4 Ba	91.3 Aa	106.4 Aa	1600[i]	695-02-7
γ-octalactone	2111	1270	olac	42.4 Aa	69.8 Aa	14.4 Ba	27.9 ABa	10.9 Ba	12.2 Ba	nd	18.8 ABa	7[i]	104-50-7
decanoic acid	2407	1390	deac	nd	19.0 Ba	nd	nd	<10 Bb	24.3 Ba	25.7 Ab	108.8 Aa	2200[g]	334-48-5
δ-decalactone	2417	1507	dlac	10.4 Ab	107.5 Aa	<10 Ab	36.4 Ba	nd	nd	nd	nd	31[f]	211-889-1
γ-dodecalactone	2587	1697	dolac	15.8Ab	41.0 Aa	<10 Ba	<10 Ba	nd	nd	nd	nd	0.43[f]	2305-05-7
total esters				1749.0 (36)[f] Bb	11207.0 z(76.8) Aa	1596.6 (34.2) Ba	1219.6 (21) Ba	5816.3 (68.3) Aa	449.1 (11.3) Bb	904.6 (8) Ba	942.7 (9.9) Ba		
total lactones				167.6 (3.5) Ab	328.9 (2.3) Aa	71.4 (1.5) Ba	115.0 (2) Ba	43.7 (0.5) Ba	47.5 (1.2) Ba	91.3 (0.8) Ba	125.2 (1.3) Ba		
total aldehydes				1004.8 (21) Aa	580.7 (4) Ab	523.2 (11.2) Ba	541.6 (9.3) Aa	493.3 (5.8) Ba	387.2 (9.8) Aa	1109.4 (10) Aa	681.1 (7.2) Ab		
total ketones				274.1 (5.7) Bb	520.6 (3.7) BCa	940.4 (20.2) ABa	1027.8 (17.7) Ba	431.4 (5.1) Ba	421.5 (10.6) Ca	1503.3 (13.3) Aa	1684.3 (17.8) Aa		
total terpenes				38.3 (0.8) Ba	21.4 (0.15) Ba	399.0 (8.6) Bb	1703.4 (29.4) Ba	242.1 (2.8) Bb	587.0 (14.8) Bb	6067.9 (53.9) Aa	3602.7 (38) Ab		
total acids				863.3 (18) ABb	1144.2 (7.8) Aa	840.6 (18) Ba	883.6 (15.2) Aa	1181.5 (14.9) ABb	1629.6 (41) Aa	1382.7 (12.3) Aa	1800.0 (19) Aa		
total alcohols				711.5 (15) Aa	794.3 (5.3) Aa	293.4 (6.3) Ba	309.3 (5.4) Aa	311.3 (3.6) Bb	448.3 (11.3) Aa	196.4 (1.7) Bb	642.2 (6.8) Aa		
total				4808.6 Bb	14597.0 Aa	4664.7 Ba	5800.2 Ba	8519.6 Aa	3970.3 Bb	11255.6 Aa	9478.3 Aba		

[a]Kovats retention index in column cross-linked FFAP. [b]Kovats retention index in a 5% phenyl polysilphenylene-siloxane BPX5. (−, eluted with the solvent; nd, not detected; nf, not found). [c]Codes using for PCAs. [d]Odor threshold (μg kg^{-1}) in water as reviewed in ref [d]46 and reported in refs [f]43, [g]47, [h]48, [i]45, and [j]49. [e]For each day at 20 °C, different capital letters indicate significant differences among cultivars, and for each cultivar, different lower case letters indicate differences between days at 20 °C ($P \leq 0.05$) by the least significant difference (LSD) test. [f]Relative proportion (percent) of the main families of compounds in parentheses.

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Table 3. Volatile Compounds Emitted (Nanograms per Kilogram) by 'Early Rich' and 'Royal Glory' Peaches after Cold Storage, plus 0 and 3 Days at 20 °C, and Relative Proportion (Percent) of the Main Classes of Compounds (in Bold)[a]

	Early Rich													
	harvest		10 days at −0.5°C				20 days at −0.5°C				40 days at −0.5°C			
	0 daysat 20 °C		0 days at 20 °C		3 days at 20 °C		0 days at 20 °C		3 days at 20°C		0 days at 20°C		3 days at 20°C	
ethyl acetate	nd	–	47.9	b	nd		4643.9	a	nd		nd		nd	
propyl acetate	18.9	e	1098.0	a	231.1	b	66.7	d	103.1	c	nd		nd	
2,3-butanodione	240.8	d	754.7	b	1348.8	a	283.4	cd	461.6	c	427.2	c	944.3	b
eucalyptol	nd		32.9	a	25.8	b	nd		nd		nd		nd	
2-methylpropyl acetate	25.7	c	87.6	c	504.7	a	47.8	c	314.0	b	nd		327.7	b
hexenal	672.1	b	1255.1	a	752.4	b	367.1	b	529.9	b	363.3	b	385.1	b
ethyl 2-methyl-butanoate	<10	b	10.2	b	45.0	a	12.0	b	20.0	ab	nd		35.5	a
butyl acetate	51.6	b	34.9	c	66.6	ab	24.2	c	56.7	b	nd		75.5	a
2-methylbutyl acetate	96.4	c	254.7	b	199.5	bc	443.5	a	178.6	bc	210.9	b	77.1	c
butyl propanoate	37.1	a	20.1	b	11.2	c	24.3	b	12.5	c	nd		nd	
2-ethyl-l-hexenal	240.7	a	332.3	a	273.0	a	194.0	ab	205.3	ab	149.5	b	171.8	ab
pentyl acetate	15.9	b	19.8	b	52.1	a	11.2	c	26.1	b	9.0	c	19.1	b
2-methylbutyl 2-methylpropa-noate	42.4	b	71.0	a	71.1	a	27.7	b	36.3	b	11.4	c	18.0	c
2-methy1-1-butanol	nd		13.8	b	12.2	b	23.5	a	nd		25.5	a	26.5	a
butyl 2-methyl-butanoate	16.4	a	26.2	a	25.3	a	<10	b	15.0	ab	nd		nd	
1-pentanol	27.2	b	58.9	a	38.1	b	16.9	c	30.2	b	15.4	c	18.6	c
hexyl acetate	127.9	b	128.1	b	336.5	a	64.2	c	149.1	b	49.1	c	119.4	b
2-methylbutyl 2-methylbutanoate	<10	b	25.1	a	14.2	b	12.3	b	<10	b	nd		nd	
acetic acid	616.4	b	nd		111.6	c	998.5	b	1730.2	a	1026.4	b	1495.7	a
hexy1propanoate	nd		63.2	a	nd		nd		nd		nd		nd	
propyl hexanoate	39.1	b	25.3	b	1056.5	a	17.5	b	68.0	b	nd		nd	
Z-3-hexenyl acetate	89.1	b	32.2	c	208.8	a	32.7	c	64.8	b	nd		nd	
1-hexanol	64.0	ab	112.2	a	127.6	a	26.5	b	52.9	b	33.1	b	47.6	b
methyl octanoate	38.5	b	27.3	b	118.0	a	50.9	b	65.2	b	nd		44.2	b
Z-3-hexen-l-ol	nd		<10	b	137.6	a	nd		<10	b	nd		16.3	b
benzaldehyde	92.0	a	73.8	a	98.1	a	71.2	a	81.8	a	106.3	a	97.5	a
penty1 hexanoate	26.6	a	32.7	a	32.4	a	23.3	a	33.7	a	nd		nd	
hexyl 2-methyl-butanoate	280.7	a	442.2	a	313.5	a	182.1	b	201.7	a	91.7	b	121.6	b
ethyl octanoate	376.7	c	172.1	d	643.3	b	230.6	c	305.6	c	60.3	d	1148.2	a
benzoic acid	246.8	a	102.9	d	128.8	c	131.8	c	157.2	c	222.6	b	276.9	a
2-ethyl-l-hexanol	583.9	b	1361.6	a	769.4	b	643.8	b	583.3	b	508.7	b	532.4	b
butyl hexanoate	53.8	a	70.5	a	79.3	a	27.0	ab	27.2	ab	<10	b	11.7	b
(*R*)-linalool	38.3	a	nd		10.2	b	<10	b	nd		nd		nd	
hexyl hexanoate	330.3	c	605.2	a	411.5	b	241.8	d	377.7	b	164.5	e	252.9	d
acetophenone	33.2	c	149.3	b	342.8	a	152.8	b	112.7	b	140.6	b	90.6	b
butyl octanoate	68.9	a	90.7	a	70.2	a	51.4	a	64.1	a	23.5	a	30.9	a
benzyl alcohol	36.5	ab	40.0	ab	53.5	a	24.3	b	43.3	a	46.9	a	39.0	ab
γ-hexalactone	99.0	b	108.4	b	155.1	a	100.7	b	95.1	b	74.9	b	73.3	b
γ-octalactone	42.4	a	26.9	b	42.6	a	47.8	a	35.1	a	nd		22.2	b
decanoic acid	nd		nd		114.2	a	nd		40.3	b	11.2	c	25.5	bc
δ-decalactone	10.4	c	38.0	c	174.0	a	80.7	b	73.8	b	nd		nd	
γ-dodecalactone	15.8	a	<10	b	<10	b	<10	b	nd		nd		nd	
total esters	1749.0	**36.4**	3385.2	**42.7**	4490.9	**48.3**	6235.1	**66.5**	2119.4	**33.1**	620.5	**16.6**	2281.8	**34.7**
total lactones	167.6	**3.5**	173.3	**2.3**	371.7	**4.2**	229.2	**2.5**	203.9	**3.2**	74.9	**2.0**	95.4	**1.5**
total aldehydes	1004.8	**20.9**	1661.2	**21.3**	1123.5	**12.3**	632.3	**6.4**	816.9	**12.9**	619.0	**16.4**	654.5	**10.1**
total ketones	274.1	**5.7**	904.0	**11.6**	1691.6	**18.5**	436.3	**4.7**	574.3	**9.1**	567.8	**15.1**	1034.9	**15.9**
total terpenes	38.3	**0.8**	32.9	**0.4**	36.0	**0.4**	nd		nd		nd		nd	
total acids	863.3	**18.0**	102.9	**1.3**	354.5	**3.9**	1130.3	**12.1**	1927.8	**30.4**	1260.2	**33.3**	1798.1	**27.6**
total alcohols	711.5	**14.8**	1586.5	**20.4**	1138.4	**12.5**	735.0	**7.9**	709.6	**11.3**	629.6	**16.7**	680.4	**10.2**
total	4808.6		7845.9		9206.7		9398.1		6352.0		3772.0		6545.2	

Table 3. continued

Royal Glory													
harvest		10 days at −0.5°C				20 days at −0.5°C				40 days at −0.5°C			
0 days at 20°C		0 days at 20°C		3 days at 20°C		0 days at 20°C		3 days at 20°C		0 days at 20°C		3 days at 20°C	
599.0	a	nd		nd		nd		nd		nd		nd	
22.1	c	400.9	a	565.8	a	183.2	b	193.6	b	nd		nd	
873.3	b	442.3	b	1854.2	a	807.2	b	630.9	b	1707.0	a	1743.5	a
nd		nd		nd		nd		nd		25.7	b	21.8	b
21.7	b	28.9	b	31.4	b	43.4	b	54.3	b	59.3	b	168.7	a
214.7	b	145.8	c	153.3	c	169.9	bc	271.1	a	218.7	a	150.7	c
nd		nd		nd		11.9	a	10.3	a	nd		nd	
68.5	b	110.9	a	146.5	a	56.9	b	45.8	b	105.6	ab	109.2	a
30.3	c	134.7	b	45.1	c	125.5	b	42.4	c	217.7	a	50.6	c
50.1	a	nd		nd		nd		nd		nd		nd	
109.0	b	66.4	c	65.5	c	72.1	c	54.9	c	139.5	b	185.2	a
15.1	b	<10	b	<10	b	19.2	ab	13.7	b	29.5	a	34.3	a
314.9	a	34.5	b	36.2	b	25.3	b	25.3	b	37.3	b	32.5	b
12.5	c	nd		<10	c	68.2	a	nd		41.2	b	10.3	c
29.4	c	16.1	cd	11.9	d	52.4	b	31.4	c	135.0	a	nd	
13.9	b	12.7	b	11.6	b	33.2	a	nd		15.9	b	19.4	b
108.1	a	32.6	b	22.2	b	46.0	b	51.9	b	90.4	a	80.0	a
nd		nd		nd		nd		nd		18.3	a	nd	
554.3	d	nd		nd		919.3	c	1071.6	c	2374.7	a	1564.9	b
nd		nd		nd		24.1	a	nd		nd		nd	
51.2	a	<10	b	<10	b	nd		nd		nd		nd	
59.3	b	72.9	a	31.4	c	14.9	d	25.9	c	nd		nd	
27.7	a	19.3	ab	21.6	ab	21.6	ab	14.5	b	34.3	a	22.9	ab
33.5	a	nd		<10	c	nd		11.5	b	nd		15.8	b
nd		<10	b	nd		21.4	a	26.2	a	26.7	a	39.2	a
199.4	a	98.4	b	nd		37.1	b	33.6	b	79.0	b	93.2	b
<10	a	nd		nd		nd		nd		nd		nd	
12.9	a	11.3	a	<10	a	nd		<10	a	17.5	a	15.9	a
113.8	c	128.4	c	246.6	b	308.5	b	523.6	b	686.9	a	876.3	a
286.2	b	258.7	bc	202.6	c	150.3	d	148.1	d	383.1	a	293.3	b
167.0	b	130.7	b	70.0	c	118.3	b	85.9	bc	242.8	a	132.9	b
nd		nd		52.7	a	nd		nd		nd		nd	
399.0	a	21.1	b	45.7	b	52.0	a	17.8	b	34.7	b	nd	
40.6	a	40.9	a	23.8	b	nd		nd		nd		nd	
67.1	b	44.8	b	159.7	a	118.2	ab	60.7	b	182.5	a	66.5	b
24.9	b	19.3	b	32.5	a	nd		nd		nd		nd	
72.4	a	91.6	a	33.2	b	32.3	b	23.2	b	65.2	a	45.7	ab
43.2	a	44.2	a	24.5	b	29.8	b	42.5	ab	62.4	a	53.6	a
14.4	b	24.3	a	20.7	a	nd		nd		nd		nd	
nd		nd		46.8	a	12.3	c	27.5	b	22.1	bc	18.4	bc
8.8	b	67.5	a	23.6	b	nd		nd		nd		nd	
<10	c	13.1	b	11.3	b	nd		33.6	a	nd		nd	
1596.6	**34.2**	1031.6	**42.2**	1246.0	**31.7**	911.3	**25.0**	1029.7	**28.6**	1397.5	**19.8**	1383.3	**23.8**
71.4	**1.5**	149.1	**6.0**	80.1	**1.7**	29.8	**0.8**	76.1	**2.2**	62.4	**0.9**	53.6	**0.9**
523.2	**11.2**	310.7	**10.6**	218.8	**5.5**	279.1	**7.9**	359.7	**10.2**	437.2	**6.2**	429.1	**7.4**
940.4	**20.2**	487.2	**19.8**	2014.0	**50.2**	925.3	**26.3**	691.6	**19.6**	1889.5	**27.0**	1809.9	**31.3**
399.0	**8.6**	21.1	**0.9**	45.7	**1.1**	52.0	**1.5**	17.8	**0.5**	60.4	**0.7**	21.8	**0.2**
840.6	**18.0**	258.7	**10.5**	249.4	**6.2**	1081.9	**30.7**	1247.2	**35.4**	2779.8	**39.7**	1876.6	**32.4**
293.4	**6.3**	254.3	**10.1**	136.3	**3.6**	295.1	**7.8**	149.8	**3.5**	426.2	**5.7**	270.3	**4.0**
4664.7		2512.7		3990.3		3574.5		3571.9		7053.1		5844.6	

[a]Means within each row followedby different letters indicate significant differences at $P \leq 0.05$, least significant difference (LSD) test. Volatile-compounds not detected are indicated as nd.

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Table 4. Volatile Compounds Emitted (Nanograms per Kilogram) by 'Sweet Dream^{cov}' and 'Elegant Lady' Peaches after Cold Storage, plus 0 and 3 Days at 20 °C,and Relative Proportion (Percent) of the Main Classes of Compounds(in Bold)[a]

	Sweet Dream^{cov}													
	harvest		10 days at −0.5°C				20 days at −0.5°C				40 days at −0.5°C			
	0 daysat 20 °C		0 days at 20 °C		3 days at 20 °C		0 days at 20 °C		3 days at 20°C		0 days at 20°C		3 days at 20°C	
ethyl acetate	5049.2	a	nd		1309.1	b	428.0	d	703.3	c	479.6	d	nd	
propyl acetate	56.1	c	<10	d	12.6	d	225.2	a	<10	d	10.3	d	134.9	b
2,3-butanodione	368.9	e	2059.8	a	1793.3	b	458.4	de	591.1	de	344.2	e	795.5	cd
eucalyptol	21.4	a	nd		11.2	b	nd		nd		nd		nd	
2-methylpropyl acetate	15.7	c	36.6	a	16.9	b	10.8	c	21.4	b	nd		21.8	b
hexenal	184.9	c	514.4	a	304.7	b	424.1	ab	208.7	d	408.5	ab	479.3	a
ethyl 2-methyl-butanoate	nd		nd		nd		nd		nd		nd		20.9	a
butyl acetate	40.2	b	29.0	b	29.7	bc	232.1	a	16.3	c	nd		34.6	b
2-methylbutyl acetate	69.8	a	15.6	b	17.1	b	15.0	b	14.6	b	15.2	b	37.3	b
butyl propanoate	nd		32.5	b	653.6	a	nd		nd		nd		nd	
2-ethyl-1-hexenal	256.8	a	242.8	b	nd		70.7	c	25.7	d	67.5	c	76.0	c
pentyl acetate	14.7	b	nd		136.1	a	nd		nd		nd		nd	
2-methylbuty1-2-methylpropanoate	30.0	a	33.7	a	nd		nd		nd		nd		nd	
2-methyl-1-butanol	nd		nd		nd		nd		nd		nd		17.5	a
butyl 2-methyl-butanoate	nd		nd		53.4	a	19.3	b	nd		nd		nd	
1-pentanol	nd		11.5	a	nd		nd		nd		nd		nd	
hexyl acetate	79.7	a	42.3	b	nd		<10	c	18.2	bc	16.6	bc	33.0	b
2-methylbutyl 2-methylbutanoate	nd		nd		nd		nd		nd		nd		nd	
acetic acid	864.2	a	732.0	a	1010.1	a	1043.2	a	356.8	b	447.5	b	974.3	a
hexyl propanoate	nd		nd		nd		nd		nd		nd		nd	
propylhexanoate	nd		nd		nd		nd		nd		nd		nd	
Z-3-hexenyl acetate	17.7	a	nd		nd		nd		nd		nd		35.3	a
1-hexanol	nd		24.4	a	26.6	a	nd		11.9	a	16.5	a	37.8	a
methyl octanoate	16.5	ab	nd		nd		nd		20.2	a	nd		13.6	b
Z-3-hexen-l-ol	nd		19.7	a	19.8	a	10.2	a	16.2	a	17.0	a	17.0	a
benzaldehyde	51.6	a	57.5	a	44.4	a	52.8	a	47.9	a	56.8	a	63.3	a
pentyl hexanoate	<10	a	nd		nd		nd		nd		nd		nd	
hexyl 2-methyl-butanoate	71.8	a	96.6	a	99.4	a	47.9	a	20.3	b	38.6	a	34.8	ab
ethyl octanoate	221.9	a	26.8	c	42.6	c	nd		35.9	c	11.4	c	183.9	b
benzoic acid	311.5	a	240.1	ab	204.0	b	155.4	b	260.9	ab	244.2	ab	280.6	a
2-ethyl-l-hexanol	262.0	b	548.3	a	358.1	ab	491.0	a	178.3	b	502.6	a	588.4	a
butyl hexanoate	nd		nd		nd		nd		nd		nd		nd	
(*R*)-linalool	220.7	a	nd		16.5	b	14.1	b	10.9	b	21.8	b	19.0	b
hexyl hexanoate	108.7	ab	225.1	a	nd		nd		30.9	b	91.2	b	118.3	ab
acetophenone	62.5	b	108.1	ab	142.1	ab	68.7	b	68.2	b	159.8	a	127.1	ab
butyl octanoate	15.7	ab	23.7	a	nd		28.6	a	<10	b	10.7	b	nd	
benzyl alcohol	49.3	a	38.4	ab	21.9	b	30.6	ab	29.9	ab	16.2	b	20.6	b
γ-hexalactone	32.7	a	13.9	b	<10	b	13.6	b	<10	b	14.8	b	16.0	b
γ-octalactone	10.9	a	nd		nd		nd		nd		24.6	a	nd	
decanoic acid	<10	b	<10	b	11.3	b	10.5	b	18.3	ab	16.8	ab	20.8	a
δ-decalactone	nd		nd		nd		nd		nd		nd		nd	
γ-dodecalactone	nd		nd		nd		nd		nd		nd		nd	
total esters	5816.3	**68.3**	561.9	**11.0**	2370.4	**37.6**	1006.8	**25.9**	881.1	**32.3**	673.5	**21.8**	668.4	**15.3**
total lactones	43.7	**0.5**	13.9	**0.3**			13.6	**0.4**			39.3	**0.9**	16.0	**0.2**
total aldehydes	493.3	**5.8**	814.8	**15.8**	349.1	**5.5**	547.6	**14.4**	282.4	**10.5**	532.7	**17.9**	618.6	**15.1**
total ketones	431.4	**5.1**	2167.9	**42.0**	1935.4	**30.8**	527.1	**13.8**	659.4	**24.6**	503.9	**16.9**	922.5	**22.5**
total terpenes	242.1	**2.8**	nd		276.6	**0.4**	14.1	**0.4**	10.9	**0.2**	21.8	**0.7**	19.0	**0.2**
total acids	1181.5	**13.9**	972.1	**18.9**	1225.4	**19.5**	1209.0	**31.6**	636.0	**23.7**	708.5	**23.8**	1275.8	**31.1**
total alcohols	311.3	**3.7**	642.3	**12.1**	426.5	**6.2**	531.8	**13.7**	236.4	**8.2**	552.3	**18.0**	681.2	**15.5**
total	8519.6		5172.9		6334.5		3850.1		2706.0		3032.0		4201.6	

Table 4. continued

Elegan Lady													
harvest		10 days at −0.5°C				20 days at −0.5°C				40 days at −0.5°C			
0 days at 20°C		0 days at 20°C		3 days at 20°C		0 days at 20°C		3 days at 20°C		0 days at 20°C		3 days at 20°C	
nd		5790.6	a	3875.6	b	3998.3	b	nd		1887.4	c	nd	
49.6	b	43.4	b	31.2	b	1157.4	a	324.3	ab	72.9	b	806.7	a
1114.2	b	2762.9	ab	3330.6	a	462.7	c	2135.2	b	316.4	c	723.7	c
<10	a	nd		26.8	a	18.9	a	39.4	a	18.2	a	17.2	a
27.8	c	24.3	c	124.1	b	50.4	c	280.3	a	32.1	c	133.2	b
204.9	b	220.9	b	273.5	ab	166.7	b	441.0	a	173.8	b	112.4	b
nd		nd		nd		nd		nd		nd		20.5	a
67.4	cd	58.9	cd	93.8	c	1561.1	a	129.5	b	34.9	d	115.8	b
86.4	b	75.5	b	51.1	b	170.4	a	57.1	b	53.4	b	103.5	ab
nd		nd		nd		17.3	a	nd		nd		nd	
839.9	a	734.5	a	281.7	b	36.5	b	224.9	b	26.4	b	nd	
17.4	b	15.2	b	23.7	b	12.8	b	49.1	a	nd		17.3	b
105.0	a	91.9	b	54.6	c	nd		nd		nd		nd	
nd		nd		nd		nd		nd		nd		nd	
21.7	a	19.0	a	nd		nd		nd		nd		nd	
nd		nd		17.9	a	nd		14.5	a	nd		nd	
126.2	b	110.4	b	206.8	ab	79.4	b	221.9	a	40.9	b	87.8	b
14.4	a	12.6	a	13.1	a	nd		nd		nd		nd	
1111.2	b	986.4	b	1095.4	b	1559.0	a	1211.5	ab	620.1	b	2394.9	a
nd		nd		nd		nd		nd		nd		nd	
nd		nd		nd		nd		nd		nd		nd	
47.0	a	41.2	a	nd		nd		45.2	a	46.9	a	nd	
18.9	a	16.5	a	44.0	a	nd		36.9	a	44.5	a	35.8	a
34.6	b	30.3	b	36.3	b	nd		215.5	a	70.0	b	nd	
19.5	b	17.1	b	82.9	a	21.7	b	12.9	b	nd		nd	
64.7	a	39.1	a	98.6	a	48.7	a	90.0	a	101.2	a	57.6	a
nd		nd		nd		nd		nd		nd		nd	
nd		nd		60.3	a	<10	b	17.2	b	nd		15.4	b
245.8	b	229.0	b	369.6	a	205.2	b	245.9	ab	228.7	b	266.3	ab
134.5	b	117.7	b	488.2	a	124.0	b	152.7	b	161.7	b	97.6	b
nd		nd		nd		nd		nd		nd		nd	
6058.5	a	5302.5	a	3762.2	b	12.9	c	nd		nd		nd	
nd		nd		183.4	a	nd		11.3	b	36.9	b	nd	
389.1	b	965.8	a	665.0	ab	717.3	ab	425.3	b	368.5	b	270.5	b
nd		nd		27.5	a	24.1	a	nd		nd		nd	
23.6	b	37.4	a	22.7	b	38.5	a	18.1	b	39.9	a	20.3	b
91.3	b	79.8	b	113.8	a	33.5	c	108.6	a	18.0	c	21.6	c
nd		nd		20.1	a	18.9	a	13.5	a	nd		nd	
25.7	c	17.5	c	113.5	a	26.8	c	89.9	b	16.1	c	14.3	c
nd		nd		nd		10.8	b	79.2	a	nd		nd	
nd		nd		nd		nd		nd		nd		nd	
904.6	**8.0**	6582.0	**36.3**	4995.9	**31.1**	7170.7	**67.4**	1983.7	**27.0**	2335.0	**51.9**	1840.0	**31.4**
91.3	**0.8**	79.8	**0.4**	133.9	**0.9**	63.2	**0.5**	201.3	**2.8**	18.0	**0.2**	21.6	**0.4**
1109.4	**9.9**	994.5	**5.5**	653.7	**4.2**	252.0	**2.2**	756.0	**10.3**	301.4	**6.6**	170.0	**2.9**
1503.3	**13 4**	3728.8	**20.6**	3995.6	**25.5**	1180.0	**11.1**	2560.5	**35.0**	684.9	**15.6**	994.2	**17.0**
6067.9	**53.9**	5302.5	**29.3**	3789.0	**24.1**	31.8	**0.2**	39.4	**0.5**	18.2	**0.4**	17.2	**0.1**
1382.7	**12.3**	1232.9	**6.8**	1578.6	**10.1**	1791.1	**16.9**	1547.3	**21.1**	864.9	**19.7**	2675.5	**45.6**
196.4	**1.7**	188.7	**1.0**	655.6	**4.2**	184.2	**1.7**	235.2	**3.2**	246.2	**5.6**	153.7	**2.6**
11255.6		18109.1		15802.4		10672.9		7323.3		4468.5		5872.3	

[a]Means within each row followedby different letters indicate significant differences at $P \leq 0.05$, by the least significant difference (LSD) test. Volatilecompounds not detected are indicated as nd.

extraction rather than vacuum steam distillation.[30] However, esters have been identified as the main family contributing to the aroma of nine peach accessions using vacuum steam distillation as the extraction method.[8]

The concentrations of volatile compounds emitted by 'Early Rich', 'Royal Glory', 'Sweet Dream^{cov}', and 'Elegant Lady' peaches at harvest and after 3 days at 20 °C are shown (Table 2). At harvest, the 'Early Rich' and 'Royal Glory' cultivars showed significantly lower total volatile compounds than 'Sweet Dream^{cov}' and 'Elegant Lady'. However, after 3 days at 20 °C, the total volatile concentration emitted by 'Early Rich' increased 3-fold, that of 'Royal Glory' and 'Elegant Lady' remained statistically stable, and that of 'Sweet Dream^{cov}' declined 2-fold. Infante et al.[31] on four different yellow-flesh peaches reported that the typical aroma of peach develops after a variable period at 21 °C. Quantitatively speaking, for all four cultivars the most important volatile compounds were hexyl acetate, 2-methylbutyl acetate, and ethyl octanoate, as esters; γ-hexalactone and γ-octalactone, as lactones; hexanal and 2-ethyl-1-hexenal, as aldehydes; 2,3-butanodione, as ketone; acetic acid, as carboxylic acid; and 1-hexanol and 2-ethyl-1-hexanol, as alcohols. No clear preference in terpenes was detected. Differences in the emissions of volatile compounds were found both before and after cold storage as a function of early-season and mid-season cultivars. At harvest, the total volatiles ranged from 8520 to 11256 ng kg^{-1} for the two mid-season peaches 'Sweet Dream^{cov}'and 'Elegant Lady', respectively (Table 2). These values were 1.8−2.4 times higher than those of the early-season peaches 'Early Rich' and 'Royal Glory'. Nevertheless, after 20 or 40 days of cold storage, the total volatile compound concentrations were 9398.1 and 7053.1 ng kg^{-1} for the two early-season peaches ('Early Rich' and 'Royal Glory'), respectively (Tables 3 and 4). These values were about double those for the mid-season peaches 'Sweet Dream^{cov}'and 'Elegant Lady' (3850 and 4468.5 ng kg^{-1}, respectively). These results suggest that the two early-season peaches studied in this work could have more cold-storage potential than the two midseason fruits.

Cold storage affected total volatile emissions in all four peach cultivars. After 40 days of cold storage, total volatile emissions were 1.5 times higher than at harvest for 'Royal Glory', and after 20 days of storage, the same result was obtained for 'Early Rich' (Table 3). The greatest increase in volatile compounds emitted by these early-season cultivars was also obtained after 40 days for 'Royal Glory' and 20 days for 'Early Rich' (Table 3). In contrast, after 40 days at −0.5 °C total volatile emissions were 2.5 times lower than at harvest in the 'Sweet Dream^{cov}' and 'Elegant Lady' cultivars (Table 4). These results confirm those reported by Robertson et al.,[3] who claimed that extending storage beyond 4 weeks would reduce the total volatile fraction of 'Cresthaven' peaches, although no similar reduction was observed between 20 and 40 days of cold storage in 'Royal Glory' fruits (Table 3).

Esters are chemical compounds responsible for fruity and floral aromas. Therefore, high ester concentrations should give the peaches a pleasant flavor.[32] At harvest, ester compounds represented more than 68, 36, 34, and 8% respectively of total volatile compounds in 'Sweet Dream^{cov}', 'Early Rich', 'Royal Glory', and 'Elegant Lady' (Table 2). Ethyl acetate (ea), hexyl hexanoate (hh), and ethyl octanoate (eo) represented 92% of the total esters in 'Sweet Dream^{cov}'. The main compound was ethyl acetate (58%), which is also the most abundant in 'Luxiang', a Chinese cultivar,[6] and in 'Sunprice' peaches stored in a cold air atmosphere.[33] However, the concentration of this ester was below its odor threshold of 13500 μg kg^{-1} (Table 2) and therefore would not have contributed to the aroma.

After cold storage, esters tended to predominate in the volatile profiles of acid cultivars 'Early Rich' and 'Elegant Lady' (Tables 3 and 4). The best storage period for maximizing esters from these acid varieties was 20 days of cold storage. There were changes from the harvest ester composition during cold storage. For example, hexyl propanoate was detected for the first time after 10 days of cold storage plus in 'Early Rich' and after 20 days of storage in 'Royal Glory' (Table 3). Ethyl acetate was the most important ester detected in 'Royal Glory' (20%) at harvest (Table 2), but it was not detected in this variety during cold storage (Table 3), nor was it detected after 40 days of cold storage plus 3 days at 20 °C in any cultivar studied (Tables 3 and 4). In contrast, ethyl 2-methylbutanoate was initially absent at harvest (Table 2), but was found after cold storage (Tables 3 and 4). This branched-chain ester was present in the greatest quantities after 20 days at −0.5 °C in 'Royal Glory', regardless of the subsequent commercialization period, and after 40 days of cold storage plus 3 days at 20 °C in the other cultivars. Ethyl 2-methylbutanoate directly affects peach flavor because it has a very low odor threshold (6 ng kg^{-1}; Table 2) and plays an important role in the characteristic aroma of many fruits.[34−37]

Lactones are considered to be major contributors to peach aroma, and the concentrations of γ-hexalactone and γ- and δ-decalactones are generally low at harvest and increase during fruit ripening.[38] Four lactones were found in this study (Table 2), and these accounted for 0.5−3.5% of the total volatiles. Similar low proportions have also been reported by other researchers[6,7] and in our previous works on different peach cultivars.[39,40] Significant differences in lactone concentrations were found among the four cultivars at harvest (Table 2), γ-hexalactone being the most important component, accounting for >80% of total lactones. 'Early Rich' and 'Elegant Lady' cultivars showed the highest concentrations of all detected lactones. Eduardo et al.,[8] working with 'Early Rich' cultivar, also obtained high emission of lactones. The latter result has remained consistent with two different methods of volatile extraction: steam distillation[8] and headspace extraction (our results). Results from other authors also showed that γ- and δ-decalactones were the most important lactones of different origins.[6]

The relative proportions of total volatile production consisting of lactones during cold storage and days at 20 °C were similar to those achieved at harvest (Tables 2−4). After 40 days of cold storage, total lactone concentrations were >2 times lower than after 10 days with the only exception being 'Sweet Dream^{cov}' when it was ripened for 0 days at 20 °C (Tables 3 and 4). Raffo et al.[28] reported an increase in lactone fractions after 7 days of cold storage at 1 °C in other yellow-fleshed cultivars, whereas after 14 days of cold storage plus 1 day of ripening at 22 °C, the total lactone concentration was significantly lower than in fruits stored for 7 days. Individual lactones did not contribute to these global changes in the same way. Lactones with shorter side chains, particularly γ-hexalactone, kept constant concentrations during storage in 'Royal Glory' and 'Sweet Dream^{cov}' but declined in 'Early Rich' and 'Elegant Lady' peaches (Tables 3 and 4).

Terpenoids contribute the characteristic fruity aroma of peaches.[41] At harvest, the two terpenes identified in the four cultivars constituted >50% of the total volatile compounds emitted by 'Elegant Lady' and conferred fruity citrus note[43] (Table 2). In contrast, these compounds represented 8.6, 3, and 0.8% of total volatile compounds in 'Royal Glory', 'Sweet Dream[cov]', and 'Early Rich', respectively. The sum of terpenes in 'Elegant Lady' was significantly greater than in the other cultivars at harvest (Table 2). The monoterpene linalool was the most abundant; its concentration was >20 times greater in 'Elegant Lady' (6.1 μg kg^{-1}) than in the other cultivars (38.3–399 ng kg^{-1}). Linalool is one of the major compounds found in mature peaches,[3,39] and its predominance has also been noted in 'Early Rich'[8] and 'Majestic' (by up to 30). During storage and days at 20 °C, the relative proportion of total terpenes decreased from 29 to 0.1% ('Elegant Lady'), from 1.5 to 0.2% ('Royal Glory'), and from 0.7 to 0.2% ('Sweet Dream[cov]'). Terpenes were not detected in samples of the 'Early Rich' cultivar stored for 20 days at −0.5 °C plus 3 days at 20 °C (Tables 3 and 4). Eucalyptol was not detected in early-season cultivars at harvest and was emitted after 3 days at 20 °C (Table 3). Eucalyptol was identified in mid-season cultivars at harvest and after cold storage in 'Elegant Lady' (Tables 2–4).

The total aldehyde concentration accounted for 2–21% of the total volatile fraction at harvest and during cold storage (Tables 2–4) and depends on the genetic background.[6] For 'Sweet Dream[cov]' peaches, the three storage periods did not significantly influence benzaldehyde, and the greatest amounts of 2-ethyl-1-hexenal were obtained after 10 days at −0.5 °C without days at 20 °C for mid-season cultivars. In previous studies carried out on another yellow-fleshed peach ('Spring Lady'), higher concentrations of hexanal and 2-ethyl-1-hexenal were obtained after 14 days of cold storage at 1 °C plus 1 day at 22 °C than after 7 days.[28] It is well-known that benzaldehyde is derived from cyanogenic glycoside, amydalin, and prunasin, typical constituents of many *Prunus* species. Benzaldehyde is recognized as the almond aroma present in peach,[42] but it was present in quantities above its odor threshold of 350 μg kg^{-1} (Table 2) and would therefore not contribute to peach aroma.

Two ketones were detected in the four cultivars and account for 4–20% of total volatiles at harvest. During cold storage, the concentrations of 2,3-butanodione decreased in 'Early Rich', 'Elegant Lady', and 'Sweet Dream[cov]' but increased in 'Royal Glory' after 40 days of cold storage (Tables 3 and 4). The predominant ketone was 2,3-butanodione. This compound has a low odor threshold (1 μg kg^{-1}, Table 2) and would contribute buttery notes[43] to the aroma in 'Elegant Lady' at harvest and after 10 days of cold storage, in 'Royal Glory' after 10 and 40 days of cold storage followed by 3 days at 20 °C, and in 'Early Rich' and 'Sweet Dream[cov]' after 10 days of cold storage plus 3 days at 20 °C (Tables 2–4). Nevertheless, to the best of our knowledge, no data have been reported on the effect of cold storage on its concentration in peach.

Six alcohol compounds accounted for ∼1–20% of the total volatiles, depending on cultivar, cold storage period, and days at 20 °C (Tables 2–4). No common trend was found for any of the detected alcohols, reflecting the different metabolic origins of these compounds. This is in accordance with previous work on 'Tardibelle' peach.[39] During cold storage, the concentration of (*Z*)-3-hexen-1-ol remained constant in 'Sweet Dream[cov]', increased in 'Royal Glory', and declined in 'Elegant Lady' and 'Early Rich'. The C_6 alcohols contribute green sensory notes in ripening peach fruit.[37] 1-Hexanol increased in 'Sweet Dream[cov]' and 'Elegant Lady' cultivars after 20 days of cold storage (Table 4).

A similar trend was reported for 'Spring Lady' peaches after 14 days of cold storage plus 1 day at 22 °C.[28]

Relationship between Consumer Acceptance and Volatile Compounds Emission. Because of the large amount of information obtained, five PLSR models were used to correlate consumer acceptance (*Y*-variable) to a set of potentially explanatory variables (*X*-variables), including emission of volatile compounds. The first PLSR was run with the data obtained for the four cultivars at harvest. The rest of the PLSR models were developed separately for each peach cultivar; in all models, the emission of volatile compounds and consumer acceptance were used to characterize the samples.

The first PLSR model for the harvest samples showed that the 'Early Rich' cultivar was perceived as being more appreciated by consumers, possibly due to higher emissions of some volatile compounds such as γ-hexalactone, γ-octalactone, δ-decalactone, γ-dodecalactone, propyl acetate, 2-methylpropyl acetate, ethyl and hexyl 2-methylbutanoate, butyl hexanoate, pentyl hexanoate, hexyl hexanoate, ethyl octanoate, butyl octanoate, acetic acid, 1-hexanol, and (*Z*)-3-hexen-1-ol (data not shown). This is in agreement with previous reports[9,40,44,45] that lactones, particularly γ- and δ-decalactone and γ- and δ-dodecalactone, are character impact compounds in peach aroma, often in association with other volatiles such as C_6 aldehydes, aliphatic alcohols, and terpenes. Odor descriptors for decalactones and dodecalactones include "peach" or "peach-like",[45] and thus higher concentrations of these compounds are likely to influence the perception of a characteristic peach flavor by the consumer.

Because aroma perception is an important attribute for consumer acceptance of peaches, we investigated how volatile profile changes affect consumer acceptance. Special attention was focused on the emission of volatile compounds after storage, comparing the different cold storage periods among them with respect to harvest. To determine the volatile profile that most satisfied consumers for each cultivar, a PLSR model for cultivar (including harvest and cold-storage samples) was carried out. The PLSR model obtained for 'Early Rich' showed that volatile compound emissions accounted for up to 99% of the total variability in consumer preference (Figure 1A). 'Early Rich' fruits maintained for 3 days at 20 °C after harvest were situated on the right side of PC1 and were the most appreciated (Figure 1B). The bigger acceptability scores were related to higher emissions of propyl acetate, butyl and pentyl hexanoate, hexyl 2-methylbutanoate, ethyl and butyl octanoate, γ-octalactone, γ-dodecalactone, linalool, and (*Z*)-3-hexen-1-ol (Figure 1C).

The PLSR model obtained for 'Royal Glory' showed that volatile compound emissions accounted for up to 99% of the total variability in consumer preference (Figure 2A). 'Royal Glory' samples after harvest were situated on the left side of the PC1 axis, which explained 83% of total variance. 'Royal Glory' samples stored for 10, 20, and 40 days were located on the right side of PC1, away from the first group (Figure 2A). Figure 2B shows that this latter sample (stored for 40 days) was more appreciated by the participating consumers, possibly due to higher emissions of 2-methylpropyl, butyl and pentyl acetate, 2-ethyl-1-hexanal, 2,3-butanodione, eucalyptol, benzoic acid, 1-pentanol, and 1-hexanol (Figure 2C).

The PLSR model obtained for 'Elegant Lady' showed that volatile compound emissions accounted for up to 95% of the total variability in consumer preference (Figure 3A). 'Elegant Lady' cold stored for 10 days or just after harvest was situated

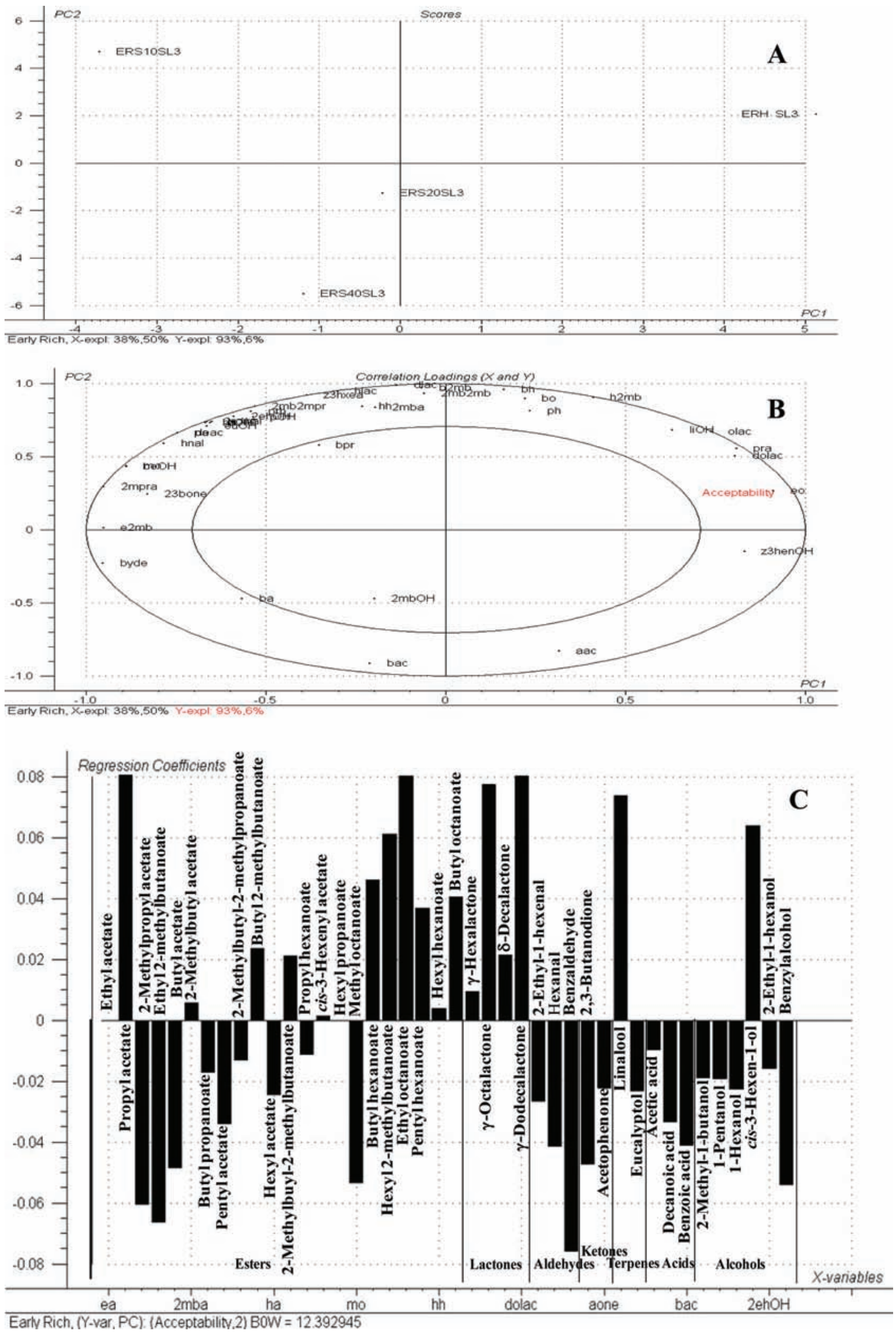

Figure 1. PLS model using the data for 'Early Rich' cultivar: (A) scores; (B) correlation loadings; (C) regression coefficients from a PLS model of variable acceptance.

on the right side of the PC1 axis, which explained 77% of total variance. In contrast, 'Elegant Lady' samples stored for 20 and 40 days were located in the middle and on the left side of PC1, respectively (Figure 3A). The corresponding loadings plot (Figure 3B) shows that 'Elegant Lady' fruits cold stored for 10 days were more appreciated by the participating consumers, possibly due to higher emissions of ethyl and hexyl acetate, γ-hexalactone, γ-octalactone, 2-ethyl-1-hexanal,

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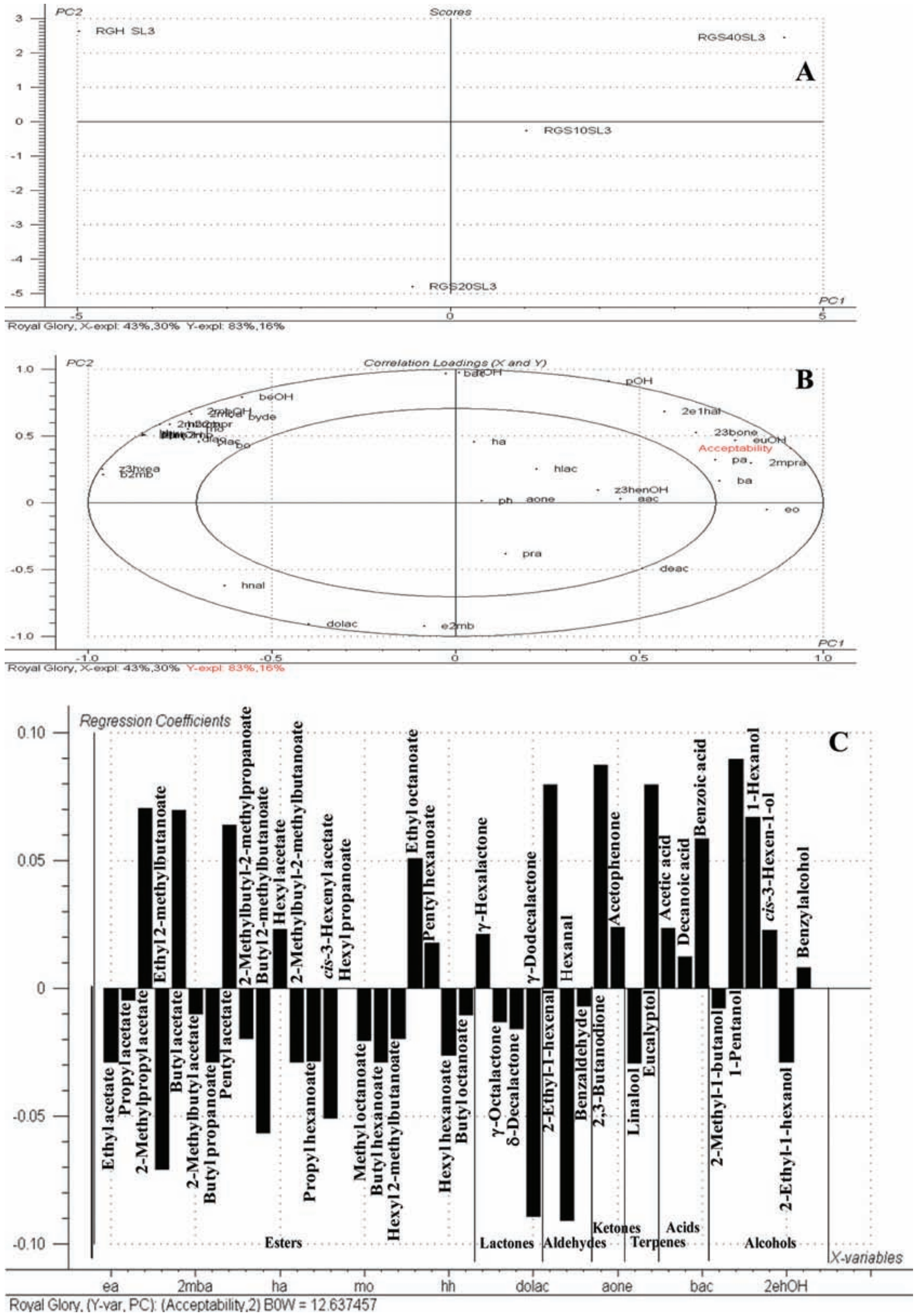

Figure 2. PLS model using the data for 'Royal Glory' cultivar: (A) scores; (B) correlation loadings; (C) regression coefficients from a PLS model of variable acceptance.

2,3-butanodione, decanoic acid, 1-pentanol, 1-hexanol, and (*Z*)-3-hexen-1-ol (Figure 3C).

The PLSR model obtained for 'Sweet Dream[cov]' showed that volatile compound emissions accounted for up to 100% of the total variability in consumer preference (Figure 4A). 'Sweet Dream[cov]' samples cold stored for 10 days and just after harvest were situated on the right side of the PC1 axis, which explained 98% of total variance. In contrast, 'Sweet Dream[cov]' samples stored for 20 and 40 days were located in the middle and on the left side of the PC1 axis, respectively

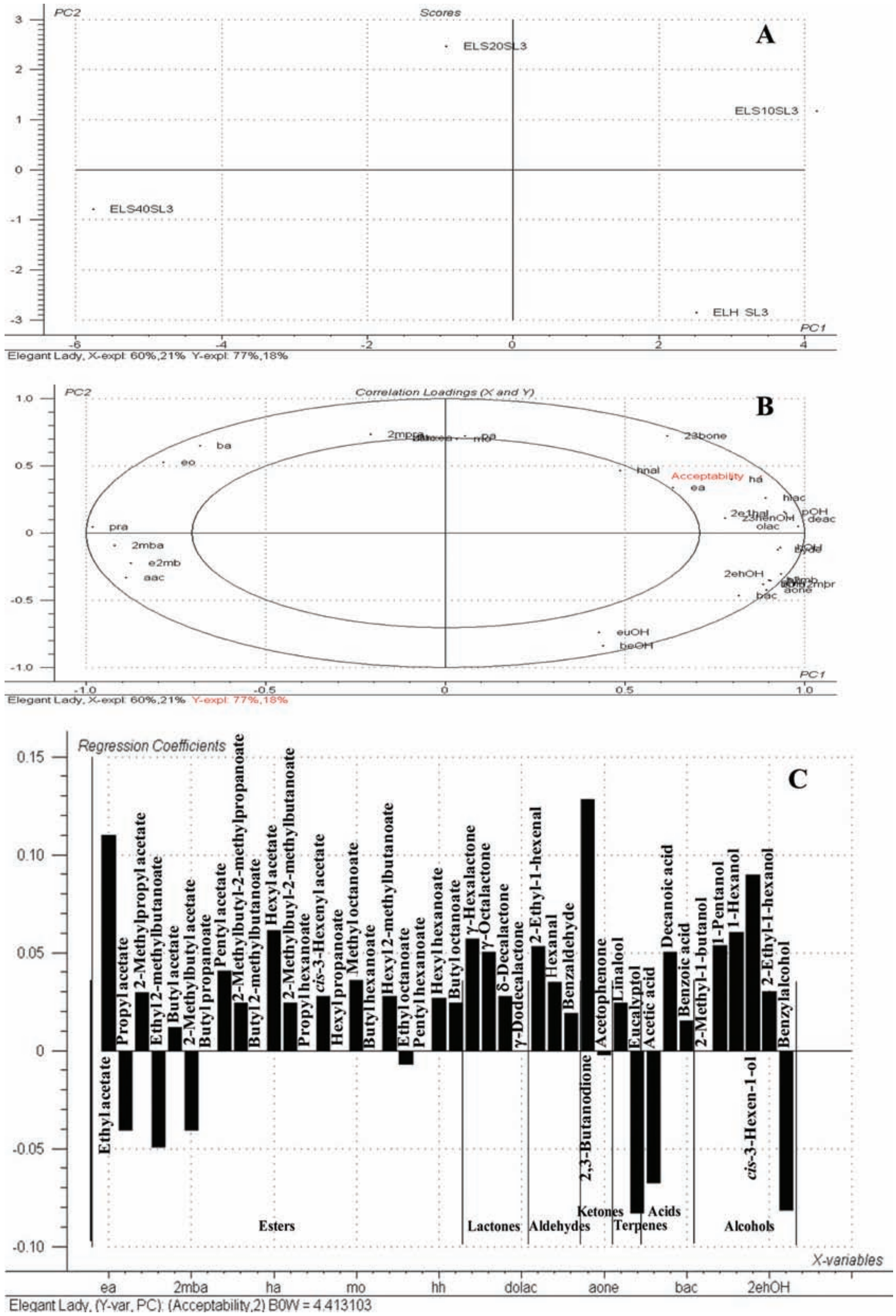

Figure 3. PLS model using the data for 'Elegant Lady' cultivar: (A) scores; (B) correlation loadings; (C) regression coefficients from a PLS model of variable acceptance.

(Figure 4A). 'Sweet Dream[cov]' fruits cold stored for 10 days were more appreciated by the participating consumers (Figure 4B), possibly due to higher emissions of ethyl and pentyl acetate, butyl propanoate, butyl 2-methylbutanoate, 2,3-butanodione, acetophenone, acetic acid, and (*Z*)-3-hexen-1-ol (Figure 4C).

To summarize, we note that quantitative criteria do not ensure the contribution of major volatiles to consumer acceptance.

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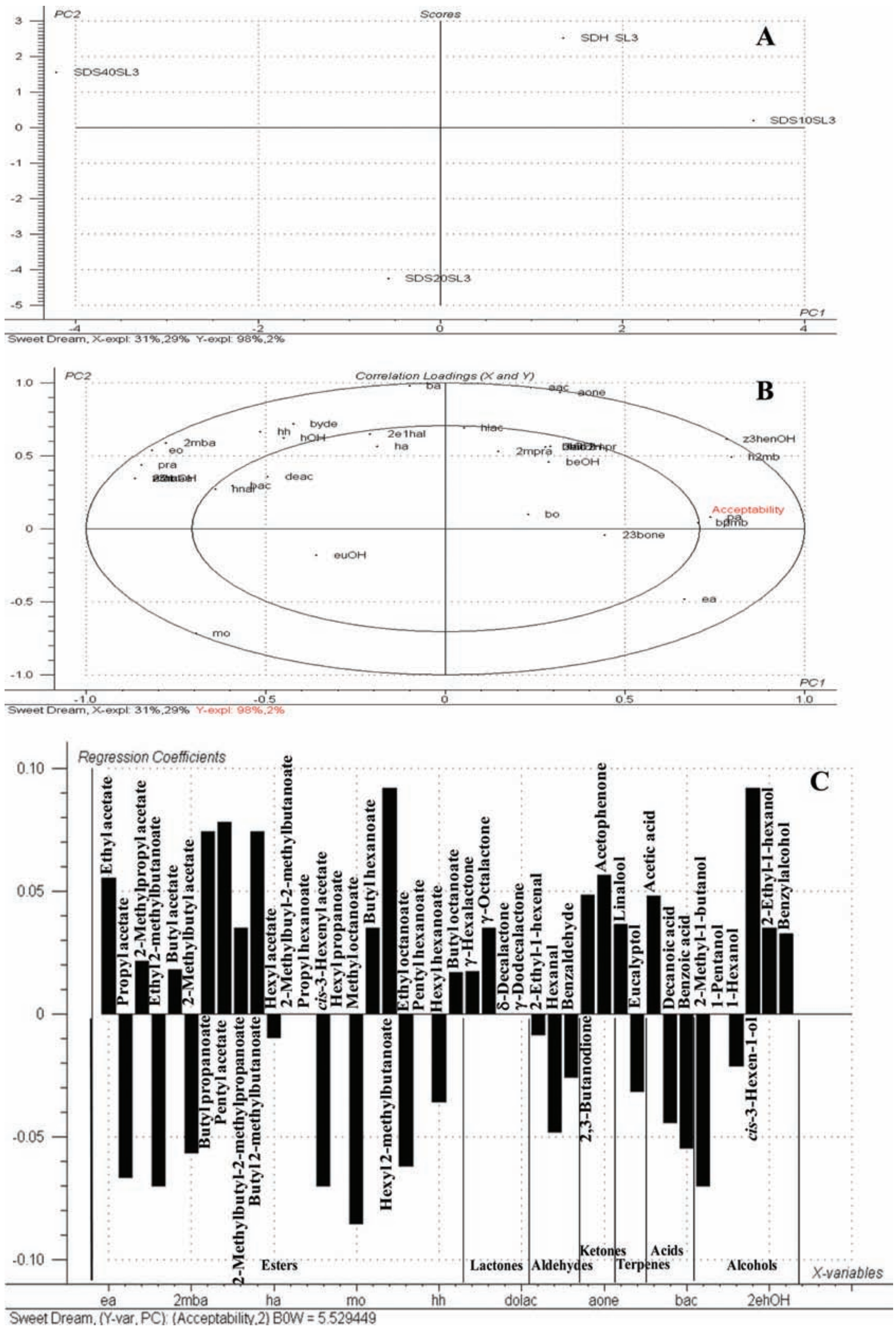

Figure 4. PLS model using the data for 'Sweet Dream' cultivar: (A) scores; (B) correlation loadings; (C) regression coefficients from a PLS model of variable acceptance.

In our study, the fruits most accepted by consumers were influenced by γ-hexalactone and (Z)-3-hexen-1-ol concentration in all of the analyzed cultivars. However, these two volatile compounds are not major volatiles in the volatile fraction.

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