Physicochemical Characteristics of Selected Sweet Cherry Cultivars

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The volatile, sugar, and organic acid constituents in 12 cultivars and selections of sweet cherries (*Prunus avium* L.) were characterized and quantified by high-performance liquid chromatography and gas chromatography (GC). Fruit weight, soluble solids concentration (SSC), pH, titratable acidity (TA), and color (CIE L^*, a^*, b^*) were also determined at harvest. Weight ranged from 8.8 to 14.5 g per fruit, SSC from 13.5 to 24.5 °Brix, and SSC/TA ratio from 18.3 to 29.0. Chroma was a better indicator of color variations among sweet cherry cultivars compared to the hue angle as it correlated highly with L^*, a^*, and b^* values ($r > 0.90$). The major nonvolatile constituents varied widely among cultivars: glucose [5.2−8.8 g/100 g of fresh weight (FW)], fructose (4.4−6.4 g/100 g of FW), sorbitol and mannitol (2.2−8.0 g/100 g of FW), and malic acid (502.7−948.3 mg/100 g of FW). Three principal components accounted for 53.3% of the total variation among 50 volatile compounds assessed by a dynamic headspace GC method. (*E*)-2-Hexenol, benzaldehyde, hexanal, and (*E*)-2-hexenal were predominant flavor volatiles and could be used to segregate commercial and new cherry selections into various subgroups.

Keywords: *Sweet cherry; volatiles; sugars; acids; color*

INTRODUCTION

The selection and introduction of new sweet cherry cultivars are important to maintaining a competitive fruit industry in British Columbia. Over the past five decades, the cherry breeding program at the Summerland Research Centre has introduced 20 cultivars. Van, Stella, Lapins, and Summit are among the major cultivars with an international impact, and efforts are continuing in developing new selections with improved market qualities. Cultivars are screened mainly on the basis of field growth factors as well as postharvest fruit quality attributes such as size, color, texture, and flavor by sensory means (Dever et al., 1996). Multiple regression models were developed to assess visual and flavor/texture liking based on relevant sensory attributes for North American consumers (Cliff et al., 1996).

Quantitative determination of chemical entities provides a means to increase our understanding of physicochemical and sensory relationships. To this end, Gao and Mazza (1995) characterized and quantified the distribution of anthocyanins and colorless phenolics in 11 cultivars and selections of sweet cherries. Due to the current interest in modified-atmosphere packaging, the fruit quality, headspace volatiles, and sensory attributes for specific sweet cherry cultivars such as Lapins and Sweetheart have been assessed during storage in sealed plastic films (Meheriuk et al., 1995, 1997). However, instrumental assessment of individual volatile and nonvolatile flavor components is mostly lacking in comparative studies of cherry cultivars but would be desirable and complementary to ongoing research. Thus, the objective of this investigation was to characterize and compare four promising numbered selections and eight commercial sweet cherry cultivars for their sugar, acid, and volatile constituents.

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MATERIALS AND METHODS

Plant Source. Eight commercial cherry cultivars and four new selections (*Prunus avium* L.) from the breeding program at Agriculture and Agri-Food Canada, Research Centre, Summerland, BC, were harvested during the months of July and August 1993. Maturity criteria used to establish harvest dates were based on weight, color, texture and taste characteristics (Fisher-Fleming, 1993; Dever et al., 1996; Cliff et al., 1996).

Standard Quality Evaluation. Random samples of 30 cherries were weighed, and skin color (L^*, a^*, b^*) was assessed with a Minolta CR-200 Chromameter having an aperture size of 10 mm (Minolta Canada Inc., Mississauga, ON, Canada). The hue and chroma (saturation) attributes of chromaticity were calculated using the formulas $\tan^{-1}(b^*/a^*)$ and $[(a^*)^2 + (b^*)^2]^{1/2}$, respectively. Juice extracted from triplicate composite blended samples of pitted cherries (65 g) was used to determine titratable acidity (TA, titration with 0.1 N NaOH to pH 8.1 and expressed as percent malic acid) on a Brinkmann autotitrator (Metrohm, Herisau, Switzerland), and soluble solids concentration (SSC) was determined by a temperature-compensated Abbé refractometer (AO Scientific Instruments, Buffalo, NY).

Analysis of Nonvolatile Constituents. Pitted cherries (50 g) were homogenized with deionized distilled water (200 mL) at low speed for 30 s in a Waring blender. After a 15-min contact time, the homogenate was filtered through Whatman no. 4 filter paper. Aliquots of these extracts were used for sugar and acid analysis.

The determination of sugars was carried out according to the method of Chapman and Horvat (1989). Test tubes (12 × 100 mm) containing cherry extracts (0.5 mL) were placed on a block heater at 75 °C, and the evaporation of water was facilitated with a stream of dry nitrogen. Sugars were converted to their oximes by the addition of 0.5 mL of hydroxyamine (25 mg/mL of pyridine) containing phenyl β-glycoside as internal standard (6 mg/mL of pyridine) and heated at 75 °C for 30 min. They were then converted to their TMS derivatives by addition of 0.5 mL of BSTFA plus 1%

S0021-8561(97)00646-8 CCC: $15.00 Published 1998 by the American Chemical Society
Published on Web 01/01/1998

Table 1. Standard Physicochemical Attributes of Selected Sweet Cherry Cultivars (Mean ± Standard Deviation)

cherry variety	date (1993)	weight[a] (g)	SSC[b,c] (°Brix)	pH[b]	TA[b,c] (% malic acid)	SSC/TA[b,c]
13S-43-48	July 26	8.8 ± 0.9	13.5 ± 0.1	4.0 ± 0.1	0.55 ± 0.05	24.8 ± 2.5
13S-51-24	July 29	11.2 ± 0.8	16.4 ± 0.2	3.8 ± 0.1	0.78 ± 0.01	21.0 ± 0.4
13S-20-30	July 27	11.0 ± 1.3	13.6 ± 0.1	3.8 ± 0.2	0.63 ± 0.01	21.6 ± 0.2
13S-10-40	July 16	11.1 ± 0.9	18.6 ± 0.1	3.4 ± 0.3	1.02 ± 0.02	18.3 ± 0.5
Van	July 19	9.4 ± 0.7	17.9 ± 0.1	3.5 ± 0.1	0.90 ± 0.02	19.9 ± 0.6
Bing	July 20	9.8 ± 1.0	16.7 ± 0.2	3.7 ± 0.2	0.83 ± 0.05	20.2 ± 1.6
Salmo	Aug 03	10.6 ± 1.1	24.5 ± 0.3	3.8 ± 0.2	0.84 ± 0.06	29.0 ± 1.1
Comp Stella	July 21	13.7 ± 1.7	19.7 ± 0.2	3.9 ± 0.2	0.85 ± 0.02	23.3 ± 0.2
Lapins	July 28	14.5 ± 1.4	16.4 ± 0.2	3.9 ± 0.0	0.63 ± 0.01	25.9 ± 0.4
Lambert	July 15	11.3 ± 0.8	17.2 ± 0.1	3.7 ± 0.2	0.87 ± 0.01	19.9 ± 0.3
Summit	July 23	13.5 ± 0.8	19.6 ± 0.1	4.0 ± 0.1	0.69 ± 0.02	28.6 ± 0.6
Sweetheart	Aug 05	10.7 ± 1.1	16.4 ± 0.2	3.9 ± 0.1	0.87 ± 0.06	18.8 ± 1.6

[a] Replication, $n = 30$. [b] Replication, $n = 3$. [c] SSC, soluble solids concentration; TA, titratable acidity.

Table 2. Color Characteristics of Selected Sweet Cherry Cultivars (Mean ± Standard Deviation)[a]

cherry variety	L^*	a^*	b^*	hue	chroma
13S-43-48	28.7 ± 0.9	11.5 ± 2.0	2.3 ± 0.6	5.1 ± 1.0	11.7 ± 2.0
13S-51-24	29.9 ± 1.7	16.3 ± 3.3	4.2 ± 1.2	3.9 ± 0.5	16.9 ± 3.5
13S-20-30	28.4 ± 1.4	11.9 ± 3.9	3.2 ± 1.4	3.9 ± 1.0	12.4 ± 4.1
13S-10-40	30.5 ± 1.4	17.0 ± 5.3	4.6 ± 2.1	3.9 ± 0.8	17.6 ± 5.7
Van	28.5 ± 1.2	6.7 ± 1.9	1.3 ± 0.7	6.1 ± 3.0	6.9 ± 1.9
Bing	28.5 ± 0.9	8.0 ± 2.4	1.6 ± 0.7	5.6 ± 1.8	8.2 ± 2.5
Salmo	25.1 ± 1.4	1.9 ± 0.5	0.7 ± 0.4	3.4 ± 2.9	2.1 ± 0.5
Comp Stella	29.6 ± 1.0	11.0 ± 2.8	2.4 ± 0.9	4.7 ± 0.9	11.3 ± 2.9
Lapins	31.1 ± 2.3	16.4 ± 5.8	4.0 ± 2.5	5.0 ± 2.2	17.0 ± 6.2
Lambert	29.5 ± 1.3	13.9 ± 4.7	3.3 ± 1.6	4.6 ± 1.1	14.3 ± 4.9
Summit	28.8 ± 1.0	8.5 ± 2.2	1.5 ± 0.8	7.7 ± 7.3	8.6 ± 2.3
Sweetheart	31.8 ± 2.1	16.6 ± 4.4	4.5 ± 2.1	3.9 ± 0.9	17.2 ± 4.8

[a] Replication, $n = 30$.

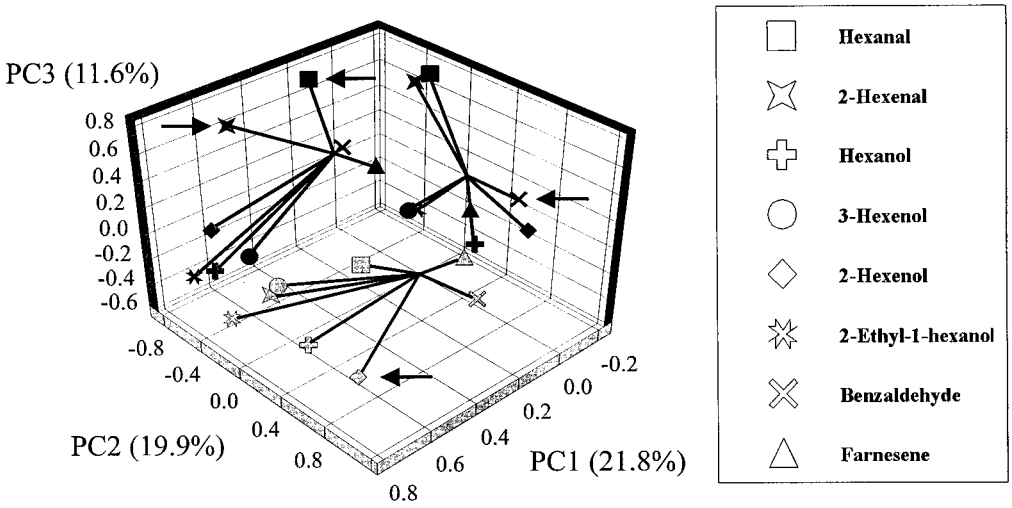

Figure 1. Principal component (PC) analysis of cherry volatile constituents. Arrows mark important flavor volatiles with high PC loadings.

TMCS (Pierce Chemical Co.) and heated at 75 °C for an additional 20 min. After the reaction was complete, a small amount of anhydrous sodium sulfate was added to ensure dryness. Derivatized samples (1 μL) were injected (split ratio 20:1) in a Varian Vista 6000 gas chromatograph equipped with a DB-1 capillary column, 15-m length × 0.25-mm i.d. × 0.25-μm film thickness (J&W, Alltech Inc.), and a flame ionization detector. Oven temperature was held at 150 °C for 4 min, ramped to 192 °C at 4 °C/min, held for 0.5 min, and then programmed to 240 °C at 10 °C/min, and held for 7 min.

The procedure used for organic acids was adapted from that of Wang et al. (1993). Cherry extracts were passed through a 0.45-μm filter (Gelman Sciences) and a Sep-Pak C_{18} column (Waters Associates Inc). Aliquots (10-μL) were injected into a Waters Associates HPLC system equipped with a multi-wavelength detector set at 214 nm. A Brownlee Spheri-5 RP-18, 5-μm particle size, 220 × 4.6 mm, in tandem with a Waters μ-Bondapak C_{18}, 10-μm particle size, 300 × 3.9 mm, were used as separation columns. A Bio-Rad ODS-10 microguard column preceded these columns, and elution was carried out with 0.2 M KH_2PO_4 buffer at pH 2.4 (as mobile phase) at 0.8 mL/min flow rate. The organic acids were identified and quantified by comparison of retention times and peak areas with standard solutions of known acids.

Analysis of Volatile Constituents. Whole cherries (437.5 g), saturated calcium chloride (87.5 mL), deionized distilled water (175 mL), and the internal standard (100 μL of 396 ppm of cyclohexanone in water) were homogenized at the lower setting of a two-speed Waring blender (1-L jar) for 30 s. Preliminary tests indicated that the seeds were not damaged by this procedure. The sample was transferred to a 1000-mL purge and trap apparatus (Wheaton, Millville, NJ) maintained at 35 °C. Purified nitrogen was supplied through a sparger at a rate of 100 mL/min as the sample was stirred with a magnetic bar. Volatiles were collected for 2 h on a preconditioned glass trap (4-mm i.d. × 180-mm length) packed with

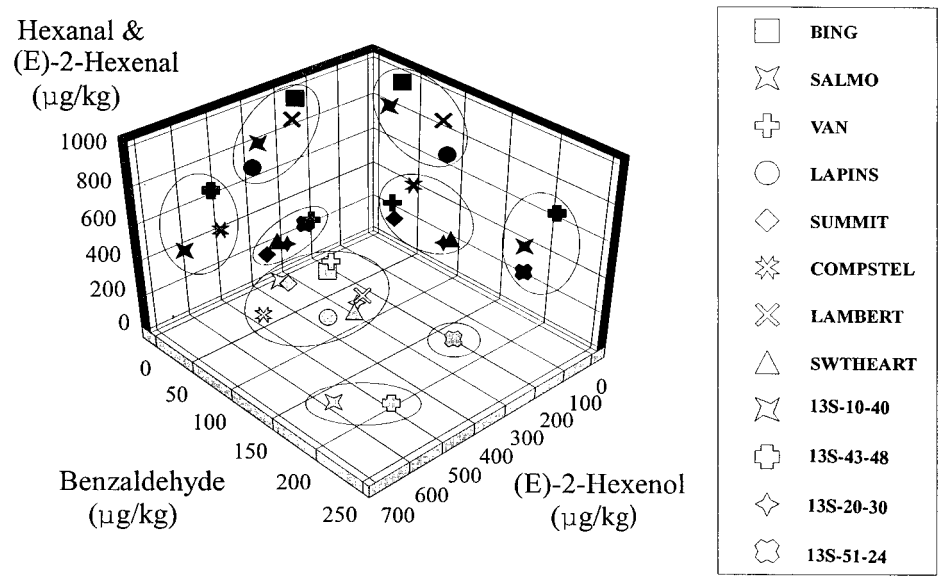

Figure 2. Segregation of 12 sweet cherry cultivars based on 4 flavor volatile compounds.

Table 3. Concentration of Sugars in Selected Sweet Cherry Cultivars (Mean ± Standard Deviation)[a]

	sugar component (g/100 g of FW)			
cherry variety	glucose	fructose	sorbitol and mannitol	total
13S-43-48	5.2 ± 0.2	4.4 ± 0.1	2.5 ± 0.4	12.0 ± 0.5
13S-51-24	6.6 ± 0.4	4.8 ± 0.1	3.4 ± 0.4	14.9 ± 1.0
13S-20-30	5.5 ± 0.2	4.4 ± 0.3	2.2 ± 0.1	12.1 ± 0.4
13S-10-40	7.4 ± 0.1	6.1 ± 0.3	3.3 ± 0.0	16.8 ± 0.4
Van	6.8 ± 0.3	5.0 ± 0.3	4.0 ± 0.3	15.7 ± 0.8
Bing	6.3 ± 0.1	5.1 ± 0.3	3.6 ± 0.1	15.0 ± 0.3
Salmo	8.8 ± 0.8	5.5 ± 0.7	8.0 ± 0.4	22.4 ± 1.0
Comp Stella	7.5 ± 0.4	6.4 ± 0.3	3.4 ± 0.3	17.3 ± 0.9
Lapins	6.6 ± 0.1	5.4 ± 0.2	2.8 ± 0.4	14.8 ± 0.4
Lambert	6.8 ± 0.1	5.1 ± 0.1	3.4 ± 0.2	15.3 ± 0.3
Summit	7.2 ± 0.3	5.1 ± 0.4	4.7 ± 0.5	17.0 ± 0.8
Sweetheart	6.5 ± 0.6	4.7 ± 0.3	3.0 ± 0.1	14.2 ± 0.8

[a] Replication, $n = 3$.

Tenax (60/80 mesh, 100 mg) in a Tekmar LSC 2000 purge and trap unit (Tekmar Corp., Cincinnati, OH). They were then desorbed at 200 °C for 8 min and cryofocused in the GC oven onto a 1-m length of deactivated fused silica capillary precolumn immersed in a Dewar flask of liquid nitrogen. The oven temperature program was initiated upon removal of the Dewar flask. For volatile quantitation, separation was performed on a Supelcowax 10 fused silica capillary column (60-m length × 0.25-mm i.d. × 0.25-μm film thickness) housed in a Varian Vista 6000 gas chromatograph equipped with a flame ionization detector. Oven temperature was held initially at 35 °C for 10 min and then increased by 2 °C/min to 175 °C. Column head pressure was maintained at 30 psi. For volatile identification, the same sample preparation and capillary column were used with a Hewlett-Packard 5890-5970 GC-MSD system to record the mass spectral data. The MS operated with an ion source temperature of 250 °C, ionizing energy of 70 eV, and scan range of 25−250 amu at a rate of 2.6 scan/s. Identification of compounds was obtained with an HP G1034C MS Chem Station containing an HP G1035A Wiley (138.1) PBM library and confirmed with retention data of available authentic compounds.

Statistical Analysis. Statistical analyses were carried out using the MEANS, CORR, and FACTOR procedures of SAS software ver. 6.07 (SAS Inc., Cary, NC). Results were obtained on a fresh weight (FW) basis.

RESULTS AND DISCUSSION

Cherry harvest was staggered during a 4-week period as the 12 sweet cherry cultivars from the same orchard came within their window of commercial maturity. Fruit size ranged between 8.8 and 14.5 g (Table 1) but weight was independent of harvest date ($r = -0.004$). Most new selections reached maturity between early and mid-season, and weighed ≈11.0 g on average. The highest correlation obtained was that of pH and TA ($r = -0.778$). A wide range of SSC and TA was found among cherry cultivars (Table 1) as indicated by a lower correlation value ($r = 0.504$). Selections 13S-43-48 and 13S-51-24 had low TA and SSC while 13S-10-40 con-

Table 4. Concentration of Organic Acids in Selected Sweet Cherry Cultivars (Mean ± Standard Deviation)[a]

	acid component (mg/100 g of FW)					
cherry variety	malic	ascorbic	citric	succinic	fumaric	total
13S-43-48	502.7 ± 6.4	8.4 ± 0.2	3.8 ± 0.6	25.6 ± 1.2	0.093 ± 0.005	540.7 ± 8.2
13S-51-24	716.5 ± 52.7	12.5 ± 0.9	3.3 ± 1.0	32.3 ± 5.7	0.084 ± 0.007	764.6 ± 56.0
13S-20-30	591.6 ± 32.7	10.3 ± 0.5	2.0 ± 0.8	22.9 ± 10.3	0.107 ± 0.060	626.8 ± 42.3
13S-10-40	948.3 ± 12.7	17.6 ± 1.3	4.3 ± 2.1	35.6 ± 1.2	0.306 ± 0.101	1006.1 ± 14.3
Van	845.9 ± 21.6	14.8 ± 0.8	2.6 ± 0.5	22.4 ± 1.7	0.201 ± 0.050	885.9 ± 21.3
Bing	755.0 ± 31.9	12.5 ± 1.2	5.6 ± 1.0	38.1 ± 3.2	0.124 ± 0.024	811.3 ± 36.6
Salmo	783.6 ± 27.2	15.9 ± 1.0	5.6 ± 1.1	24.2 ± 1.4	0.172 ± 0.070	829.4 ± 30.2
Comp Stella	792.3 ± 39.5	10.2 ± 1.7	6.6 ± 2.7	24.8 ± 3.3	0.162 ± 0.005	834.0 ± 34.5
Lapins	585.8 ± 5.9	10.4 ± 2.1	5.7 ± 1.2	23.4 ± 3.0	0.102 ± 0.002	625.3 ± 9.2
Lambert	805.6 ± 21.8	13.1 ± 0.5	4.9 ± 0.2	32.0 ± 0.8	0.166 ± 0.007	855.7 ± 21.8
Summit	640.2 ± 36.9	11.5 ± 2.1	3.2 ± 0.3	24.7 ± 2.8	0.082 ± 0.026	679.7 ± 41.4
Sweetheart	823.6 ± 33.9	14.8 ± 0.8	4.8 ± 0.3	24.8 ± 3.8	0.382 ± 0.077	868.3 ± 35.8

[a] Replication, $n = 3$.

Table 5. Volatile Constituents in Selected Sweet Cherry Cultivars

	relative concentration[a] (μg/kg of fruit FW)												
compound	Bing	Salmo	Van	Lapins	Summit	Comp Stella	Lambert	Sweet-heart	13S-10-40	13S-43-48	13S-20-30	13S-51-24	av (%)
acetaldehyde	4.4	8.2	5.5	4.6	3.8	3.2	2.8	8.0	6.1	5.3	4.8	3.9	0.46
1,4-hexadiene	1.3	1.7	1.4	2.2	1.6	5.5	3.2	2.8	2.2	1.4	1.2	1.5	0.20
octane	0.4	0.5	1.0	0.4	0.5	0.4	0.5	0.5	0.6	0.5	1.0	0.6	0.05
2-propanone	0.2	0.4	0.2	0.4	0.2	0.8	0.3	0.6	0.3	0.2	0.1	0.2	0.03
butanal	3.1	4.2	4.7	2.5	3.5	2.5	2.0	3.0	2.7	2.7	3.4	2.5	0.28
nonane	0.7	1.1	0.5	0.6	0.4	0.5	0.6	0.4	0.9	0.4	0.4	0.5	0.05
3-buten-2-one	1.3	4.4	2.0	0.7	1.9	2.3	3.1	0.8	2.3	1.0	1.2	0.6	0.16
pentanal	1.7	3.8	1.6	1.6	1.3	2.4	1.7	2.2	2.3	2.7	2.5	1.7	0.19
4-methyl-2-pentanone	4.2	18.0	1.7	17.6	8.9	3.7	1.4	3.0	2.0	2.4	18.6	2.2	0.64
toluene	0.3	1.2	0.2	0.2	0.6	0.4	0.2	0.3	0.3	0.3	0.2	0.2	0.03
butyl acetate	0.5	0.5	0.3	0.4	0.4	0.7	0.5	0.2	0.5	0.4	0.5	0.3	0.04
hexanal	262.8	161.2	97.3	261.8	97.6	112.8	254.1	171.1	292.9	237.9	139.0	199.4	17.48
xylene	1.6	2.6	1.5	2.1	1.3	2.9	1.5	1.6	1.9	2.1	1.0	0.9	0.16
(*E*)-4-pentenal	1.7	1.2	0.5	2.2	0.5	1.4	2.0	0.4	2.4	1.3	0.6	0.6	0.12
β-myrcene	1.2	0.4	0.3	0.3	0.6	1.4	1.1	0.4	0.5	0.4	0.3	0.3	0.06
1-methylethyl-benzene	0.8	0.4	0.4	0.3	0.2	1.1	0.4	0.4	0.4	0.3	0.4	0.3	0.04
1-butanol	1.2	0.5	0.5	0.9	0.7	0.9	2.1	0.7	0.7	0.5	0.4	0.9	0.08
limonene	1.0	2.3	3.1	4.2	1.6	2.4	2.9	2.3	2.8	1.4	1.4	1.4	0.20
heptanal	2.9	7.3	1.4	2.2	1.1	4.0	3.3	3.1	3.5	0.8	1.7	1.3	0.25
propylbenzene	0.5	4.4	3.0	0.5	1.4	2.1	0.6	1.1	0.6	3.6	1.5	1.3	0.16
1-ethyl-2-methyl-benzene	0.4	1.4	0.5	1.2	0.7	2.1	1.0	0.9	0.8	1.0	0.4	0.6	0.08
(*E*)-2-hexenal	692.9	218.5	143.8	414.4	53.4	296.3	596.7	33.2	501.3	405.8	21.1	34.4	26.06
β-ocimene	2.1	8.4	2.1	1.2	3.3	4.8	3.5	4.2	0.8	5.5	5.7	7.0	0.37
α-terpinolene	1.4	1.7	0.9	3.9	1.2	0.7	0.8	0.7	1.0	1.1	0.7	0.6	0.11
1-pentanol	2.4	9.2	4.0	1.5	4.7	6.2	0.8	4.3	4.7	2.5	2.0	1.4	0.33
hexyl acetate	2.0	4.6	1.3	0.5	1.2	4.7	9.6	2.6	5.8	2.0	1.5	1.8	0.29
1-octen-3-one	0.7	0.7	0.7	0.7	1.2	0.4	1.7	0.6	0.5	0.6	0.5	0.2	0.06
(*Z*)-2-hexenyl acetate	3.2	0.9	2.5	2.4	2.9	3.7	4.0	2.3	0.6	3.7	0.5	1.2	0.21
(*E*)-2-heptenal	1.3	0.6	0.6	0.7	0.2	0.6	0.3	0.5	0.3	0.2	0.2	0.3	0.04
(*E*)-2-hexenyl acetate	1.7	1.9	2.6	1.4	1.3	2.5	3.4	0.9	2.8	3.4	1.8	1.2	0.19
6-methyl-5-hepten-2-one	3.5	0.4	0.7	1.0	0.4	1.3	1.0	1.3	1.7	0.6	0.4	0.9	0.10
1-hexanol	21.0	39.6	11.9	40.6	22.5	66.3	25.6	59.5	14.3	32.4	25.3	23.4	2.92
(*E*)-3-hexen-1-ol	3.0	1.1	23.8	1.9	1.5	42.6	35.4	16.8	25.8	14.7	9.0	8.8	1.41
nonanal	2.7	4.6	2.2	2.5	0.4	1.9	2.4	1.1	1.4	0.4	2.1	1.1	0.18
(*E*)-2-hexen-1-ol	253.4	609.4	214.1	392.9	363.6	500.0	264.7	328.9	372.1	518.6	296.5	235.8	33.23
(*E*)-1-hepten-3-ol	1.7	0.9	0.5	0.7	0.8	1.4	1.0	0.7	1.0	1.1	0.7	1.3	0.09
1-heptanol	2.0	1.9	1.1	3.3	1.5	3.0	1.1	2.2	1.4	2.0	1.1	2.8	0.18
2-ethyl-1-hexanol	20.4	10.2	12.8	14.3	15.0	53.9	22.1	17.8	23.4	11.8	15.4	13.1	1.76
decanal	0.7	0.8	0.5	1.0	0.6	2.0	4.7	0.7	0.8	3.6	1.8	0.9	0.14
benzaldehyde	34.6	178.0	24.4	88.6	27.1	50.3	83.0	96.6	19.5	207.9	87.9	178.9	8.23
linalool	3.2	4.2	4.3	4.0	4.3	5.6	3.6	5.4	3.5	3.4	2.6	3.0	0.36
hexyl hexanoate	1.5	0.4	0.4	1.7	0.8	1.6	2.2	0.8	1.1	0.4	1.8	1.7	0.11
(*E*)-2-decenal	0.8	0.5	1.3	1.4	1.4	1.2	1.4	0.6	0.4	0.5	0.5	0.6	0.08
estragole	5.7	6.6	1.1	2.2	1.4	6.3	1.5	2.1	1.1	6.1	1.8	1.5	0.29
α-terpineol	2.0	3.7	0.4	1.0	0.7	0.8	3.5	0.5	0.9	0.8	1.0	1.4	0.13
α-farnesene	0.9	1.0	2.5	2.7	0.2	16.2	2.6	7.8	32.4	124.5	46.6	13.5	1.92
β-damascenone	1.3	0.3	0.2	0.2	0.2	0.3	0.5	1.6	0.4	0.2	0.3	0.3	0.04
geranyl acetate	0.7	0.7	0.5	0.8	0.5	0.7	0.7	0.7	0.8	1.5	2.4	0.8	0.08
2-methyl-3-hydroxy-2,4,4-trimethylpentyl propanoate[b]	2.6	2.9	0.7	3.4	1.4	0.8	0.6	0.8	0.8	1.2	1.6	2.1	0.14
2,2,4-trimethyl-pentane-1,2-diol diisobutanoate[b]	1.6	7.3	0.6	2.6	1.0	0.9	0.8	1.8	0.7	2.2	1.0	2.9	0.18

[a] Concentration relative to internal standard cyclohexanone, $n = 2$. [b] Tentative identification only.

tained the highest acidity. Cultivar Salmo possessed the highest level of SSC.

In addition to SSC, TA, and fruit size, color is another indicator of maturity (Pruthi et al., 1980). Selective/multiple picking and postharvest sorting at packinghouses can provide color and quality consistency for cherries destined to fresh market. Darker cherries (lower L^* values) tended to be less red (lower a^* value) and less yellow (lower b^* value) (Table 2). Specifically, Sweetheart, Lapins, 13S-10-40, and 13S-10-40 were lighter, redder, and yellower than the remaining cultivars, while Salmo was the darkest cherry. During maturation, the change in fruit color from green can be followed with a^* values and hue angle (Barrett and Gonzalez, 1994). However, our results indicated that chroma was highly correlated with L^*, a^*, and b^* values as compared to the hue angle (0.90, 0.99, and 0.97 vs 0.01, −0.28, and −0.472, respectively) and therefore provided a better indicator of color differences among matured sweet cherry cultivars. Some of the factors influencing the color of cherries are the concentration and distribution of the different anthocyanins and colorless phenolics as well as pH (Gao and Mazza, 1995).

The major sugars found in the 12 sweet cherry cultivars were glucose and fructose in a ratio of 8:6 with respective means of 6.77 and 5.17 g/100 g of FW (Table 3). In addition, cherries contained two coeluting sugar alcohols, sorbitol and mannitol. The combined concentration of these two sugar alcohols averaged 3.69 g/100 g of FW. The sum of the above four sugar compounds

constituted 89.1% of the SSC. The predominant organic acid in cherries was malic acid (94.2%) (Table 4). Succinic (3.6%), ascorbic (1.6%), citric (0.57%), and fumaric (0.02%) acids were minor constituents. Once converted in milliequivalents per/100 g of FW, the sum of the latter five organic acids accounted for 98.8% of titratable acidity levels. Variations in acids and sugars were within expected limits (Shaw and Wilson, 1983; Pruthi et al., 1980; Singh et al., 1970; Fernandez-Flores et al., 1970) with the exception of Salmo, which contained twice the level of sorbitol and mannitol as compared to other cultivars.

Fifty volatile compounds were detected and quantified in all sweet cherry cultivars by the dynamic headspace method (Table 5). The volatile classes (and their relative total concentrations averaged over 12 cultivars) included 13 hydrocarbons (38 ± 36 μg/kg), 12 aldehydes (584 ± 294 μg/kg), 11 alcohols (445 ± 143 μg/kg), 7 esters (13 ± 4 μg/kg), and 7 ketones (12 ± 7 μg/kg). Large variations were observed in the eight most prominent volatiles [(*E*)-2-hexen-1-ol, 362 ± 124 μg/kg; 2-hexenal, 284 ± 237 μg/kg; hexanal, 191 ± 70 μg/kg; benzaldehyde, 90 ± 66 μg/kg; 1-hexanol, 32 ± 17 μg/kg; α-farnesene, 21 ± 36 μg/kg; 2-ethylhexanol, 19 ± 12 μg/kg; 3-hexen-1-ol, 15 ± 14 μg/kg], which collectively provided 93.0% of total relative volatile concentration. Most compounds have previously been identified in sweet cherry fruit (Schmid and Grosch, 1986a; Mattheis et al., 1992; Meheriuk et al., 1995, 1997).

Principal component analysis (PCA) applied to all volatiles measured in the 12 cultivars revealed that the three first PCs accounted for 53.3% of the total variation. High positive and negative PC loadings represented by the transposed side panel vectors indicated several collinear relationships among the above eight prominent volatiles (Figure 1). (*E*)-2-Hexenol, benzaldehyde, hexanal, and (*E*)-2-hexenal were four of the most abundant volatile compounds, which respectively had high component correlations with PC1, PC2, and PC3. These latter volatiles are known to provide flavor impact in cherry juice (Schmid and Grosch, 1986b). Benzaldehyde is a primary contributor to characteristic cherry flavor (Schmid and Grosch, 1986a) and originates from enzymatic hydrolysis of amygdalin in stone fruits or can be derived from precursors such as phenylalanine and benzyl alcohol (Souty and Reich, 1978; Blaise, 1986; Nahrstedt, 1972). C_6 aldehydes, hexanal and (*E*)-2-hexenal, are formed by the action of the lipoxygenase pathway on fatty acids with corresponding secondary compounds such as (*E*)-2-hexenol (Drawert et al., 1966; Paillard and Rouri, 1984). C_6 aldehydes are associated with green/grassy notes while (*E*)-2-hexenol exhibits a fruity/leafy/sweet/nutty odor (Paillard, 1990; Fenaroli, 1990).

The concentrations of the four volatiles, (*E*)-2-hexenol, benzaldehyde, and C_6 aldehydes [hexanal and (*E*)-2-hexenal] were projected onto the side panels of a three-dimensional plot and allowed a visual segregation of the various sweet cherry cultivars (Figure 2). Average levels of all four volatile compounds were found in Sweetheart and 13S-20-30. Highest concentrations occurred in 13S-43-48 while Summit and Van contained lowest levels for all four volatiles. Salmo had high concentrations of benzaldehyde and (*E*)-2-hexenol. A high content of hexanal was found in Bing, Lapins, Lambert, and 13S-10-40; comparatively high contents of 2-hexenol and benzaldehyde were measured in Comp Stella and 13S-51-24, respectively. New cherry selections may therefore be regrouped with established cultivars on the basis of the content of these key volatile compounds. Such information on volatile groupings along with the identified variability in the nonvolatile constituents contributes to a better appreciation of the compositional differences that exist among sweet cherry cultivars. Furthermore, it provides a systematic means to help decipher the inherently complex perception of flavor intensity and liking in future sensory experiments.

CONCLUSION

The major compositional variations among cherry cultivars can be summarized in the determination of glucose, fructose, and sorbitol and mannitol for sugars, malic acid for organic acids, and (*E*)-2-hexenol, benzaldehyde, hexanal, and (*E*)-2-hexenal for volatile compounds. Phenolic compounds were not included in this study but may also be influential in further characterizing taste attributes and color. These results, however, established an initial framework upon which additional information based on agronomic, genotypic, and phenotypic variability can ascertain a better representation of the sweet cherry population. Research studies comprising simultaneous detailed compositional and sensory aspects are necessary to complement and strengthen our understanding of the determinant flavor relationships.

ACKNOWLEDGMENT

We acknowledge B. Fisher-Fleming, F. Kappel, and E. Hogue for providing the cherry cultivars.

LITERATURE CITED

Barrett, D. M.; Gonzalez, C. Activity of softening enzymes during cherry maturation. *J. Food Sci.* **1994**, *59*, 574−577.

Blaise, A. Le goût d'amande amère dans les vins. *Journée de Rencontres Oenologiques*; Fac. Pharma.: Montpellier, France, 1986.

Chapman, G. W., Jr.; Horvat, R. J. Determination of nonvolatile acids and sugars from fruits and sweet potato extracts by capillary GLC and GLC/MS. *J. Agric. Food Chem.* **1989**, *37* (7), 947−950.

Cliff, M. A.; Dever, M. C.; Hall, J. W.; Girard, B. Development and evaluation of multiple regression models for prediction of sweet cherry liking. *Food Res. Int.* **1996**, *28*, 583−589.

Dever, M. C.; MacDonald, R. A.; Cliff, M. A.; Lane, W. D. Sensory evaluation of sweet cherry cultivars. *HortScience* **1996**, *31*, 150−153.

Drawert, F.; Heiman, W.; Emberger, R.; Tressl, R., II. Enzymatische bildung von hexen (2) al (1), hexanal und deren vorstuffen. *Ann. Chem.* **1966**, *694*, 200−208.

Fenaroli, G. *Fenaroli's Handbook of Flavor Ingredients*, CRC Press: Boca Raton, FL, 1990.

Fernandez-Flores, E.; Kline, D. A.; Johnson, A. R. GLC determination of organic acids in fruits as their trimethylsilyl derivatives. *J. Assoc. Off. Anal. Chem.* **1970**, *53*, 17−20.

Fisher-Fleming, B. *Selecting tree fruit cultivars for the Okanagan Industry—Cherry Report, Section 2*; Okanagan Valley Tree Fruit Authority and Agriculture Canada: Summerland, BC, 1993; pp 1−17.

Gao, L.; Mazza, G. Characterization, quantification, and distribution of anthocyanins and colorless phenolics in sweet cherries. *J. Agric. Food Chem.* **1995**, *43*, 343−346.

Mattheis, J. P.; Buchanan, D. A.; Fellman, J. K. Identification of headspace volatile compounds from 'Bing'sweet cherry fruit. *Phytochemistry* **1992**, *31*, 775−777.

Meheriuk, M.; Girard, B.; Moyls, A. L.; Beveridge, H. J. T.; McKenzie, D. L.; Harrison, J.; Weintraub, S. E.; Hocking,

R. Modified atmosphere packaging of Lapins sweet cherry. *Food Res. Int.* **1995**, *28*, 239−244.

Meheriuk, M.; McKenzie, D. L.; Girard, B.; Moyls, A. L.; Weintraub, S. E.; Hocking, R.; Kopp, T. Storage of Sweetheart cherries in sealed plastic film. *J. Food Qual.* **1997**, *20*, 189−198.

Nahrstedt, A. Zur cyanogenese von Prunus avium. *Phytochemistry* **1972**, *11*, 3121−3126.

Paillard, N. The flavor of apples, pears and quinces. In *Food Flavours. Part C. The Flavour of Fruits*; Morton, I. D., MacLeod, A. J., Eds.; Elsevier Science Publishers: Amsterdam, The Netherlands, 1990.

Paillard, N.; Rouri, O. Production de aldéhydes en C_6, hexanal et 2-hexènal, par des tissus de pommes broyés. *Lebensm. Wiss. Technol.* **1984**, *17*, 345−350.

Pruthi, J. S.; Saxena, A. K.; Teotia, M. S. Cherries. I. Agri-horticultural and chemical aspects. *Indian Food Packer* **1980**, *34*, 33−58.

Schmid, W.; Grosch, W. Identification of highly aromatic volatile compounds from cherries *(Prunus cerasus* L.*). Z. Lebensm. Unters. Forsch* **1986a**, *182*, 407−412.

Schmid, W.; Grosch, W. Quantitative analysis of the volatile flavour compounds having high aroma values from sour (*Prunus cerasus* L.) and sweet (*Prunus avium* L.*)* cherry juices and jams. *Z. Lebensm. Unters. Forsch.* **1986b**, *183*, 39−44.

Shaw, P. E.; Wilson III, C. W. Organic acids in orange, grapefruit and cherry juices quantified by high-performance liquid chromatography using neutral resin or polyamine columns. *J. Sci. Food Agric.* **1983**, *34*, 1285−1288.

Singh, B.; Littlefield, N. A.; Salunkhe, D. K. Effects of controlled atmosphere (CA) storage on amino acids, organic acids, sugars, and rate of respiration of Lambert sweet cherry fruit. *J. Am. Soc. Hortic. Sci.* **1970**, *95*, 458−461.

Souty, M.; Reich, M. Effets de traitements technologiques—congélation et appertisation—sur certains constituents de l'arôme des pêches. *Ann. Technol. Agric.* **1978**, *27*, 837−848.

Wang, T.; Gonzalez, A. R.; Gbur, E. E.; Aselage, J. M. Organic acid changes during ripening of processing peaches. *J. Food Sci.* **1993**, *58*, 631−632.

Received for review July 28, 1997. Revised manuscript received November 6, 1997. Accepted November 16, 1997.

JF970646J