

Postharvest Changes in Physicochemical Properties and Volatile Constituents of Apricot (*Prunus armeniaca* L.). Characterization of 28 Cultivars

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To investigate the changes in physicochemical properties and volatile constituents in apricot during postharvest ripening, the volatile compounds of 28 apricot cultivars were investigated by means of liquid–liquid microextraction (LLME), GC-FID, and GC-MS. Fruits picked at their optimal harvestable stage of maturity were analyzed at harvest and after ripening at 20 °C under controlled conditions. Soluble solids (SS), titratable acidity (TA), levels of sugars (saccharose, fructose, and glucose), and organic acids (citric and malic acids) were also determined. Thirty-three volatile compounds, including 6 esters, 5 C₆ compounds, 4 alcohols, 3 carbonyl compounds, 6 terpenic compounds, and 9 lactones, were identified. Changes in the levels of volatiles have been found to increase greatly during postharvest ripening in comparison to the modifications observed for the other physicochemical characteristics. The discrimination of the 28 apricot cultivars into four distinguishable aroma groups was achieved by statistical treatment of the data including ANOVA, principal component, and cluster analyses.

KEYWORDS: Apricot; volatile compounds; aroma; postharvest; ripening

INTRODUCTION

Contrary to what its scientific name suggests, the apricot (*Prunus armeniaca* L.) does not originate from Armenia, but from China, and was introduced in Europe at the beginning of the Roman era (1). Apricots are members of the Rosaceae family, along with peach, pear, strawberry, apple, and cherry. They belong to the subfamily Prunoideae and the subgenus *Prunus* of the genus *Prunus*. Botanically, apricots are drupes or “stone fruits”—like peaches, plums, cherries, and mangoes—in which an outer fleshy part (exocarp and mesocarp) surrounds a hard stone (endocarp) with a seed inside. With a world production of ~2.8 Mt in 2005 (FAOSTAT, 2005), apricot is the third most widely grown stone fruit crop. The production is mainly located in the Mediterranean countries which collectively account for 40% of global production. With ~13% of the world production, Turkey, with a production mainly located in the province of Malatya, is the main producer and provides ~85% of the world’s dried apricot and apricot kernels. The other main Mediterranean producers are Italy (8%), France (6%), Spain (5%), Algeria (4%), Morocco (3%), and Greece (3%). In the United States, apricot production was about 80000 t in 2005 (~3%), over 90% of which was grown in California.

Harvesting apricot at the proper stage of maturity is essential for its quality. Nevertheless, for commercial reasons (handling, long-distance transport, storage, etc.), apricot is generally harvested at a stage of maturity hardly compatible with rapid consumption. This harvestable maturity stage does not neces-

sarily mean that the product has the maturity requirements for an immediate use, but rather that the fruit “has reached a sufficient stage of development that after harvesting and postharvest handling, its quality will be at least the minimum acceptable to the ultimate consumer” (2). Nevertheless, the latter often complains about the low quality of apricot, and two previous surveys have cited the lack of both aroma and sugar in fresh apricots as the main reason for dissatisfaction among consumers (3, 4). However, when they were asked how they kept apricots at home, it appeared that ~20% of them did not allow the fruits to ripen at ambient temperature but rather immediately placed them in the refrigerator (3). The formation of the volatile compounds in fruits is a dynamic process, and generally the typical flavor of most of them is not present at harvest but develops after a ripening process. In contrast to other fruits such as apple, strawberry, or peach, the flavor of apricot, although strong and typical, has hardly been investigated (1, 5–20). If variability in aroma compounds has been reported to depend on cultivars (8, 10, 11, 13, 15), maturity (16), or processing and storage conditions (7, 11, 12, 17), the evolution of apricot volatiles during postharvest maturation has, to our knowledge, not been studied. Given the rather low quality level of the apricots that are available to the consumer, and also because the latter is generally confused by the diversity of the marketed varieties available, the aim of this work was (i) to investigate the changes in physicochemical properties and volatile constituents of 28 apricot cultivars during postharvest ripening under controlled conditions and (ii) to compare the levels of volatiles of the different cultivars in order, initially,

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Table 1. Physicochemical Characteristics of the 28 Apricot Cultivars

no.	cultivar	skin color at harvest ^a	harvest date	days to ripen ^b	firmness (ID ₁₀)		rate of softening (ID ₁₀ per day)	titratable acidity (mequiv/100 g)		soluble solids (%Brix)		saccharose (g/100 g)		glucose (g/100 g)		fructose (g/100 g)		citric acid (g/100 g)		malic acid (g/100 g)	
					UR ^c	R ^d		UR	R	UR	R	UR	R	UR	R	UR	R	UR	R	UR	R
1	Early Blush Rutbhart (cov) ^e	4	May 29	2	68	26	21.0	39.5	38.8	11.3	12.1	5.3	6.0	1.0	1.0	0.1	0.1	0.1	0.1	2.8	2.8
2	Spring Blush EA3126TH (cov)	7	May 29	2	74	37	18.5	26.7	25.1	13.0	13.3	5.6	6.1	2.3	2.2	0.7	0.5	1.5	1.5	0.5	0.5
3	PSB 28-58	7	May 29	2	68	35	16.5	32.5	31.3	11.1	11.7	5.4	5.9	1.2	1.3	0.3	0.2	2.1	2.2	0.4	0.4
4	Earlycot 1	5	May 29	2	63	45	9.0	32.8	30.0	13.1	14.6	7.0	7.7	0.6	0.8	0.1	0.1	1.7	1.8	0.7	0.6
5	Flodea (cov)	8	June 5	3	78	43	11.7	27.4	32.1	12.8	14.3	6.5	6.9	1.0	1.5	0.5	0.5	2.0	2.2	0.6	0.6
6	Sylfred (cov)	7	June 5	3	73	47	8.7	30.8	31.9	13.3	13.8	6.2	6.2	1.5	1.6	0.8	1.0	2.2	2.1	0.5	0.4
7	Soledane (cov)	4	June 5	3	72	43	9.7	29.6	31.7	11.4	12.3	6.0	6.2	0.9	1.0	0.3	0.2	1.6	1.6	0.9	0.8
8	Red Sylver	8	June 9	3	71	45	8.7	21.5	19.5	13.8	14.9	7.0	7.3	1.7	1.7	0.8	0.9	1.2	1.2	0.5	0.5
9	Lilly Cot (cov)	7	June 9	5	81	49	6.4	34.0	35.2	15.1	16.0	9.0	8.9	0.7	1.1	0.1	0.3	2.2	2.4	0.5	0.4
10	Tom Cot Toyaco (cov)	8	June 12	7	72	35	5.3	33.6	30.1	16.7	17.4	7.9	8.4	1.7	2.5	0.9	1.1	1.9	1.8	0.9	0.7
11	Sweet Cot Toyuda (cov)	6	June 12	4	69	36	8.3	30.5	29.1	12.7	14.2	6.3	7.1	1.4	1.6	0.5	0.5	0.6	0.6	1.7	1.6
12	Latica (cov)	8	June 14	5	77	43	6.8	29.5	28.5	11.5	12.1	6.0	6.3	1.1	1.3	0.3	0.3	1.6	1.6	0.6	0.6
13	Perle Cot (cov)	8	June 14	5	81	44	7.4	27.4	24.9	13.6	15.5	7.2	7.7	1.3	2.0	0.7	0.8	0.7	0.8	1.6	1.5
14	Mascot	8	June 14	5	71	46	5.0	29.8	27.2	13.2	15.1	5.9	6.7	1.4	1.8	0.5	0.5	1.4	1.3	0.5	0.4
15	Robada (cov)	7	June 14	5	73	45	5.6	23.9	22.0	11.8	13.2	7.0	8.3	1.6	1.8	0.4	0.4	1.7	1.6	0.4	0.4
16	Orangered Bhart (cov)	7	June 14	5	83	34	9.8	14.4	14.9	11.8	13.3	6.5	7.2	1.5	1.8	0.4	0.5	0.8	0.9	0.4	0.4
17	Goldstrike Toyesi (cov)	6	June 14	5	77	33	8.8	33.0	29.4	13.9	14.3	5.6	6.7	1.6	1.6	0.6	0.6	1.6	1.6	0.9	0.7
18	Bigred	8	June 16	10	79	44	3.5	27.0	25.9	13.8	15.3	7.6	7.6	1.7	2.1	0.5	0.6	1.4	1.5	0.7	0.6
19	Goldfich	7	June 21	5	69	46	4.6	36.0	33.3	12.7	13.2	6.0	5.9	1.4	1.7	0.5	0.6	1.9	1.8	0.9	0.7
20	Flavor Cot Bayoto (cov)	8	June 23	6	76	45	5.2	23.1	24.6	14.4	15.5	7.1	7.1	2.3	2.4	0.7	0.8	0.2	0.3	1.6	1.4
21	Helor	7	June 23	6	75	50	4.2	14.0	17.7	13.3	14.4	5.5	5.5	3.1	3.4	1.0	1.0	1.0	1.0	0.2	0.2
22	Kioto (cov)	8	June 26	7	72	45	3.9	33.3	33.1	12.1	13.8	5.4	6.2	1.6	2.0	0.7	0.8	2.1	2.1	0.4	0.4
23	Hargrand	7	July 3	4	69	40	7.3	19.0	16.8	14.2	15.9	6.7	8.8	1.4	1.5	0.5	0.5	1.0	0.9	0.6	0.6
24	Royal Roussillon	5	July 3	4	71	45	6.5	20.7	20.2	14.0	14.4	4.8	6.2	3.2	2.8	0.8	0.6	1.2	1.3	0.5	0.5
25	Frisson (cov)	4	July 20	3	76	49	9.0	21.5	20.1	15.5	16.2	6.7	7.6	2.9	2.8	0.6	0.6	1.3	1.3	0.7	0.7
26	Bergeron	4	July 20	4	65	54	2.8	22.7	20.7	10.5	10.6	4.8	4.9	1.7	1.6	0.4	0.3	0.4	0.4	1.3	1.4
27	Vertige (cov)	7	July 20	3	67	45	7.3	13.5	14.3	15.3	15.7	8.2	8.1	1.9	1.7	0.7	0.6	0.7	0.8	0.6	0.6
28	Tardif de Tain (cov)	5	July 20	4	67	53	3.5	18.3	16.6	12.0	12.5	5.0	5.6	2.1	2.1	0.5	0.6	0.6	0.6	1.0	0.9

^a According to the Citifi apricot color code. ^b Days to ripen to a firmness of 55 ID₁₀ or less. ^c Unripened apricots. ^d Apricot ripened at 20 °C. ^e (cov), varietal denomination.

Table 2. Concentrations^a of Volatiles in the 28 Apricot Cultivars^b at Harvest and after Ripening

compound	RI ^c	ID ^d	stage ^e	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	
Esters																																
butyl acetate	1075	A	UR	224	—	1	97	16	11	6	—	8	109	110	—	1	103	—	tr ^g	1	tr	6	164	—	2	10	29	2	113	5	14	
			R	1922	—	6	203	54	69	42	—	32	692	307	—	3	880	—	3	333	2	575	2688	—	52	81	208	35	301	74	74	63
3-methylbutyl acetate	1115	A	UR	1	—	1	tr	—	tr	—	1	1	—	1	1	1	1	1	1	1	—	—	1	tr	6	tr	tr	tr	tr	tr	tr	
			R	7	—	1	tr	—	1	—	1	—	1	1	—	1	1	1	1	2	—	—	—	1	3	tr	tr	1	1	2	2	1
pentyl acetate	1152	A	UR	2	—	2	3	—	tr	—	—	1	3	2	—	—	4	—	—	—	—	tr	6	tr	1	1	2	6	8	1	1	
			R	10	—	3	4	—	tr	—	—	1	12	5	—	—	—	—	—	—	—	—	3	47	tr	3	3	7	1	8	3	4
hexyl acetate	1275	A	UR	12	1	1	15	3	tr	6	—	9	35	22	—	—	41	—	tr	1	—	1	73	—	1	5	12	1	56	3	5	
			R	54	2	3	32	5	3	19	—	23	121	63	—	—	139	—	2	4	—	16	578	—	11	48	75	27	73	50	36	
(Z)-3-hexenyl acetate	1321	A	UR	6	1	2	7	2	—	2	—	1	7	4	—	—	11	—	—	—	—	2	3	tr	2	3	2	3	13	3	3	
			R	5	2	2	5	1	—	3	—	1	8	1	—	—	20	—	—	—	—	—	1	5	tr	1	2	6	2	8	2	3
(E)-2-hexenyl acetate	1338	A	UR	10	2	1	1	—	—	—	—	—	—	2	—	—	5	—	—	—	—	—	—	—	—	—	—	1	1	—	3	—
			R	3	2	2	3	—	—	—	—	—	—	1	—	—	3	—	—	—	—	—	—	—	—	—	—	4	1	—	1	—
total			UR	255	4	8	123	21	11	15	1	19	153	142	1	1	164	1	1	3	tr	9	247	1	11	19	47	12	190	14	23	
			R	2002	6	15	246	61	73	65	1	58	833	378	1	4	1054	1	7	338	2	594	3319	4	66	135	300	67	392	132	107	
relative %			UR	27	1	2	19	6	3	5	<1	4	26	26	<1	1	33	1	1	1	<1	7	27	1	15	8	17	6	60	8	18	
			R	58	1	2	36	8	7	10	<1	5	42	34	<1	1	66	<1	1	33	<1	58	68	1	23	27	32	9	46	29	26	
C ₆ Compounds																																
hexanal	1080	A	UR	11	9	15	32	4	5	5	3	—	9	5	—	4	7	2	2	7	2	3	10	—	3	6	2	5	3	5	3	
			R	11	6	23	16	5	4	7	3	—	5	6	—	3	2	2	3	7	2	3	10	—	1	6	3	7	3	4	5	
(E)-2-hexenal	1220	A	UR	123	69	120	283	57	48	75	19	28	84	47	8	61	63	11	9	82	6	12	97	—	—	55	15	76	29	88	29	
			R	133	59	153	130	42	24	58	11	10	47	56	8	18	17	9	13	73	4	7	47	—	—	43	25	117	33	69	38	
hexanol	1355	A	UR	18	6	10	4	3	4	3	3	7	15	6	3	6	6	2	1	6	1	1	22	3	1	3	3	2	5	2	1	
			R	11	6	12	10	3	4	5	5	11	56	14	3	4	16	1	4	2	5	5	174	16	4	11	15	18	13	11	7	
(Z)-3-hexen-1-ol	1386	A	UR	10	4	16	5	8	4	1	2	—	8	2	—	—	4	1	tr	5	—	—	—	—	—	1	tr	2	1	1	1	
			R	4	3	10	3	3	1	1	1	—	4	1	—	—	2	tr	1	1	—	—	—	—	—	—	1	1	3	2	1	2
(E)-2-hexen-1-ol	1409	A	UR	70	12	23	4	5	8	2	2	—	7	5	—	—	3	2	1	13	—	—	—	—	—	1	tr	2	2	1	1	
			R	20	9	21	4	2	4	2	2	—	3	1	—	—	tr	tr	2	1	—	—	—	—	—	tr	1	4	2	1	2	
total			UR	232	100	183	328	77	69	85	29	35	124	66	10	71	83	17	12	113	9	16	129	3	4	67	20	86	40	96	35	
			R	179	83	218	163	55	36	74	22	22	115	78	11	25	38	13	22	84	10	14	232	16	5	62	44	148	53	87	54	
relative %			UR	24	18	45	49	20	21	25	8	7	21	12	4	27	17	10	5	45	7	12	14	2	5	27	7	41	13	55	27	
			R	5	11	23	23	8	4	11	4	2	6	7	2	3	2	3	3	3	8	2	1	5	4	2	12	5	19	6	19	13
Alcohols																																
butanol	1125	A	UR	10	—	1	17	2	6	3	3	4	10	4	1	3	3	tr	1	1	1	1	8	tr	tr	2	1	1	9	1	1	
			R	88	—	2	40	5	23	8	3	6	51	14	4	14	12	1	2	34	9	20	69	28	4	8	5	25	12	7	3	
2-methylbutanol	1208	A	UR	3	—	1	1	—	1	—	—	—	—	—	—	—	—	—	—	tr	—	—	—	—	—	—	—	—	—	—	—	
			R	18	—	1	2	—	3	—	—	—	—	—	—	—	—	—	—	9	—	—	—	—	—	—	—	—	—	—	—	
6-methyl-5-hept-en-2-ol	1575	A	UR	5	5	7	—	7	5	tr	5	5	7	7	7	7	9	5	4	2	2	3	6	3	3	—	—	—	—	—	—	
			R	10	6	7	—	10	8	1	5	5	7	7	9	9	10	6	8	2	5	4	7	3	5	—	—	—	—	—	—	
benzyl alcohol	1880	A	UR	4	2	5	4	—	—	—	4	—	4	—	3	2	5	3	2	5	3	2	16	—	1	10	3	—	—	—	—	
			R	7	5	4	5	—	—	—	3	—	13	—	3	3	12	2	2	4	5	6	17	—	2	3	2	—	—	—	—	
total			UR	22	5	9	18	9	12	3	8	9	17	11	8	10	11	5	5	3	3	4	15	3	4	2	1	1	9	1	1	
			R	123	6	10	42	15	33	9	8	11	58	21	13	22	22	7	9	45	14	25	76	31	9	8	5	25	12	7	3	
relative %			UR	2	1	2	3	2	3	1	2	2	3	2	3	4	2	3	2	1	3	3	2	2	2	5	1	<1	<1	3	1	1
			R	4	1	1	6	2	3	1	1	1	3	2	3	3	1	1	1	4	3	2	2	7	3	2	1	3	1	2	1	
Carbonyl Compounds																																
2-octanone	1287	A	UR	tr	6	6	—	7	6	7	1	6	1	9	7	10	6	6	6	tr	1	tr	9	6	7	7	6	8	9	7	9	
			R	1	6	6	—	8	6	7	2	7	2	11	6	26	6	6	6	tr	2	1	14	7	8	13	12	9	9	8	10	
6-methyl-5-hept-en-2-one	1341	A	UR	6	1	5	1	1	1	1	1	1	1	2	1	1	1	1	1	1	1	tr	1	1	1	2	1	1	—	1	—	
			R	9	10	2	2	3	1	1	1	1	1	1	2	1	1	1	1	1	1	1	2	1	1	5	1	1	—	1	—	
benzaldehyde	1520	A	UR	18	20	11	92	13	12	27	12	9	116	95	13	14	19	11	19	73	20	27	248	13	6	61	77	22	5	16	15	
			R	23	31	6	93	17	12	47	15	15	311	205	22	21	33	38	44	128	29	34	860	17	16	123	96	33	9	25	26	
total			UR	23	27	22	94	22	18	35	14	17	118	106	21	25	26	18	27	74	22	28	258	20	14	70	84	31	14	24	24	
			R	32	47	14	94	28	18	54	18																					

Table 2 (Continued)

compound	RI ^c	ID ^d	stage ^e	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	
Lactones																																
δ-octalactone	1965	A	UR	6	tr	3	–	1	1	tr	2	4	–	–	–	1	–	–	1	1	tr	1	tr	tr	1	–	1	1	tr	–	tr	
				R	30	2	12	–	6	6	7	3	15	–	–	–	6	–	–	4	2	1	4	1	10	tr	–	7	1	tr	–	tr
γ-nonalactone	2028	A	UR	3	–	2	–	–	1	1	2	2	tr	–	–	1	–	tr	1	1	1	tr	tr	1	tr	1	–	–	–	–		
				R	6	–	5	–	–	5	3	4	6	2	–	–	5	–	1	4	3	2	2	1	1	1	tr	3	–	–	–	
γ-decalactone	2144	A	UR	148	28	59	19	89	84	41	52	86	14	18	4	16	7	4	3	4	5	6	12	8	1	10	36	25	19	9	11	
				R	454	105	281	35	178	350	106	182	316	71	115	39	212	56	45	120	125	26	116	82	49	21	27	176	230	134	89	89
γ-jasmolactone	2181	A	UR	17	6	6	3	12	13	11	9	11	4	6	4	7	3	3	2	3	4	3	2	3	1	4	3	3	3	3	2	
				R	52	14	26	5	40	86	45	20	79	36	30	41	66	25	42	35	38	38	22	5	8	14	8	16	12	38	7	12
δ-decalactone	2192	A	UR	43	5	18	4	23	14	4	8	28	2	1	1	8	2	tr	1	1	tr	tr	2	1	tr	tr	6	3	2	1	2	
				R	227	35	131	4	48	69	17	42	81	8	6	2	34	7	3	27	15	3	41	28	20	1	1	37	117	47	24	22
(Z)-7-decen-5-olide	2255	B	UR	2	tr	1	tr	1	1	tr	–	2	–	–	1	3	1	tr	tr	–	tr	tr	tr	tr	–	1	tr	3	2	2	2	
				R	24	1	8	tr	6	9	5	–	13	–	–	1	7	2	2	4	–	2	4	tr	3	–	8	10	7	15	3	4
γ-dodecalactone	2372	A	UR	4	1	2	–	1	1	tr	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	tr	1	tr	tr
				R	13	3	6	–	2	1	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	2
total			UR	300	78	126	44	185	173	114	105	186	60	57	21	60	27	14	15	23	18	20	54	26	7	33	81	56	53	26	32	
				R	993	226	623	84	471	792	377	331	800	506	265	244	528	239	205	314	372	318	292	281	298	129	117	429	466	367	184	190
relative %			UR	32	14	31	7	49	52	34	29	37	10	11	8	23	5	8	7	9	14	15	6	17	9	13	29	26	17	15	24	
				R	29	30	65	12	65	77	55	52	66	26	24	48	70	15	44	45	37	70	29	6	68	44	23	45	60	43	40	47
total			UR	952	567	405	665	376	335	334	367	506	597	535	253	259	499	173	225	253	127	131	916	148	78	246	278	212	318	174	131	
				R	3465	760	954	694	721	1030	680	634	1210	1981	1109	512	753	1588	469	694	1012	458	1022	4911	436	291	501	942	781	860	460	406

^a Values expressed in $\mu\text{g}/\text{kg}$ equivalent of 2-octanol. ^b For code see Table 1. ^c Linear retention index on DB-Wax Etr (J&W Scientific) based on a series of *n*-hydrocarbons. ^d A, identified by mass spectrum and linear retention index of reference compounds; B, tentatively identified by mass spectrum and linear retention index similar to mass libraries or published data. ^e Unripened apricots (UR) and apricots ripened at 20 °C (R). ^f –, not detected. ^g tr, <1 ppb.

to constitute references and databases, which may subsequently allow consumer expectations to be met.

MATERIALS AND METHODS

Solvent and Chemicals. Analytical grade chloroform (Chromasolv Plus, 99.9%) and *n*-propyl gallate ($\geq 98\%$) were, respectively, from Sigma and Fluka (Saint Quentin Fallavier, France). Ammonium sulfate ($(\text{NH}_4)_2\text{SO}_4$ (puriss. p.a., $\geq 99\%$), and *n*-alkane standards (C_8 – C_{40}) were from Riedel-de Haën (Saint Quentin Fallavier, France). Reference compounds were obtained from Sigma-Aldrich (Saint Quentin Fallavier, France) [butyl acetate, 3-methylbutyl acetate, pentyl acetate, hexyl acetate, (Z)-3-hexenyl acetate, (E)-2-hexenyl acetate, hexanal, (E)-2-hexenal, (E)-2-hexen-1-ol, butanol, 2-methylbutanol, 6-methyl-5-hepten-2-ol, benzyl alcohol, 2-octanone, 6-methyl-5-hepten-2-one, benzaldehyde, linalool, β -cyclocitral, α -terpineol, geraniol, γ -octalactone, γ -nonalactone, and γ -decalactone], Interchim (Montluçon, France) (γ -hexalactone, δ -octalactone, δ -decalactone, and γ -dodecalactone), and Fluka [hexanol, (Z)-3-hexen-1-ol, and γ -jasmolactone].

Samples. Apricots (*P. armeniaca* L.) of different maturities, according to their period of production in France, were collected during the 2006 season over a 3-month period during the peak of normal harvest (May–July) in the experimental orchard of the Ctifl (Balandran, Gard, France). Among the main apricot cultivars available in France, 28 were selected (see Table 1). Cultivars 1–4 were very early apricots; cultivars 5–16 were early varieties; cultivars 17–19 were midseason apricots; cultivars 20–24 were full-season varieties; and cultivars 25–28 were late apricots. The stage of maturity was measured by external color and firmness. The harvest date was determined by skin ground color changes from green to orange. Measurements were performed using the Ctifl apricot color chart that provides 10 shades from 1 (green) to 10 (red-orange) (21). The exact yellowish green color at harvest being dependent on the variety, most of them were in accordance with those recommended by professionals. Fruits were hand-picked and immediately transported to the laboratory. For each cultivar, healthy fruits (~ 10 – 15 kg) were immediately selected for their skin color uniformity and size and divided into two batches. Physicochemical measurements and volatile analysis were performed on the fruits at harvest (batch I) and after ripening (batch II). For each cultivar, fruits from batch II were placed in trays and stored in ripening chambers maintained at 20 °C and 60–70% relative humidity until complete maturity (up to 10 days depending on the cultivar, see Table 1). Firmness measurement of 30 fruits, randomly picked in each ripening sample, was performed daily as described below. Maturity was

considered to be complete when the average firmness of the ripened samples was 55 ID₁₀ or less.

Firmness Determination. Firmness was determined on two opposite sides of 30 apricots using an electronic Durofel (licensed by Copac-Tifl) with a 0.10 cm² tip. Durofel is a nondestructive dynamometer that provides a measure of the force used to press a spring-loaded pawl against the fruit surface (22, 23). The measurements are expressed in ID₁₀ on a scale of 0 (very soft) to 100 (very hard).

Chemical Analyses. Thirty apricots from each cultivar were sliced, pitted, and homogenized in a Waring Blendor. Soluble solids (SS) were determined on the purée with an Atago PR-101 digital refractometer. Titratable acidity (TA) was determined by diluting 5 g of the purée with 50 mL of deionized water and titrating to pH 8.1 with 0.1 N NaOH using an automatic titrator Crison Compact II with autosampler. After centrifugation of the purée (14000g, 5 min, 4 °C), the individual sugars (glucose, fructose, and sucrose) and organic acids (malic and citric) were simultaneously determined from 1 mL of supernatant, diluted 20-fold with deionized water, by HPLC as described by Doyon et al. (24). All measurements were performed in triplicate.

Isolation of Volatiles. Thirty apricots from each cultivar were sliced and pitted, and flesh cubes (~ 1 cm³) were prepared. Cubes were then immediately frozen with liquid nitrogen and stored at -25 °C until analysis. Isolation of volatiles was performed according to the liquid–liquid microextraction (LLME) method previously described by Aubert et al. (25) with some modifications. One hundred grams of frozen apricot, 100 mL of *n*-propyl gallate (10 mM), 40 g of $(\text{NH}_4)_2\text{SO}_4$, and 100 μL of 2-octanol (401.3 $\mu\text{g}/\text{mL}$) (internal standard) were homogenized in a Waring Blendor for 90 s. The mixture was centrifuged (14000g, 5 min, 4 °C) and the supernatant filtered through a Whatman paper filter (grade 113v) and centrifuged again (21000g, 5 min, 4 °C). Forty milliliters of supernatant, filtered again through a Whatman paper filter (grade 113v), was introduced into a 50-mL screw-capped conical centrifuge tube (34 \times 98 mm glass borosilicate) containing a magnetic stir bar (15 \times 6 mm). Two hundred and fifty microliters of chloroform was added, and the mixture was extracted for 60 min under magnetic stirring at room temperature. After removal of the magnetic stir bar, the tube was sonicated for 1 min in a Branson Ultrasonic Cleaner 5510 and centrifuged (1000g, 5 min, 4 °C). Chloroform extract was then recovered with a 50 μL syringe, transferred to a 100 μL vial, and immediately injected in GC-MS and GC-FID. Concentrations of volatiles (Table 2) are given as the average of data from three isolations. The average standard deviation was 15.5% for concentrations ranging from 1 to 10 ppb and 7.7% for higher concentrations.

Table 3. One-Way ANOVA Results for Physicochemical Characteristics and Volatile Compounds between Unripened and Ripened Apricots

	unripened		ripened		t_{27}^a	p^b
	mean	range	mean	range		
Physicochemical Characteristics						
firmness (ID ₁₀)	72.8	63.0–83.0	42.9	26.0–54.0	18.65	***
TA (mequiv/100 g)	26.6	13.5–39.5	25.9	14.3–38.8	1.95	
SS (%Brix)	13.1	10.6–16.7	14.1	10.6–17.4	–9.63	***
saccharose (g/100 g)	6.36	4.80–9.04	6.90	4.89–8.92	–5.50	***
glucose (g/100 g)	1.64	0.64–3.19	1.81	0.79–3.44	–3.35	**
fructose (g/100 g)	0.53	0.09–0.95	0.56	0.03–1.05	–1.35	
citric acid (g/100 g)	1.32	0.07–2.19	1.33	0.08–2.40	–1.01	
malic acid (g/100 g)	0.81	0.24–2.80	0.76	0.22–2.82	4.30	***
Volatile Compounds ^c						
butyl acetate	36.9	nd ^d –223.8	308.0	nd–2687.6	–2.53	*
3-methylbutyl acetate	0.7	nd–6.0	1.1	nd–7.5	–1.17	
pentyl acetate	1.5	nd–7.8	4.5	nd–47.0	–1.98	
hexyl acetate	10.8	nd–73.2	49.4	nd–577.8	–2.15	*
(Z)-3-hexenyl acetate	2.7	nd–13.0	2.8	nd–20.1	–0.23	
(E)-2-hexenyl acetate	0.9	nd–9.6	0.6	nd–3.6	0.98	
sum of esters	53.5	0.3–254.7	366.5	0.7–3318.6	–2.52	*
hexanal	5.8	nd–31.9	5.2	nd–23.0	0.82	
(E)-2-hexenal	56.9	nd–283.5	44.5	nd–152.7	1.89	
hexanol	5.2	0.7–22.1	16.0	1.3–174.3	–1.97	
(Z)-3-hexen-1-ol	2.7	nd–15.8	1.6	nd–9.7	2.92	**
(E)-2-hexen-1-ol	5.8	nd–69.9	2.9	nd–21.3	1.61	
sum of C ₆ compounds	76.4	2.6–328.1	70.2	5.3–231.5	0.74	
butanol	3.3	nd–16.9	17.7	nd–87.9	–3.98	***
2-methylbutanol	0.2	nd–2.7	1.2	nd–18.1	–1.57	
6-methyl-5-hepten-2-ol	3.7	nd–8.8	4.8	nd–10.2	–4.00	***
benzyl alcohol	2.8	nd–16.2	3.5	nd–17.1	–1.25	
sum of alcohols	10.1	0.7–30.8	27.1	3.1–123.1	–3.93	***
2-octanone	5.5	nd–10.4	7.1	nd–25.9	–2.67	*
6-methyl-5-hepten-2-one	1.2	nd–5.6	1.8	nd–10.3	–1.70	
benzaldehyde	38.8	5.1–248.1	83.1	5.8–860.5	–1.98	
sum of carbonyl compounds	45.5	13.7–257.9	92.0	13.5–877.2	–2.06	*
linalool	59.0	5.2–225.8	68.0	6.1–255.6	–2.12	*
β -cyclocitral	0.7	nd–3.5	0.7	nd–2.7	0.14	
α -terpineol	16.1	nd–56.1	18.9	nd–62.7	–2.21	*
geraniol	11.0	nd–33.6	12.4	nd–39.1	–1.48	
linalool hydrate	4.5	nd–26.6	4.3	nd–20.5	0.62	
dihydroactinidiolide	14.0	0.5–66.3	17.8	0.9–80.1	–3.62	**
sum of terpenic compounds	105.3	11.8–352.7	122.2	16.2–391.3	–2.48	*
γ -hexalactone	15.6	2.7–38.1	116.2	23.8–336.6	–7.89	***
γ -octalactone	11.6	1.1–41.5	37.2	12.4–79.5	–10.01	***
δ -octalactone	0.9	nd–6.3	4.2	nd–30.2	–3.33	**
γ -nonalactone	0.6	nd–2.9	2.0	nd–6.5	–4.84	***
γ -decalactone	29.2	0.8–148.1	136.7	21.0–453.8	–7.18	***
γ -jasmolactone	5.4	1.3–16.6	30.7	5.3–85.8	–7.06	***
δ -decalactone	6.4	0.1–42.8	39.2	0.9–226.5	–4.18	***
(Z)-7-decen-5-olide	0.8	nd–2.6	5.0	nd–23.9	–4.43	***
γ -dodecalactone	0.7	nd–8.1	1.7	nd–12.9	–2.48	*
sum of lactones	71.1	6.7–300.0	372.9	83.9–992.9	–9.80	***
total	361.9	79.6–952.1	1050.9	292.9–4928.0	–4.51	***

^a t_{27} is the paired Student's *t*-test value. Plus sign means a larger amount in unripened apricots. Minus sign means a larger amount in ripened apricots. ^b *, $p < 0.05$; **, $p < 0.01$; ***, $p < 0.001$. ^c Values expressed in $\mu\text{g}/\text{kg}$ equivalents of 2-octanol. ^d Not detected.

GC-FID Conditions. A Varian 3800 gas chromatograph equipped with a DB-Wax Etr (J&W Scientific) capillary column (30 m \times 0.25 mm i.d., 0.25 μm film thickness) was used. The flow of hydrogen 5.7 (Linde) carrier gas was 1.3 mL/min. The oven temperature was kept at 40 °C for 3 min, then programmed to 250 °C at 5 °C/min, and kept at 250 °C for 15 min. Injections (1 μL) were performed using a 1079 PTV injector from Varian under the following injection program: initially 20 °C for 0.1 min, then programmed to 250 °C at 200 °C/min, and kept at 250 °C. Injections were performed using a CombiPAL autosampler equipped with a Peltier cooling rack at 4 °C (CTC Analytics). The FID detector was kept at 250 °C. The levels of the volatile compounds were expressed as 2-octanol equivalent (assuming all of the response factors were 1). The concentrations are to be considered as relative data because recovery after extraction and calibration factors related to the standard were not determined.

GC-MS Conditions. A Varian 3800 gas chromatograph was used with the same DB-Wax Etr capillary column as above. The oven and

injector temperature programs were as above. Injections (1 μL) were performed using a CombiPAL autosampler (CTC Analytics). The flow of helium 6.0 (Linde) carrier gas was 1 mL/min. A Saturn Ion-Trap mass spectrometer was used. Mass spectra were recorded in electronic impact (EI) ionization mode. The ion trap, the manifold, and the transfer line temperatures were set, respectively, at 150, 45, and 250 °C. Mass spectra were scanned in the range of m/z 30–350 amu at 1 s intervals. Compounds were first identified using NIST/EPA/NIH MS Search 2.0 and our own mass spectra libraries. The identities of most of them were then confirmed by comparison of their linear retention indices and EI mass spectra with those of reference compounds.

HPLC Conditions. A Varian ProStar 230 liquid chromatograph was used with a photodiode area (Varian PDA detector 330) and a refractometer (Varian RI detector 350) connected in series. The PDA was set at 210 nm. Twenty microliters of each sample was injected using a Varian 410 autosampler on a 300 mm \times 7.8 mm i.d. cation-exchange ICsep ICE-ION-300 column equipped with an ICsep ICE-

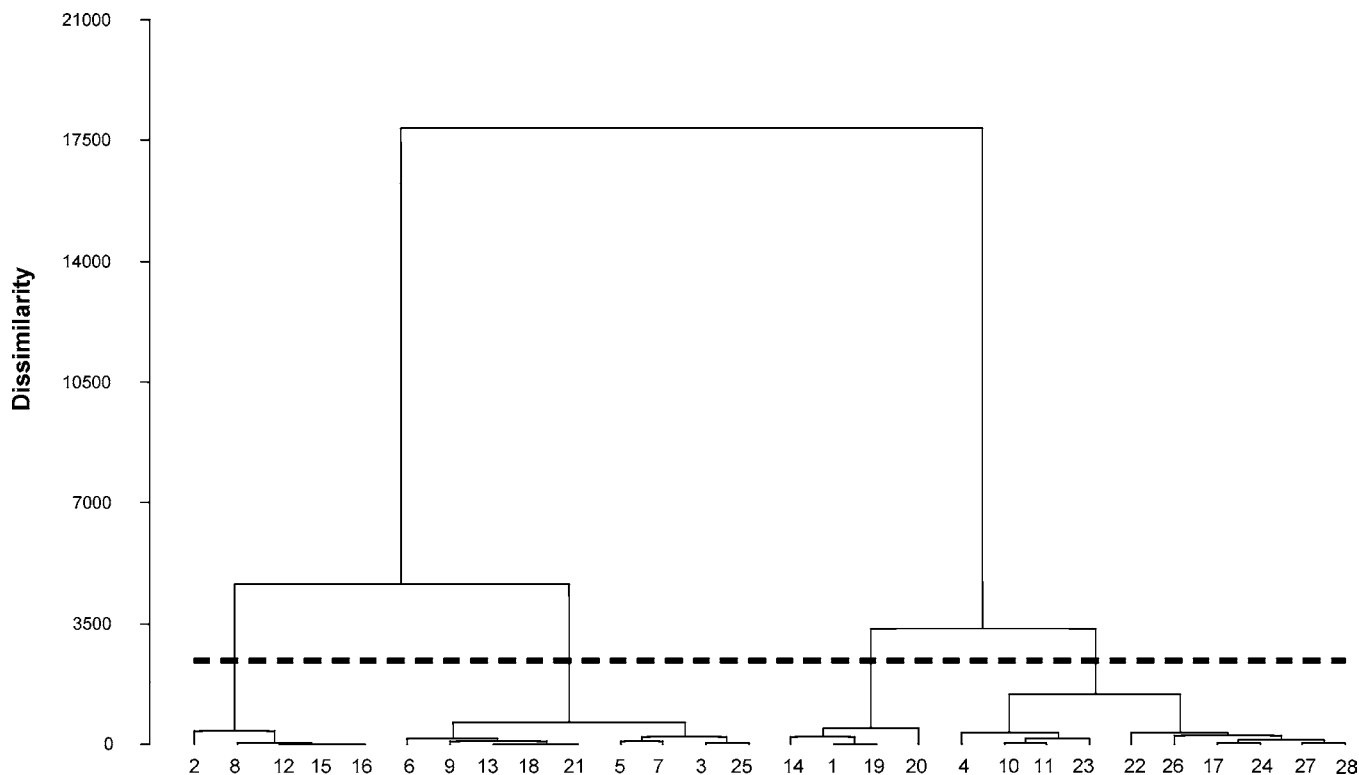


Figure 1. Dendrogram resulting from cluster analysis. The dotted horizontal line separates the main clusters (for cultivar codes see **Table 1**).

GC-801/C guard column (Transgenomic, San Jose, CA). The column oven temperature was set at 30 °C. The flow of mobile phase (0.008 N H₂SO₄) was 0.4 mL/min.

Statistical Analysis. Analyses of variance, principal component analysis (PCA), and ascendant hierarchical classification (AHC) were performed using Statbox 6.7 (Grimmsoft, Paris, France). In the cluster analysis the distances between pairs of samples were compared on the basis of the squared Euclidean distance. The resulting clusters were then connected using Ward's method, which merges the two clusters for which the total sum-of-square error is smallest (26).

RESULTS AND DISCUSSION

The effects of postharvest ripening on the physicochemical characteristics and volatile constituents of 28 apricot cultivars of different maturities were investigated during the 2006 season. Fruits were picked at their "optimal harvestable" stage of maturity as advised by the professional organizations (21) and ripened at 20 °C and 60–70% relative humidity until complete maturity. Maturity was considered to be complete when the firmness of the fruit was 55 ID₁₀ or less, that is, when the apricot is "ready-to-eat". Firmness, SS, TA, organic acids (malic and citric acids), sugars (glucose, fructose, and saccharose), and the levels of the main volatiles were determined at harvest and after ripening. Thirty-three volatile compounds, including 6 esters, 5 C₆ compounds, 4 alcohols, 3 carbonyl compounds, 6 terpenic compounds, and 9 lactones, were extracted by LLME (25) and analyzed by GC-FID and GC-MS. The effects of postharvest ripening on the physicochemical characteristics and volatile compounds of the 28 apricot cultivars are summarized in **Tables 1** and **2**. A one-way analysis of variance, using the paired Student's *t* test, was performed to determine the effect of ripening on the physicochemical characteristics and the levels of volatile compounds (**Table 3**). The discrimination of the 28 cultivars after ripening in four groups, based on the relative abundances (percent) of the main volatile classes, was performed by cluster and principal component analyses (**Figures 1** and

2). Finally, **Table 4** shows the results of the one-way analysis of variance using the GLM procedure and the Newman–Keuls test (SNK) performed on the levels of volatiles in the four different groups of apricots after ripening.

Changes during Ripening. As indicated in **Table 1**, the skin color at harvest was greatly different according to the cultivar, from yellow-green (color grade 4) for Early Blush (1), Soledane (7), Frisson (25), and Bergeron (26) to orange (color grade 8) for Flodea (5), Red Sylver (8), Tom Cot (10), Latica (12), Perle Cot (13), Mascot (14), Bigred (18), Flavor Cot (20), and Kioto (22). As indicated in **Tables 1** and **3** the most significant change in physicochemical characteristics due to postharvest ripening at 20 °C was a decrease in firmness. Ripening softened the fruit to a mean firmness of 43 ID₁₀, whereas the mean firmness at harvest was 73 ID₁₀. The average time for the apricots to ripen was 4 days at 20 °C; nevertheless, the rate of fruit ripening varies considerably among cultivars. As indicated in **Table 1**, Early Blush (1), Spring Blush (2), and PSB 28-58 (3) required only 2 days to ripen at 20 °C and have a high rate of softening (loss of firmness higher than 15 ID₁₀ per day), whereas Bigred (18), Goldrich (19), Helor (21), Kioto (22), Bergeron (26), and Tardif de Tain (28) required up to 10 days and have a low rate of softening (loss of firmness lower than 5 ID₁₀ per day). No significant correlation has been observed between the skin color at harvest and the number of days to ripen ($r^2 = 0.2381$). As for other physicochemical characteristics, although some results were statistically different between unripened and ripened samples (**Table 3**), the changes were relatively small and the levels in samples after ripening were found to be similar overall to those observed at harvest (**Table 1**).

As indicated in **Table 2**, the total volatile contents generally highly increased with ripening. Except for Earlycot 1 (4), the levels of total volatiles in ripened samples were ~1.4–8-fold higher than those observed in unripened apricots. As shown in **Table 3**, the results obtained from the analysis of variance and

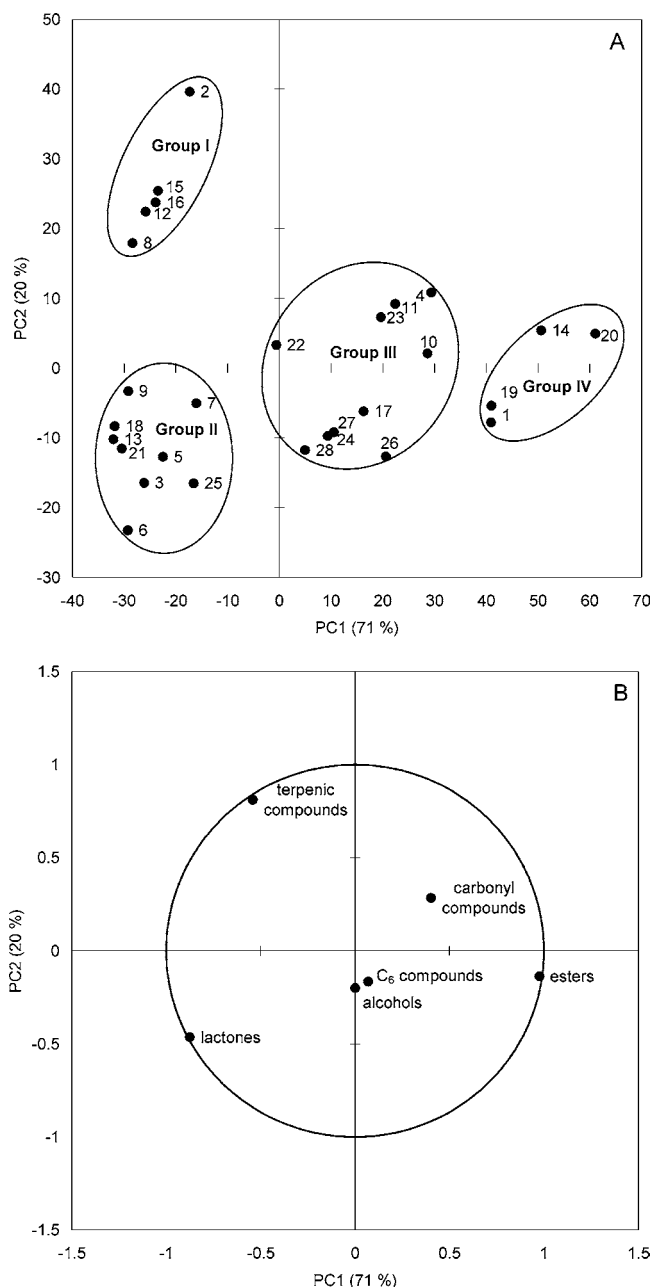


Figure 2. Results from PCA analysis: (A) projection of the samples (for cultivar codes see Table 1); (B) factor loadings of variables.

the values of the paired Student's *t* test demonstrate that the concentrations of volatiles vary considerably with postharvest maturation. A significant difference was observed, at the 0.05 level, for 18 of the 33 compounds. Except for (*Z*)-3-hexen-1-ol, all of these compounds are present in higher quantities in ripened samples. Among them, the most discriminating compounds were lactones and, more particularly, γ -octalactone, γ -hexalactone, γ -decalactone, γ -jasmolactone, γ -nonalactone, (*Z*)-7-decen-5-olide, and δ -decalactone ($p < 0.001$). These compounds, previously reported to be important impact compounds in stone fruits (27–30), have been shown to be responsible for the fruity background aroma of apricot (6, 8, 9) as in cling peach (31). As reported in Table 2, in all cultivars the levels of lactones greatly increased with ripening, those of γ -C₆, γ -C₈, γ -C₁₀, γ -jasmolactone, and δ -C₁₀, which were generally the predominant lactones, showing 1–45-fold increases of their levels in ripened samples compared to those observed in unripened apricots. Among other discriminating

compounds (Table 3), butyl and hexyl acetates have been previously described in this fruit as banana-like, nail polish, and solvent, whereas linalool and α -terpineol have been previously described to be responsible for the flowery note of apricot (6, 8, 9). As indicated in Table 2, levels of esters, and more particularly those of butyl and hexyl acetates, which were the predominant esters, greatly increased with ripening. The same trend was observed for terpenols, except in Sweet Cot (11), Flavor Cot (20), Helor (21), Hargrand (23), and Tardif de Tain (28) for which the levels of linalool and α -terpineol were generally found to be significantly lower in ripened samples. Finally, although one-way ANOVA indicated no significant difference, examination of individual data shows that the levels of benzaldehyde, which had been previously described to be responsible for secondary notes such as bitter almond in apricot aroma (9), generally increased during ripening, in particular in Flavor Cot (20), Tom Cot (10), Sweet Cot (11), Hargrand (23), and Goldstrike (17) (Table 2).

Differentiation of Ripened Apricot Cultivars. As indicated in Table 1, the levels of TA in Early Blush (1), Lilly Cot (9), Goldrich (19), Kioto (22), and Flodea (5) after ripening were found to be generally ~2–3-fold higher than those observed in Helor (21), Hargrand (23), Tardif de Tain (28), Orangered (16), and Vertige (27). Similarly, the levels of SS in Tom Cot (10), Lilly Cot (9), Frisson (25), Hargrand (23), and Vertige (27) were ~30–60% higher than those observed in Bergeron (26), PSB 28-58 (3), Latica (12), Early Blush (1), and Soledane (7). The results also indicated that saccharose was the main sugar in all cultivars and accounted for ~60–90% of the total sugars, followed by glucose and fructose, which represented, respectively, ~10–30 and ~1–10%. Finally, citric acid was found to be predominant in most cultivars, ranging from ~60 to 90% of the total acids, excepted in Tardif de Tain (28), Perle Cot (13), Sweet Cot (11), Bergeron (26), Flavor Cot (20), and Early Blush (1), in which malic acid was the main organic acid (up to 97% of the total acids).

As seen in Table 2, the total contents of volatile compounds in the 28 cultivars after ripening ranged between <500 ppb in Robada (15), Bigred (18), Vertige (27), Helor (21), Tardif de Tain (28), and Kioto (22) and up to ~5 ppm in Flavor Cot (20). As indicated in Table 2, esters, terpenic compounds, and lactones were qualitatively and quantitatively predominant, accounting for ~60–95% of the total volatiles quantified. As mentioned above, these compounds have been previously reported to be important compounds in apricot aroma, and among them, butyl acetate, hexyl acetate, linalool, α -terpineol, γ -hexalactone, and γ - and δ -decalactone were the main components in our samples. Nevertheless, their distributions within the 28 apricot cultivars were greatly different. Butyl acetate accounted for ~55% of the total volatiles quantified in Early Blush (1), Mascot (14), Goldrich (19), and Flavor Cot (20), whereas linalool made up ~30% in Spring Blush (2) or in Orangered (16). Among lactones, γ -hexalactone represented ~40–50% in Bigred (18) and Helor (21), whereas the levels of γ -decalactone were about 30% in PSB 28-58 (3), Sylred (6), Red Sylver (8), Perle Cot (13), or Frisson (25). To discriminate the varieties according to their main classes of volatile compounds, an AHC and a PCA were performed using the 28 cultivars and the relative proportions of the main classes of volatiles given in Table 2. A dendrogram obtained by cluster analysis, using the squared Euclidean distance and Ward's method, is shown in Figure 1, and four different groups were observed: group I, Spring Blush (2), Red Sylver (8), Latica (12), Robada (15), and Orangered (16); group II, PSB 28-58

Table 4. Concentrations (Micrograms per Kilogram Equivalents of 2-Octanol) of Volatile Compounds in the Four Different Groups^a of Apricots Resulting from PCA and AHC

compound	F ^b	p ^c	group I		group II		group III		group IV	
			mean	range	mean	range	mean	range	mean	range
butyl acetate	59.4	***	0.6 a	0–3.3	27.1 a	0–70.9	231.3 b	50.5–713.6	1516.2 c	570.1–2756.0
3-methylbutyl acetate	5.9	***	0.7 a	0–1.4	0.8 a	0–3.5	0.9 a	0–2.1	2.5 b	0–7.7
pentyl acetate	18.6	***	nd ^d		0.7 a	0–4.9	4.8 b	0–12.5	17.6 c	2.4–51.7
hexyl acetate	14.2	***	0.9 a	0–2.7	8.9 a	0–27.6	51.2 a	4.1–131.8	196.9 b	15.7–615.6
(Z)-3-hexenyl acetate	13.6	***	0.4 a	0–2.2	1.0 a	0–3.4	3.8 b	0–8.9	7.6 c	0.9–20.2
(E)-2-hexenyl acetate	3.8	*	0.4 a	0–2	0.3 a	0–1.8	0.8 ab	0–3.6	1.4 b	0–2.9
sum of esters	51.4	***	3.1 a	0.6–6.6	38.8 a	1.5–74.6	292.8 b	66.2–856.3	1742.2 c	590.1–3378.4
hexanal	1.6		2.8	0–6.6	5.5	0–23.1	5.6	0.9–16.1	6.4	2.2–11.5
(E)-2-hexenal	2.1		20.3	7.9–60	47.3	0–153.7	51.5	0–130.9	51.0	6.7–134.2
hexanol	7.5	***	3.8 a	1.2–6.6	8.7 a	2.4–18	14.4 a	1.9–56.8	51.8 b	4.8–185.7
(Z)-3-hexen-1-ol	0.9		1.0	0–2.7	2.0	0–9.8	1.6	0–4.0	1.4	0–3.9
(E)-2-hexen-1-ol	1.6		2.5	0–9.1	3.6	0–21.7	1.5	0–3.7	5.0	0–19.9
sum of C ₆ compounds	4.7	**	30.3 a	10.7–84.5	67.2 ab	10.1–219.5	74.7 ab	4.9–163.8	115.6 b	14–239.2
butanol	17.3	***	2.0 a	0–4.1	13.1 b	1.8–28.3	17.8 b	3–51.8	47.4 c	12.3–89.7
2-methylbutanol	4.6	**	nd		0.5 a	0–3.3	1.1 a	0–9.3	4.5 b	0–18.5
6-methyl-5-hepten-2-ol	16.4	***	6.7 b	5.2–9.5	5.3 b	0–10.3	2.1 a	0–7.4	7.8 b	4.3–10.1
benzyl alcohol	25.3	***	3.0 a	1.6–6	1.3 a	0–6.2	2.8 a	0–13.0	10.7 b	5.0–20.9
sum of alcohols	20.7	***	11.7 a	8.5–18.0	20.1 a	8.5–33.9	23.8 a	3.0–71.2	70.3 b	29.9–126.2
2-octanone	1.7		5.2	1.2–6.8	8.6	1.4–26.6	7.4	0–13.2	5.7	0.4–16.7
6-methyl-5-hepten-2-one	2.6		2.9	0.8–12.9	1.3	0.6–2.9	1.2	0–5.1	3.1	0.6–8.7
benzaldehyde	6.5	***	30.1 a	14.8–44.8	21.7 a	5.7–47.3	103.1 a	8.7–315.4	237.5 b	22.3–877.2
sum of carbonyl compounds	6.35	***	38.2 a	17.4–52.6	31.5 a	13.2–55.1	111.7 a	17.6–318.4	246.3 b	31.2–896.2
linalool	36.2	***	159.3 c	105.8–258.9	61.1 b	20.9–193.2	30.2 a	5.7–85.2	63.7 b	31.7–81.7
β-cyclocitral	8.3	***	1.2 b	0–2.2	0.5 a	0–1.6	0.4 a	0–3.0	1.5 b	0.7–2.7
α-terpineol	28.2	***	40.6 c	27.5–65.3	17.8 b	5.8–53.4	9.3 a	0–27.8	18.4 b	8.6–23.6
geraniol	19.2	***	25.1 b	14.5–40.8	11.7 a	0–31.8	8.0 a	0–20.2	9.3 a	0–17.6
linalool hydrate	43.3	***	13.2 b	5.9–22.7	3.6 a	0–13.8	1.1 a	0–6.3	2.7 a	0–9.5
dihydroactinidiolide	7.8	***	30.0 b	9.1–87.7	10.1 a	0.8–28.6	12.2 a	1.2–54.8	34.1 b	8.3–84.5
sum of terpenic compounds	38.5	***	269.4 c	197.5–401.5	104.6 b	30.0–300.5	61.3 a	11.4–164.9	129.7 b	59–198.5
γ-hexalactone	6.7	***	84.1 a	44.8–141	161.4 b	49.5–228.9	97.8 a	22.9–341.3	100.9 a	64.5–134.7
γ-octalactone	5.8	**	23.4 a	12.1–30.8	43.5 b	16.3–70.0	34.4 ab	10.4–70.5	47.3 b	16.3–82.8
δ-octalactone	8.5	***	1.8 a	0–4.5	7.1 b	0.5–16.8	1.0 a	0–8.2	8.7 b	0–31.7
γ-nonolactone	4.9	**	1.9 ab	0–4.4	2.9 b	0–6.5	1.0 a	0–3.7	2.3 ab	0–6.4
γ-decalactone	6.7	***	98.3 a	26.8–192.4	194.2 b	23.6–374.9	88.2 a	17.6–254.2	176.9 ab	23.4–481.3
γ-jasmolactone	7.4	***	30.5 a	13.2–51.5	44.5 b	4.7–88.9	20.4 a	3.0–70.6	26.0 a	2.8–56.1
δ-decalactone	7.3	***	21.8 a	1.1–45.9	57.9 b	2.4–179.9	16.6 a	0.7–95.3	75.6 b	4.3–242.1
(Z)-decen-5-olide	3.7	*	1.7 a	0–4.5	6.6 b	1.4–13.4	4.0 ab	0–28.6	7.6 b	0–25.6
γ-dodecalactone	8.5	***	0.7 a	0–4.6	1.3 a	0–6.8	0.8 a	0–13.4	5.8 b	0–15.0
sum of lactones	11.0	***	264.1 a	196.1–347.2	519.3 b	236.4–817.9	264.2 a	82.0–614.7	451.2 b	157.6–1051.5
total	29.5	***	616.9 a	461.1–784.1	781.6 a	368.5–1234.1	828.4 a	273.3–2006.6	2755.3 b	994.4–5001.3

^a Group I, cultivars 2, 8, 12, 15, and 16; group II, cultivars 3, 5–7, 9, 13, 18, 21, and 25; group III, cultivars 4, 10, 11, 17, 22–24, and 26–28; group IV, cultivars 1, 14, 19, and 20. Values with different letters are significantly different. ^b $F_{(0.05; 3; 80)} = 2.72$; $F_{(0.01; 3; 80)} = 4.04$; $F_{(0.001; 3; 80)} = 5.97$. ^c *, $p < 0.05$; **, $p < 0.01$; ***, $p < 0.001$. ^d Not determined.

(3), Flodea (5), Sylred (6), Soledane (7), Lilly Cot (9), Perle Cot (13), Bigred (18), Helor (21), and Frisson (25); group III, Earlycot 1 (4), Tom Cot (10), Sweet Cot (11), Goldstrike (17), Kioto (22), Hargrand (23), Royal Roussillon (24), Bergeron (26), Vertige (27), and Tardif de Tain (28); and group IV, Early Blush (1), Mascot (14), Goldrich (19), and Flavor Cot (20).

As shown in **Figure 2A**, 91% of the total variance was explained by the two first principal components (PCs), and four different groups, analogous to those previously obtained by AHC, were observed. As indicated, PC1 (71% of the variance explained) mainly discriminates the cultivars of group IV from those of groups I and II, whereas PC2 (20% of the variance explained) mainly discriminates cultivars of group I from the others. As indicated in **Figure 2B**, cultivars of group IV, positively correlated with the first PC, are mainly characterized by high proportions of esters, whereas those of groups I and II are defined, respectively, by high proportions of terpenic compounds and lactones. With regard to cultivars of group III they are both defined by high proportions of lactones and esters.

Finally, to determine significant differences between the four different groups after ripening, levels of volatiles were also analyzed by one-way analysis of variance using the GLM

procedure and the Newman–Keuls test (SNK) (**Table 4**). The data are given as average and minimum–maximum range. The F test and the p value of the ANOVA are also given. As shown in **Table 4**, previous observations from PCA and AHC were confirmed by analysis of variance. The levels of terpenic compounds were significantly higher in cultivars of group I and, more particularly, those of linalool, α-terpineol, and geraniol. Group I is also characterized by relatively high levels of lactones, but the highest amounts of these compounds were observed in cultivars of groups II and IV, in particular those of γ-C₆, C₈, C₁₀, and δ-C₁₀. Levels of esters, mainly those of butyl and hexyl acetates, were found to be significantly higher in cultivars of group IV than in other cultivars. Finally, cultivars of group III are both characterized by relatively high levels of both esters and lactones.

In this study, a great number of data have been obtained on the physicochemical properties and volatile constituents of 28 apricot cultivars. Results have shown that the levels of volatiles increase greatly during postharvest ripening in comparison to the modifications observed for the other physicochemical characteristics. They also have shown that large qualitative and quantitative differences could be observed between the 28

cultivars, particularly for compounds which contribute most to the apricot aroma such as terpenic compounds, esters, and lactones. Nevertheless, although the results have demonstrated that the 28 apricot cultivars could be discriminated into four different aroma groups, it would be particularly relevant, in further investigations, to characterize these cultivars from a sensory point of view (descriptive analyses, consumer preferences) and to identify the genetic components involved in the quality of these fruits to facilitate breeding of new cultivars meeting the consumer's expectations.

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