Volatile Compounds in Apricot, Plum, and Their Interspecific Hybrids

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The volatile components of fresh, tree-ripened apricots (*Prunus armeniaca* L.), plums (*Prunus salicina* Lindl.), and their interspecific hybrids were isolated by simultaneous distillation extraction and analyzed by gas chromatography–mass spectrometry. The study of the aromatic profiles of the parents (apricot and plum) and the progenies (plum × apricot) demonstrated that the progeny retained the ability to produce volatile compounds typical of the parents and that components important to the aromas and flavors of the parents were produced at high levels.

INTRODUCTION

Many producers of agricultural commodities try to improve their operational efficiency or develop niche markets to enhance profits. Methods employed by some tree fruit growers include trying new cultivars or fruit types before they gain general popularity. In the San Joaquin Valley of California, introduced crops such as kiwi, pistachio, and Asian pear have rewarded speculative growers during the past decades. Currently, there is commercial interest in hybrids between apricot (*Prunus armeniaca* L.) and Japanese plum (*Prunus salicina* Lindl.). Acreage is small, at present, due mainly to a lack of fertile cultivars and specific knowledge about their culture.

The Agricultural Research Service's Horticultural Crops Research Laboratory in Fresno, CA, began the development of plum–apricot hybrids during 1989. With these hybrids, we hope to provide consumers with new fruit types. The hybrids are commonly known as "plumcots" and vary widely with regard to skin and flesh color, fruit size and shape, ripening period, and flesh texture and flavor. We are trying to identify those types having flesh texture characteristics similar to those of Japanese plum and aroma/flavor characteristics resembling those of apricot. Since apricots are used as the male parent in these hybrids, we are interested in the paternal transmission of genetic information necessary for the synthesis of apricot flavor constituents.

The first significant studies on apricot flavor were performed by Tang and Jennings (1967, 1968), who utilized direct extraction, vacuum steam distillation, and charcoal adsorption to isolate the volatiles. In contrast to apricots and other types of *Prunus*, less work has been done about the aroma and flavor of plums. The first reported study of plum volatiles was carried out by Forrey and Flath (1974).

In this paper we studied the aromatic profile of three apricot selections (K604-19, K33-81, K113-40), two Japanese plum cultivars (Blackamber and Friar), and seven progenies resulting from the hybridization of these apricots and plums. Apricot selections were chosen on the basis of their genetic diversity. K604-19, a small early-fruiting type, is characterized by an intense aroma when tree-ripe. K33-81 and K113-40, although not known for their aromatic attributes, were used in hybridizations for their firm flesh and large fruit size, respectively. Simultaneous distillation/extraction has been used to isolate the volatile compounds, and the different profiles have been studied to see whether profiles of the hybrids resembled those of an apricot, a plum, or a combination of both.

MATERIALS AND METHODS

Fresh, tree-ripened apricots, plums, and plumcots were collected and stored at −18 °C until analysis. The volatile constituents were isolated using simultaneous vacuum distillation/extraction.

Fruits were cut in half, and the stones were removed and discarded. The skin and pulp (500 g) were blended with 1.5 L of HPLC grade water for 30 s. 3-Nonanone was used as an internal standard. The mixture was added to a 5-L round-bottom flask.

A modified Likens–Nickerson distillation/extraction head was used (Schultz *et al.*, 1977; Takeoka *et al.*, 1990). The fruit slurry was subjected to distillation/extraction (60 mmHg) for 3 h with 60 mL of pesticide grade hexane.

Residual water was removed by freezing the hexane sample at −40 °C. The hexane extract was then concentrated with a Vigreux column (15 cm) under reduced pressure (200 mmHg) to a final volume of 0.3–0.4 mL.

The concentrated extract was injected into a Hewlett-Packard 5890 gas chromatograph (Hewlett-Packard, Avondale, PA). Separations were performed using a DB-5 MS column (30 m × 0.25 mm, J&W Scientific, Folsom, CA) and a DB-Wax column (60 m × 0.25 mm; J&W Scientific). The oven temperature was programed from 50 °C to 250 °C (4 °C/min). Helium was used as carrier gas at linear velocities of 30 and 60 cm/s, respectively. The injector was maintained at 200 °C. The temperature of the detector (Hewlett-Packard 5971A mass-selective detector) was 170 °C. The spectra were recorded at an ionization voltage of 70 eV, with a speed of 2.1 scan/s over the mass range m/z 20–260. Data processing was performed with a Hewlett-Packard 5895 GC ChemStation.

Sample components were tentatively identified by mass spectrum matching with a mass spectral library collection. The tentative MS identifications were verified by comparison of the component's experimental retention index with that of reference standards. The retention index system proposed by Kovats (1965) was used.

RESULTS AND DISCUSSION

Table I presents the volatile constituents identified in apricots and plums. The quantification of the compounds has to be considered approximate because the response factors of all the compounds have not been calculated and all of the responses are considered the same as that of the internal standard, 3-nonanone. Also, we need to point out that this was the first year the plumcot trees fruited, and there was not enough fruit in some trees to be replicated. Therefore, the recoveries are also considered to be constant.

Compared with plums and plumcots, the apricots yielded the highest number of identified volatile compounds.

The number and quantity of identified esters were not large and were lower than when other isolation methods

Table I. Concentration of Volatile Compounds (Micrograms per Kilogram of Fresh Fruit Tissue) in the Three Apricots Used as Male Parents and the Two Plums Used as Female Parents

constituent	apricots			plums		KI[d]	ID[e]
	K604-19	K113-40	K33-81	Blackamber	Friar		
3-hexanone[a]	2[b]	1	1	2	0	784	MS, KI
2-hexanone	3	2	2	2	1	789	MS, KI
1-methylcyclopentanol	1	1	1	1	–	796	MS
hexanal	9	5	8	19	6	802	MS, KI
butyl acetate	–[c]	–	1	1	1	813	MS, KI
2,3-dimethyl-2-pentene	13	5	3	10	–	847	MS
(*E*)-2-hexenal	–	–	–	–	12	848	MS, KI
(*Z*)-3-hexen-1-ol	–	–	–	13	13	849	MS, KI
(*E*)-2-hexen-1-ol	4	–	–	2	5	858	MS, KI
2-propylfuran	2	–	–	–	–	861	MS, KI
hexanol	–	–	4	33	12	862	MS, KI
1,4-dimethylbenzene	–	–	1	2	1	865	MS
styrene	–	–	–	2	–	889	MS, KI
1,3,5-cyclooctatriene	–	–	–	–	–	890	MS
heptanal	3	1	1	2	1	898	MS, KI
(*E*)-2-heptenal	–	1	2	–	0	953	MS, KI
5-ethyl-2(*H*)-furanone	2	–	–	–	–	954	MS
2,4-dimethyl-2-decene	–	–	–	–	2	955	MS
9-methyl-5-undecene	–	–	–	–	1	957	MS
6-methyl-5-hepten-2-one	105	10	15	–	–	984	MS, KI
β-pinene	3	3	–	2	–	990	MS, KI
1,2,3-trimethylbenzene	–	–	–	2	2	996	MS, KI
(*E*,*E*)-2,4-heptadienal	13	–	–	3	–	998	MS
(*Z*)-3-hexenyl acetate	–	–	–	16	3	1005	MS, KI
hexyl acetate	–	–	4	43	2	1010	MS, KI
(*E*)-2-hexenyl acetate	–	5	–	6	1	1014	MS, KI
2,2,8-trimethyldecane	–	–	–	2	1	1022	MS
m-cymene	2	1	1	–	–	1026	MS, KI
2-ethylhexanol	–	–	1	4	1	1028	MS, KI
limonene	13	6	5	6	1	1031	MS, KI
2,5-dimethyl-2-undecene	–	2	–	3	1	1033	MS
2,2,6-trimethylcyclohexanone	12	–	9	–	–	1036	MS
phenylacetaldehyde	86	26	6	28	1	1045	MS, KI
citral methyl acetal	1	–	–	3	–	1051	MS
2,2,5,5-tetramethylhexane	–	1	–	–	–	1052	MS
isophorone	17	4	11	–	1	1059	MS, KI
3,8-dimethylundecane	–	–	–	1	1	1063	MS
acetophenone	–	–	–	2	–	1065	MS, KI
3-tetradecene	–	–	–	–	1	1072	MS
linalool	671	365	150	18	8	1104	MS, KI
nonanal	–	8	–	51	14	1105	MS, KI
2,5-dimethylphenol	–	–	33	–	–	1108	MS, KI
2,6-dimethylcyclohexanol	31	3	7	–	–	1112	MS
3,5,5-trimethyl-2-cyclohexen-1-ol	4	–	–	–	–	1147	MS
2-ethylcyclohexanone	28	4	17	–	–	1158	MS
2-undecenal	–	2	6	5	1	1159	MS
4-terpinenol	6	2	2	–	–	1182	MS, KI
(*Z*)-3-hexenyl butanoate	–	–	–	–	1	1183	MS, KI
naphthalene	6	1	1	5	1	1186	MS, KI
(*E*)-2-hexenyl butanoate	–	–	5	11	–	1191	MS, KI
ethyl octanoate	–	–	–	5	–	1196	MS, KI
α-terpineol	–	60	32	–	1	1199	MS, KI
tetradecanal	3	2	3	2	1	1207	MS
2,3,5-trimethyl-1,4-benzenediol	–	17	–	–	–	1210	MS
4-acetyl-1,2,3,5,5-pentamethyl-2-cyclopenten-1-one	–	–	65	–	–	1216	MS
β-cyclocitral	–	–	–	–	1	1219	MS, KI
geraniol	102	9	7	–	–	1221	MS, KI
2-oxo-1-methyl-3-isopropylpyrazine	29	–	–	–	–	1225	MS
isoborneol	–	–	–	4	–	1234	MS
nerol	73	21	11	1	1	1251	MS, KI
γ-octalactone	35	–	–	–	–	1255	MS, KI
geranial	25	2	3	–	–	1268	MS, KI
bornyl acetate	–	5	4	6	1	1287	MS, KI
(*E*,*E*)-2,4-decadienal	7	1	4	–	–	1295	MS, KI
nepetalactone	8	–	–	–	–	1306	MS
1,2,3,4-tetrahydro-1,5,7-trimethylnaphthalene	–	–	29	–	–	1310	MS
1-methyl-4-(methylthio)benzene	4	–	10	–	–	1316	MS
(*E*,*Z*)-2,4-decadienal	8	2	–	5	–	1319	MS
megastigma-4,6(*Z*),8(*Z*)-triene	–	2	–	–	–	1324	MS
1,2,3,4-tetrahydro-1,1,6-trimethylnaphthalene	2	2	32	–	–	1349	MS
megastigma-4,6(*E*),8(*Z*)-triene	–	4	–	–	–	1354	MS
2,3-dihydro-1,1,4,5-tetramethyl-1*H*-indene	4	–	3	–	–	1355	MS
γ-nonalactone	5	–	–	–	–	1360	MS, KI
2-ethyl-3-hydroxyhexyl 2-methylpropanoate	3	–	2	–	–	1373	MS
geranyl acetate	–	–	4	–	–	1377	MS, KI

Table I. (Continued)

constituent	apricots			plums		KI[d]	ID[e]
	K604-19	K113-40	K33-81	Blackamber	Friar		
(*Z*)-3-hexenyl hexanoate	–	–	–	14	9	1379	MS, KI
1,1′-biphenyl	15	2	–	–	–	1381	MS
2-ethyl-1,4-dimethylbenzene	62	–	143	–	–	1411	MS
α-ionone	10	–	–	–	–	1422	MS
dihydro-β-ionone	3	8	5.7	–	0	1433	MS, KI
geranylacetone	361	14	59	5	1	1449	MS, KI
2,6-bis(1,1-dimethylethyl)-2,5-cyclohexadiene-1,4-dione	6	3	3	5	–	1462	MS
γ-decalactone	1424	3	50	3	–	1476	MS, KI
β-ionone	437	61	152	8	3	1482	MS, KI
δ-decalactone	36	–	–	–	–	1493	MS, KI
BHT	85	11	7	40	1	1504	MS
pseudoionone	13	–	3	–	–	1527	MS
dihydroactinidiolide	32	0	5	–	–	1561	MS, KI
nerolidol	–	–	–	–	1	1562	MS
(*E*,*E*)-pseudoionone	24	1	2	–	–	1581	MS
diethyl phthalate	16	2	6	4	1	1585	MS
1,1-diphenylhydrazine	3	–	–	–	–	1623	MS
γ-undecalactone	9	–	–	–	–	1656	MS, KI
γ-dodecalactone	1502	3	46	16	5	1681	MS, KI
3-methoxy-1*H*-indazole	34	–	–	–	–	1699	MS
farnesol	15	–	3	–	–	1712	MS
2-quinazolinamine	6	–	6	–	–	1748	MS
2,6-bis(1,1-dimethylethyl)-4-ethylphenol	16	4	–	2	–	1760	MS
6,10,14-trimethyl-2-pentadecanone	–	2	4	1	–	1848	MS
6,10,14-trimethyl-5,9,13-pentadecatrien-2-one	233	5	23	–	–	1921	MS
α-copaene	14	5	5	5	2	1922	MS
methyl 10-methyldodecanoate	7	–	–	–	–	1926	MS
ethyl pentadecanoate	3	1	3	–	–	1991	MS
total volatiles	5711	713	1032	427	123		

[a] Mass spectra were consistent with those of reference standards. [b] Approximate concentration since percent recovery and response factors were not determined for each compound (assuming all response factor = 1). [c] Not found. [d] Kovats indices for DB-5 column. [e] Identification method.

such as headspace are used (Takeoka *et al.*, 1990). The lower presence of esters may be due to enzymatic activity during the blending of the fruit (Schreier *et al.*, 1985).

Among the important identified C_6 compounds were hexanal, (*E*)-2-hexenal, (*Z*)-3-hexenol, hexanol, and their esters. These compounds were mainly identified in plums. The presence of C_6 compounds was probably due to lipoxygenase activity, action initialized by the disruption of the fruit tissues when blended (Frankel, 1982). Others carbonyl compounds were also identified. Among the important carbonyl compounds was 6-methyl-5-hepten-2-one, described as having a floral aroma (Guichard *et al.*, 1990). It has also been identified in other fruits such as sweet cherries (Mattheis *et al.*, 1992). This ketone, together with geranylacetone, also present in apricots, plums, and plumcots, can be regarded as a norterpenoid arising from isoprenoid degradation (Takeoka *et al.*, 1988).

Another ketone found in some samples was isophorone, identified previously in kiwi flowers (Tatsuko *et al.*, 1991). 6,10,14-Trimethyl-5,9,13-pentadecatrien-2-one was very important quantitatively. This ketone appeared in all of the apricots and plumcots but in neither plum.

Geranial was first detected in apricot samples by Tang and Jennings (1967). This compound was identified in all three apricot samples but not in either plum. Dihydro-β-ionone has been found as a major constituent of the essential oil of *Osmanthis fragant* blossoms (Sisido *et al.*, 1967). It has also been reported in apricots and other fruits (Takeoka *et al.*, 1990; Chariote *et al.*, 1981). This constituent was not recovered in Friar but was quantifiable in Blackamber and all three apricots.

A large number of terpenoid compounds have been identified, all of them previously identified in apricot except geranyl acetate (Chariote *et al.*, 1981; Takeoka *et al.*, 1990).

α-Terpineol can be present free or conjugated (Krammer *et al.*, 1991). A certain increase in α-terpineol after the apricot juice is heated has been reported (Chariote *et al.*, 1981), which fits in with its presence partly in glycosidic form. α-Copaene has been reported in Bartlett pears (Miller *et al.*, 1989).

A large number of lactones have been identified. γ-Octalactone and γ-dodecalactone were the most important quantitatively in both apricots and plums. Nepetalactone was identified in the apricot K604-19 but was not observed in any other apricot, plum, or plumcot. It was the first fully characterized methylclyclopentane monoterpenoid, isolated from the volatile oil of catnip produced by *Nepeta cataria* L. (Bates and Siegel, 1963).

Naphthalene and 1,2,3,4-tetrahydro-1,1,6-trimethylnaphthalene have both been previously identified in *Prunus* (Takeoka *et al.*, 1990; Ismail *et al*, 1981; Williams and Ismail, 1981). 1,1′-Biphenyl has also been found in this study, and its presence could be due to its use as a fungistat (Takeoka *et al.*, 1992).

Several studies on the relative importance of some volatile compounds to the typical aroma of apricot have been completed. Studies on odor threshold (Takeoka *et al.*, 1990) demonstrated that the major contributors to the aroma of blended apricot were β-ionone, linalool, γ-decalactone, β-cyclocitral, phenylacetaldehyde, and γ-octalactone. β-Ionone and linalool may be responsible for the floral character and the lactones for the fruity, peach, and coconut background aroma (Takeoka *et al.*, 1990; Guichard et al., 1990). In our apricot samples, we were not able to identify β-cyclocitral. γ-Octalactone was present only in K604-19. However, the remaining four compounds associated with apricot odor were quantifiable to different degrees in each apricot sample. Rhoades *et al.* (1972) showed that a mixture of nerol, geraniol, γ-decalactone, α-terpineol, and linalool added to freeze-dried apricots gives a fresh, fruity flavor to the product. Other compounds such as the carbonyl compounds also contribute to apricot aroma (Chariote *et al.*, 1981), and

Table II. Concentration of the Volatile Compounds (Micrograms per Kilogram) of the Progenies Resulting from the Different Crosses Plum × Apricot

constituent	Friar × K33-81 P254-2	Blackamber × K604-19 P251-2	Blackamber × K604-19 P251-6	Blackamber × K604-19 P251-7	Blackamber × K113-40 P251-20	Friar × K604-19 P252-9	Friar × K604-19 P252-15	KI[d]	ID[e]
3-hexanone[a]	1[b]	1	1	2	1	3	1	784	MS, KI
2-hexanone	2	1	2	3	1	6	3	789	MS, KI
1-methylcyclopentanol	2	1	1	2	1	3	3	796	MS
hexanal	68	22	50	100	4	99	10	802	MS, KI
butyl acetate	1	–[c]	5	3	2	–	1	813	MS, KI
2,3-dimethyl-2-pentene	1	–	1	2	–	6	15	847	MS
(*E*)-2-hexenal	54	–	52	110	1	434	–	848	MS, KI
(*Z*)-3-hexen-1-ol	–	–	11	–	4	–	11	849	MS, KI
(*E*)-2-hexen-1-ol	31	1	36	27	10	44	10	858	MS, KI
hexanol	39	20	29	39	13	25	21	862	MS, KI
3-methylbutyl acetate	–	–	2	–	–	–	–	864	MS, KI
1,4–dimethylbenzene	–	1	–	4	2	9	–	865	MS
styrene	1	–	–	2	–	7	–	889	MS
1,3,5-cyclooctatriene	–	1	1	–	–	–	–	890	MS
heptanal	1	1	2	2	1	1	–	898	MS, KI
(*E*)-2-heptenal	–	2	–	3	5	1	–	953	MS, KI
2,4-dimethyl-2-decene	8	–	–	–	–	8	3	955	MS
β-phellandrene	–	–	–	5	–	–	–	978	MS, KI
6-methyl-5-hepten-2-one	5	–	12	24	5	8	6	984	MS, KI
β-pinene	–	2	2	–	–	7	–	990	MS, KI
1,2,3-trimethylbenzene	1	1	1	2	1	–	2	966	MS, KI
(*E*,*E*)-2,4-heptadienal	–	6	4	3	–	6	–	998	MS
1,3,5-trimethylbenzene	–	–	36	–	–	–	–	1002	MS
(*Z*)-3-hexenyl acetate	23	–	–	25	32	–	5	1005	MS, KI
hexyl acetate	66	4	64	49	56		8	1010	MS, KI
(*E*)-2-hexenyl acetate	64	–	55	34	43	5	–	1014	MS, KI
2,2,8-trimethyldecane	–	–	–	–	1	–	–	1022	MS
m-cymene	–	3	2	4	1	–	3	1026	MS, KI
2-ethylhexanol	6	–	7	10	5	7	7	1028	MS, KI
limonene	4	21	24	20	5	12	14	1031	MS, KI
2,5-dimethyl-2-undecene	–	–	–	4	2	–	–	1033	MS
2,2,6-trimethylcyclohexanone	2	1	6	3	1	–	–	1036	MS
phenylacetaldehyde	9	60	2	19	1	37	11	1045	MS, KI
citral methyl acetal	–	–	3	–	–	–	–	1051	MS
2,2,5,5-tetramethylhexane	–	–	–	–	1	–	–	1052	MS
isophorone	3	6	10	–	–	–	–	1059	MS, KI
3,8-dimethylundecane	–	–	–	–	1	–	–	1063	MS
acetophenone	2	–	1	3	1	–	0	1065	MS, KI
linalool	6	8	288	45	24	10	23	1104	MS, KI
nonanal	13	14	27	16	14	7	9	1105	MS, KI
2,6-dimethylcyclohexanol	1	–	4	3	0	–	–	1112	MS
2-ethylcyclohexanone	2	2	–	3	–	–	–	1158	MS
2-undecenal	1	9	4	5	1	–	–	1159	MS
ethyl benzoate	–	6	–	–	2	–	–	1170	MS, KI
4-terpinenol	–	–	3	4	–	–	–	1182	MS, KI
(*Z*)-3-hexenyl butanoate	–	–	–	–	–	–	4	1183	MS, KI
naphthalene	3	2	5	5	4	7	5	1186	MS, KI
(*E*)-2-hexenyl butanoate	3	–	8	–	7	–	–	1191	MS, KI
methyl salicylate	–	–	–	13	9	–	–	1193	MS, KI
ethyl octanoate	–	8	–	–	–	–	16	1196	MS, KI
α-terpineol	1	–	51	11	9	–	–	1199	MS, KI
octyl acetate	–	–	–	–	2	–	–	1200	MS, KI
β-cyclocitral	10	–	26	19	6	–	8	1219	MS, KI
geraniol	–	–	12	5	–	–	–	1221	MS, KI
2-oxo-1-methyl-3-isopropylpyrazine	–	7	–	–	–	–	–	1225	MS
ethyl phenylacetate	–	1	–	–	1	–	–	1235	MS, KI
nerol	–	–	20	–	2	–	–	1251	MS, KI
γ-octalactone	–	–	–	12	1	1	6	1255	MS, KI
geranial	–	–	2	5	–	–	0	1268	MS, KI
ethyl salicylate	–	5	–	–	–	31	–	1269	MS, KI
bornyl acetate	2	2	1	11	2	5	1	1287	MS, KI
(*E*,*E*)-2,4-decadienal	4	6	5	9	2	1	1	1295	MS, KI
1-methyl-4-(methylthio)benzene	4	–	–	2	1	–	–	1316	MS
(*E*,*Z*)-2,4-decadienal	3	9	5	6	2	–	–	1319	MS
megastigma-4,6(*Z*),8(*Z*)-triene	–	–	6	–	–	–	–	1324	MS
megastigma-4,6(*E*),8(*E*)-triene	–	–	1	–	–	–	–	1338	MS
1,2,3,4-tetrahydro-1,1,6-trimethylnaphthalene	–	4	1	2	1	–	–	1349	MS
megastigma-4,6(*E*),8(*Z*)-triene	–	–	3	–	–	–	–	1354	MS
megastigma-4,6(*Z*),8(*E*)-triene	–	–	16	–	–	–	–	1358	MS
γ-nonalactone	–	–	–	3	–	–	5	1360	MS, KI
2-ethyl-3-hydroxyhexyl-2-methylpropanoate	–	1	2	–	2	–	–	1373	MS
geranyl acetate	–	–	3	–	–	–	–	1377	MS, KI
(*Z*)-3-hexenyl hexanoate	7	–	6	–	14	–	21	1376	MS, KI
1,1′-biphenyl	4	5	4	13		9	–	1381	MS
(*E*)-2-hexenyl hexanoate	3	–	8	6	8	–	18	1387	MS, KI
ethyl decanoate	–	–	–	–	1	–	–	1390	MS, KI
2-ethyl-1,4-dimethylbenzene	–	5	8	–	1	–	11	1411	MS
α-ionone	–	–	–	5	–	–	–	1422	MS

Table II. (Continued)

constituent	Friar × K33-81 P254-2	Blackamber × K604-19 P251-2	Blackamber × K604-19 P251-6	Blackamber × K604-19 P251-7	Blackamber × K113-40 P251-20	Friar × K604-19 P252-9	Friar × K604-19 P252-15	KI[d]	ID[e]
dihydro-β-ionone	–	3	75	2	–	–	19	1433	MS, KI
geranylacetone	27	55	53	136	19	46	75	1449	MS, KI
2,6-bis(1,1-dimethylethyl)-2,5-cyclohexadiene-1,4-dione	2	6	5	17	–	13	20	1462	MS
γ-decalactone	32	19	99	243	12	188	334	1476	MS, KI
β-ionone	36	23	49	94	7	17	34	1482	MS, KI
δ-decalactone	–	–	5	–	–	–	9	1493	MS, KI
BHT	11	1	31	52	43	5	23	1504	MS
pseudoionone	–	–	1	2	–	–	–	1527	MS
dihydroactinidiolide	–	–	–	1	–	–	–	1561	MS, KI
nerolidol	–	2	–	–	–	–	–	1562	MS
(*E*,*E*)-pseudoionone	–	–	1	5	–	–	–	1581	MS
diethyl phthalate	–	5	7	16	7	10	–	1585	MS
1,1-diphenylhydrazine	–	–	2	–	–	–	–	1623	MS
γ-undecalactone	–	–	1	2	–	–	–	1656	MS, KI
γ-dodecalactone	49	10	153	324	21	317	199	1681	MS, KI
farnesol	2	–	–	–	–	–	–	1699	MS
2,6-bis(1,1-dimethylethyl)-4-ethylphenol	–	–	3	–	–	–	24	1760	MS
6,10,14-trimethyl-2-pentadecanone	–	–	2	–	4	–	–	1848	MS
6,10,14-trimethyl-5,9,13-pentadecatrien-2-one	10	16	32	65	6	30	49	1921	MS
α-coapene	2	–	–	–	–	24	20	1922	MS
methyl 10-methyldodecanoate	–	2	2	–	–	–	–	1926	MS
ethyl pentadecanoate	–	10	–	–	1	–	–	1991	MS
total volatiles	632	401	1458	1666	436	1452	1065		

[a] Mass spectra were consistent with those of reference standards. [b] Approximate concentration since percent recovery and response factors were not determined for each compound (assuming all response factor = 1). [c] Not found. [d] Kovats indices for DB-5 column. [e] Identification method.

Guichard *et al.* (1990) established that hexyl acetate, γ-octa-and decalactones, and (*Z*)-3-hexen-1-ol were the compounds that better correlated with the typical apricot aroma.

A comparative study among the three apricots showed that K604-19 had few esters but very high levels of linalool (671 μg/kg) and geraniol (102 μg/kg). The numbers and quantities of identified lactones were very high, with γ-decalactone and γ-dodecalactone being present at concentrations of 1424 and 1502 μg/kg, respectively. In K604-19 we could not find α-terpineol, hexyl acetate, or (*Z*)-3-hexen-1-ol.

The number of compounds identified in K113-40 was lower than in K604-19. Not many lactones were present in K113-40, but the concentration of α-terpineol was high (60 μg/kg). K33-81 had few C_6 compounds, and the content of linalool and the various lactones was also low.

In a comparison of only those aromatic constituents present in all three apricot samples, only in the cases of 1,2,3,4-tetrahydro-1,1,6-trimethylnaphthalene and dihydro-β-ionone were quantities lower in K604-19 than in K113-40 or K33-81. For all other aromatic constituents common to these samples, K604-19 had the highest concentrations. Using simultaneous vacuum distillation/extraction with standard conditions as described herein, over 5700 μg of volatile constituents/kg of fresh fruit tissue was recovered from K604-19. Extractions with K113-40 and K33-81 under the same conditions provided yields only 12.5% and 18.0% the size of the yield from K604-19, respectively. These results corroborate that K604-19 had the stronger apricot aroma with very noticeable floral and fruity notes due to the important presence of linalool, β-ionone, and lactones.

Fewer studies of the volatile constituents of fruit have been performed on plum than on apricot. On the basis of the studies of Williams and Ismail (1981) with *Prunus domestica*, linalool and ethyl butanoate are very important in the aroma of European plums. A single study on *P. salicina* indicated that esters and lactones were the main volatile constituents from this fruit (Forrey and Flath, 1974). Utilizing crosses between *P. salicina* and *P. americanum*, Horvat *et al.* (1992) found that lactones were also a major class of volatile compounds in southeastern American plums.

The number of identified compounds in plum was lower than in apricots, and in general, the compounds were present at lower concentrations. The profiles of the two plums were very similar, but most compounds appeared at higher concentrations in Blackamber. Total extractable volatiles for Blackamber and Friar were only 426 and 123 μg/kg of fresh fruit tissue, respectively. The concentrations of C_6 compounds and related esters tended to be slighty higher than in apricot. These compounds were also important to the plum aroma; hexanal, when diluted, has been described as having a plum-like aroma (Williams and Ismail, 1981). The presence of C_6 compounds and related esters was higher in Blackamber than in Friar. The concentration of linalool (18 and 8 μg/kg for Blackamber and Friar, respectively) was much lower than in apricots. This was also true for the other terpenoids; we could not detect 4-terpineol, geraniol, geranial, or pseudoionone.

We found hydrocarbons to be more prevalent in plum than in apricot. This was related to the composition of the skin, which is very rich in waxes. Also related to the skin was the presence of nonanal, a characteristic constituent of skin waxes of plums having a fragant, woody-like aroma (Ismail *et al.*, 1981; Williams and Ismail, 1981).

Some compounds with a very important quantitative presence in apricots were not present in plums, such as 6-methyl-5-hepten-2-one, most of the dienals, and 6,10,14-trimethyl-5,9,13-pentadecatrien-2-one. The lactones were also less prominent, with only γ-decalactone and γ-dodecalactone appearing in the volatile profiles.

There were also some characteristic compounds that only appear in plums, such as acetophenone, ethyl octanoate, β-cyclocitral, and nerolidol. β-Cyclocitral, together with dihydroactinidiolide and dihydro-β-ionone, can be regarded as a product of carotenoid metabolism (Ohloff, 1978).

Table II shows the different compounds appearing in the seven plumcots studied. Almost all of the compounds identified in apricots and plums were found in plumcots. Among the compounds we have not found in plumcots are

Table III. Detection Odor Thresholds in Water (Parts per Billion) and Odor Units for Some of the Identified Compounds in the Three Apricots Used as Male Parents and the Two Plums Used as Female Parents

constituent	odor threshold	odor units				
		K604-19	K113-40	K33-88	Blackamber	Friar
hexanal	5	2	1	1	2	
(*E*)-2-hexenal	17					1
6-methyl-5-hepten-2-one	50	2				
hexyl acetate	2			2	21	1
phenylacetaldehyde	4	21	6	1	7	
linalool	6	112	61	25	3	1
nonanal	1		8		51	14
β-cyclocitral	5					
geraniol	40	3				
γ-octalactone	7	5				
(*E*,*E*)-2,4-decadienal	0.07	100	14	57		
geranylacetone	60	6		1		
γ-decalactone	11	129		4		
β-ionone	0.07	6243	871	2171	114	43
γ-dodecalactone	7	215		7	2	1

2-propylfuran, 5-ethyl-(2*H*)-furanone, 3,5,5-trimethyl-2-cyclohexen-1-ol, β-ocimene, and nepetalactone. There were also some compounds only found in one or more of the hybrids and not in apricot or plum: octyl acetate and ethyl decanoate, both identified in P251-20; 3-methylbutyl acetate in P251-6; ethyl benzoate in P251-2; methyl salicylate in P251-7 and P251-20; ethyl salicylate in P251-2 and P252-9; ethyl phenylacetate in P251-2 and P252-20; and β-phellandrene in P251-7, also detected by others in apricot (Chariote *et al.*, 1981) and papaya (Flath *et al.*, 1990). The C_6 compounds and related esters were among the most abundant compounds found in the plumcots studied.

P251-2, P251-6, and P251-7 are hybrids obtained from the cross of Blackamber × K604-19; each of these will now be considered in turn. P251-2 has a nonastringent skin with a deep burgundy coloration, and its flesh density appears to be intermediate between those of apricot and plum. The content of limonene was high as was that of phenylacetaldehyde and geranylacetone, but the concentration of linalool and the lactones was low. The profile was a mix between apricot and plum, but the number of hydrocarbon compounds was not as high as in plums. Three esters that did not appear in apricot or plum were detected: ethyl benzoate, which has floral and fruity aromas, and both ethyl phenylacetate and ethyl salicylate, with sweet, floral, and fruity aromas. An apricot aroma is released by this plumcot when it is tree-ripened.

P251-6 had a slight apricot flavor when it was sensorily evaluated. Its profile strongly resembled that of an apricot, due to the relatively large concentrations of almost all of the terpenic compounds identified in apricots. This accession also had a high lactone content. The quantities of esters such as hexyl acetate and 2-hexenyl acetate were also very important.

P251-7 has a round-elliptic fruit weighing less than 50 g. Sensory evaluation indicated a strong plum flavor. This flavor can be due to the high abundance of C_6 aldehydes, hexanal, and 2-hexenal, that are considered characteristic of plum aroma. The plumcot did not present a high concentration of terpenoid compounds, but a great number of them could be found including β-phellandrene. A number of lactones could also be identified; the concentration of γ-decalactone and γ-dodecalactone were the highest on all the plumcots examined.

P252-9 and P252-15 are hybrids from Friar × K604-19. P252-9 is a small round fruit (26 g) with an acidic plum flavor when tree-ripe. Coupled with the astringent skin of this accession, it does not meet the basic objectives of the breeding program. It was not an aromatic fruit. The number of identified compounds was quite low. The concentration of 2-hexenal was very high (434 μg/kg).

P252-15 is characterized as having a banana yellow skin with a bright orange overcolor. Flesh texture is similar to that of an apricot, and the skin is strongly astringent. This plumcot was more aromatic than P252-9, but, like it, the number and quantities of identified compounds were not high. γ-Decalactone had the highest concentration (334 μg/kg).

The above-mentioned plumcots all had the same apricot parent (K604-19), but those plumcots arising from crosses with Blackamber had a higher content of aroma compounds than those coming from Friar.

P251-20 is from a cross of Blackamber × K113-40. This accession would be considered large-fruited, with fresh fruit weights averaging over 90 g. Its red skin is considered attractive, but flesh texture was mealy. This selection has a mild apricot flavor. The content of C_6 compounds was low, but the related esters were abundant, and they have fruity and floral aromas. The number of hydrocarbons was high, and octyl acetate has been identified as well as ethyl decanoate.

P254-2 is from a cross of Friar × K33-81. It had high levels of C_6 compounds and related esters, had little linalool, and was not very aromatic. Fruit from this selection ripens in early June and averages over 100 g fresh weight. Although not a flavorful fruit, P254-2 is of continuing interest, due to its relatively high fruit set.

The relative contribution of various constituents to the aroma was determined by calculating the number of odor units. The odor unit was defined by Guadagni *et al.* (1966) as the concentration of the compound divided by its odor threshold. This value gives some idea of the significance of the different volatile compounds to the total aroma. Tables III and IV list the odor units of some constituents, using the odor threshold given by other authors (Engel *et al.*, 1988; Takeoka *et al.*, 1990, 1992). For both parents and progeny, the compound with the highest odor unit was β-ionone. Linalool and (*E*,*E*)-2,4-decadienal also had high odor units in apricots. In the apricot K604-19, phenylacetaldehyde, γ-decalactone, and γ-dodecalactone all had an important contribution to its aroma. Nonanal had an important contribution in plum aroma as did hexyl acetate in the aroma of Blackamber.

Among plumcots, those compounds having the higher odor units were those characteristic of apricot such as lactones, linalool, and (*E*,*E*)-2,4-decadienal and those characteristic of plums such as hexyl acetate and nonanal. Besides these compounds, the contribution of the C_6 compounds to the plumcot aroma was higher than in either

Table IV. Detection Odor Thresholds in Water (Parts per Billion) and Odor Units for Some of the Identified Compounds in the Progenies Resulting from Different Crosses Plum × Apricot

			odor units					
			Blackamber × K604-19			Blackamber ×	Friar × K604-19	
constituent	odor threshold	Friar × K33-81 P254-2	P251-2	P251-6	P251-7	K113-40 P251-20	P252-9	P252-15
hexanal	5	14	4	10	20	1	20	2
(*E*)-2-hexenal	17	3		3	6		25	
6-methyl-5-hepten-2-one	50							
hexyl acetate	2	33	2	32	25	28		4
phenylacetaldehyde	4	2	15	1	5		9	3
linalool	6	1	1	48	7	4	2	4
nonanal	1	13	14	27	16	14	7	9
β-cyclocitral	5	2		5	4	1		1
geraniol	40							
γ-octalactone	7				2			1
(*E*,*E*)-2,4-decadienal	0.07	57	86	71	129	29	14	7
geranylacetone	60		1	1	2		1	1
γ-decalactone	11	3	2	9	22	1	17	30
β-ionone	0.07	514	329	700	1343	100	286	488
δ-decalactone	100							
γ-dodecalactone	7	7	1	22	42	3	45	28

apricot or plum. From the results obtained in this study, it appears that the ability to produce aromatic volatiles may be paternally transmitted as discrete characteristics. Aromatic constituents present in the parents may or may not appear in some or all progeny within a family. As an example, (*E*,*E*)-2,4-heptadienal is present in the apricot K604-19 as well as in Blackamber plum. This constituent was not quantifiable in the other apricot or plum parents. Plumcots arising from the hybridization of Blackamber × K604-19 all had quantifiable levels of (*E*,*E*)-2,4-heptadienal. This constituent was also identified in P252-9 (Friar × K604-19) but not in P254-2 (Friar × K33-81).

A second point with regard to the structural genes responsible for the transmission of specific aromatic constituents is that compounds that are quantitatively important compounds in the parents of plum × apricot hybridizations may also be produced in quantitatively high levels in the progeny. Geranylacetone was identified in all of the parents of this study but was quantitatively much higher in K604-19. Similarly, geranylacetone was also identified in all plumcot progeny but at higher levels in progeny for which K604-19 had been used as the apricot parent. A similar case can be made with γ-decalactone and γ-dodecalactone. These lactones had an important contribution to the aroma of the apricot K604-19. Present in all progeny from plum × apricot hybridizations, they were sensorially important to the volatile profiles of four of the five plumcots for which K604-19 had been the male parent. Another compound, nonanal, contributed significantly to Blackamber aroma. Those plumcots having Blackamber as a parent had higher odor unit values for nonanal than those plumcots for which Friar was used.

The plumcot progenies reported here are far too few to identify segregation ratios for the structural genes necessary for the production of the various volatile constituents. Family sizes were limited since the study was conducted during the first fruiting season. An additional year of tree growth will produce more fruiting wood on those family members not capable of fruit production during 1992. Hence, we expect larger fruiting progenies in the coming year. We have demonstrated that the same volatile compounds which are important for apricot aroma can also be identified in plumcot progeny in a plum × apricot hybridization. Plumcots can be objectively screened using standardized extraction procedures to identify those types whose aromatic profiles would enhance most our efficiency in attaining our breeding objectives.

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Registry No. Supplied by Author: 3-Hexanone, 589-38-8; 2-hexanone, 591-78-6; 1-methylcyclopentanol, 1462-03-9; hexanal, 66-25-1; butyl acetate, 123-86-4; 2,3-dimethyl-2-pentene, 10574-37-5; (*E*)-2-hexenal, 6728-26-3; (*Z*)-3-hexen-1-ol, 928-96-1; (*E*)-2-hexen-1-ol, 928-95-0; 2-propylfuran, 4229-91-8; hexanol, 111-27-3; 3-methylbutyl acetate, 123-92-2; 1,4-dimethylbenzene, 106-42-3; styrene, 100-42-5; 1,3,5-cyclooctatriene, 1871-52-9; heptanal, 111-71-7; (*E*)-2-heptenal, 18829-55-5; 5-ethyl-2(*H*)-furanone, 2407-43-4; 2,4-dimethyl-2-decene, 74421-03-7; 9-methyl-5-undecene, 74630-65-2; β-phellandrene, 555-10-2; 6-methyl-5-hepten-2-one, 110-93-0; β-pinene, 18172-67-3; 1,2,3-trimethylbenzene, 526-73-8; (*E,E*)-2,4-heptadienal, 4313-03-5; 1,3,5-trimethylbenzene, 108-67-8; (*Z*)-3-hexenyl acetate, 3681-71-8; hexyl acetate, 142-92-7; (*E*)-2-hexenyl acetate, 2497-18-9; 2,2,8-trimethyldecane, 62238-01-1; *m*-cymene, 535-84-4; 2-ethylhexanol, 104-76-7; limonene, 138-86-3; 2,5-dimethyl-2-undecene, 49622-16-4; 3,8-dimethylundecane, 17301-30-3; 2,2,6-trimethylcyclohexanone, 2408-37-9; phenylacetaldehyde, 122-78-1; citral diethyl acetal, 7549-37-3; 2,2,5,5-tetramethylhexane, 1071-81-4; isophorone, 78-59-1; acetophenone, 98-86-2; 3-tetradecene, 41446-67-7; linalool, 78-70-6; nonanal, 124-19-6; 2,5-dimethylphenol, 95-87-4; 2,6-dimethylcyclohexanol, 5337-72-4; 3,5,5-trimethyl-2-cyclohexen-1-ol, 470-99-5; 2-ethylcyclohexanone, 4423-94-3; ethyl benzoate, 93-89-0; 2-undecenal, 2463-77-6; 4-terpinenol, 562-74-3; (*Z*)-3-hexenyl butanoate, 16491-36-4; naphthalene, 91-20-3; (*E*)-2-hexenyl butanoate, 53398-83-7; methyl salicylate, 119-36-8; ethyl octanoate, 106-32-1; α-terpineol, 10482-56-1; tetradecanal, 124-25-4; 2,3,5-trimethyl-1,4-benzenediol, 700-13-0; 4-acetyl-1,2,3,5,5-pentamethyl-2-cyclopenten-1-one, 50506-59-7; octyl acetate, 103-09-3; β-cyclocitral, 432-25-7; geraniol, 106-24-1; 2-oxo-1-methyl-3-isopropylpyrazine, 78210-68-1; isoborneol, 124-76-5; ethyl phenylacetate, 101-97-3; nerol, 106-25-2; γ-octalactone, 698-76-0; geranial, 5392-40-5; ethyl salicylate, 118-61-6; bornyl acetate, 5655-61-8; (*E,E*)-2,4-decadienal, 25152-84-5; nepetalactone, 490-10-8; 1,2,3,4-tetrahydro-1,5,7-trimethylnaphthalene, 21893-55-0; 1-methyl-4(methylthio)benzene, 623-13-2; (*E,Z*)-2,4-decadienal, 25152-83-4; megastigma-4,6(*Z*),8(*Z*)-triene, 7186-25-9; megastigma-4,6(*E*),8(*E*)-triene, 51468-86-1; 1,2,3,4-tetrahydro-1,1,6-trimethylnaphthalene, 21693-51-6; megastigma-4,6(*E*),8(*Z*)-triene, 71186-24-8; 2,3-dihydro-1,1,4,5-tetramethyl-1*H*-indene, 40650-41-7; megastigma-4,6(*Z*),8(*E*)-triene, 51468-85-0; γ-nonalactone, 104-61-0; 2-ethyl-3-hydroxyhexyl 2-methylpropanoate, 74367-31-0; geranyl acetate, 105-87-3; (*Z*)-3-hexenyl hexanoate, 31501-11-8; 1,1′-biphenyl, 92-52-4; (*E*)-2-hexenyl hexanoate, 53398-86-0; ethyl decanoate, 110-38-3; 2-ethyl-1,4-dimethylbenzene, 1758-88-9; α-ionone, 127-41-3; dihydro-β-ionone, 17283-81-7; geranylacetone, 3796-70-1; 2,6-bis(1,1-dimethylethyl)-2,5-cyclohexadiene-1,4-dione, 719-22-2; γ-decalactone, 706-14-9; β-ionone, 79-77-6; δ-decalactone, 705-86-2; BHT, 128-37-0; pseudoionone, 141-10-6; dihydroactinidiolide, 17092-92-1; nerolidol, 7212-44-4; (*E,E*)-pseudoionone, 3548-78-5; diethyl phthalate, 84-66-2; 1,1-diphenylhydrazine, 122-66-7; γ-undecalactone, 104-67-6l; γ-dodecalactone, 2305-05-7; 3-methoxy-1*H*-indazole, 1848-41-5; farnesol, 4602-84-0; 2-quinazolinamine, 1687-51-0; 2,6-bis(1,1-dimethylethyl)-4-ethylphenol, 4130-42-1; 6,10,14-trimethyl-2-pentadecanone, 502-69-2; 6,10,14-trimethyl-5,9,13-pentadecatrien-2-one, 1117-52-8; α-copaene, 3856-25-5; methyl 10-methyldodecanoate, 5129-65-7; ethyl pentadecanoate, 41114-00-5.

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