Rept. of Toyo J. Coll. of Food Technol. & Toyo Inst. of Food Technol., 21, 77−89 (1996)

Changes in Composition of Volatile Compounds in High-Pressure Treated Peach

Hidenobu Sumitani, Sachiko Suekane,
Aya Nakatani and Kiyoaki Tatsuka

The headspace volatile components of high pressure treated (400 MPa, 20 ℃, 10 min) white peach (*Prunus persica* L. cv. Shimizu) were analyzed by capillary gas chromatography-mass spectrometry (GC-MS) and compared with headspace volatiles of ripe intact peach, crushed peach, and heat-treated peach. To examine the flavor quality, the high pressure treated peaches packed in pouches were stored at 25 and 40 ℃ for various periods and analyzed by GC-MS. The enzymical formation of benzaldehyde, C_6 aldehydes, and alcohols by disruption of the fruit tissues was observed in the high pressure treated fruit and crushed fruit. The influence of high-pressure treatment for β-glucosidase activity related to formation of glycosidically bound volatiles was examined. It was considered that increase of benzaldehyde in high pressure treated fruit during storage was caused by β-glucosidase still remaining after high-pressure treatment.

Key words : volatile compounds, peach, high pressure treatment, capillary GC-MS, dynamic headspace sampling

INTRODUCTION

Several investigations of peach aroma have been reported. Lim and Romani (1964) reported that volatile constituents increased with the maturation of peaches and nectarines. Do et al. (1969) studied peaches at different stages of maturity and found that the concentrations of major volatiles increased with maturation. Spencer et al. (1978) studied the relationship between sensory characteristics and relative concentration of the volatile compounds of fresh peaches and canned peaches and concluded the γ-lactone contributed the "peachy" background while the lower-boiling compounds contributed fruity and floral notes. Jennings and Sevenants (1964) and Sevenants and Jennings (1966) reported that lactones, particularly δ-lactones, have been implicated in peach aroma. Horvat et al. (1990) reported the major volatiles from two peach cultivars at different maturity stage. Horvat and Chapman (1990) found that benzaldehyde, linalool, and the C_{10} lactones increased in the final period of peach maturation, while the C_6 aldehydes decreased. Robertson er al. (1990 a, b) reported that five compounds contributing to typical peach aroma were significantly higher in white fresh than in yellow fresh peach and that the volatiles generally

注　本論文は *J. Agric. Food Chem.* Vol. 42, No. 3 掲載論文を転載したものである.

decreased during cold storage. Mookherjee et al. (1988) found a large difference in aroma between a living peach and a picked peach. Narain et al. (1990) used dynamic headspace method, cryofocusing technique, and high-resolution GC for the determination of peach volatiles from a promising cultivar under development. Chapman et al. (1991) reported that the major volatiles appear to be useful indices for determining maturity. In recent years, the determination of flavor precursors and intermediates, especially glycosides in various fruits, became the target of flavor studies. Free and glycosidically bound volatiles from the peach were identified by Ho et al. (1990) and Krammer et al. (1991).

When the first high pressure treated fruit products reached the Japanese market, Horie et al. (1991) studied the quality of strawberry jam prepared by high hydrostatic pressure and Watanabe et al. (1991) reported on the volatiles of strawberry jam treated by high hydrostatic pressure.

The purpose of this study is to obtain basic information about the flavor quality of high pressure treated peach in compa rison with that of ripe intact, crushed, and heattreated peaches.

EXPERIMENTAL PROCEDURES

Materials and Reagents

White peach (*Prunus persica* L. cv. Shimizu) were obtained from the local market. Intact ripe fruits were selected for the experiments. High-quality water was generated with a water purification system (Elgastat UHQ; Elga Ltd., Lane End, UK.). Sodium sulfate (special grade) and a glucose determination kit (GLUCOSE CII TEST WAKO) were obtained from Wako Pure Chemical Industries Ltd. (Osaka, Japan). High-purity nitorgen (grade ZERO-U, 99.999% pure) and high-purity synthetic air (grade ZERO-U) in a bomb obtained from Sumitomo Seika Chemicals Co., Ltd. (Osaka, Japan) were used in the dynamic headspace collection. Emulsin (almond β-glucosidase, EC 3.2.1.21) was purchased from Tokyo Kasei Kogyo Co. Ltd. (Tokyo, Japan). Amygdalin was obtained from Sigma Chemical Co. (St. Louis, MO). Tenax TA (60-80 mesh) was obtained from GL Science Co. Ltd. (Tokyo, Japan). Authentic standard flavor compounds were purchased from commercial sources. Flexible multilayer pouches (from inside, polypropylene, aluminum, and polyethylene terephthalate; 10 cm × 16 cm) were obtained from Toyo Seikan Co. Ltd. (Tokyo, Japan).

Sample Preparation

The intact ripe peach fruit was washed with distilled water, the stone was removed and discarded, and the fruit with skin was cut in quarters. The weight of a quarter was in a range of 45-55 g. The samples were prepared by three different methods. Crushed peach (C-peach): a quarter of the peach was homogenized in a Waring blender for 10 s, and then it was left for 1 h. High pressure treated peach (P-peach): a quarter of the peach was packed in a pouch under vacuum. The packed pouch was pressurized by a pressure generator (Type MFP-7000, Mitsubishi Heavy Industries, Hiroshima, Japan). The operation condition was as follows: The hydrostatic pressure reached to 400 MPa within 1 min and was held

for 10 min. The temperature of the pressure vessel rose from 20 to 28 ℃ within 3 min and then gradually dropped to 22 ℃. Heat-treated peach (H-peach): aquarter of the peach was packed in a pouch under vacuum. The packed peach was heat-treated in a boiling water bath for 30 min and then rapidly cooled in a water bath.

In order to investigate the changes in compositions of the volatile constituents during storage, one sample each of P-peaches and H-peaches was analyzed immediately, and remaining samples were placed in storage at 25 and 40 ℃. The samples were removed at 1, 2, 4, 6 and 8 weeks for analysis.

Dynamic Headspace Sampling

1. Dynamic Headspace Sampling of Treated Peach. The peach sample was taken out of the pouch and then homogenized in a Waring blender for 1 min after adding an equivalent weight of saturaterd sodium sulfate solution to the sample weight in order to prevent the foaming (Josephson et al., 1985). The homogenate was poured into a 500-mL Pyrex glass bottle (9-cm high × 8-cm i.d.) with a magnetic stirring bar. The bottle was sealed with a glass cap with a gas inlet and outlet. High-purity nitrogen, passed through a Tenax TA column (9-cm length × 0.5-cm i.d., 0.50 g) to eliminate impurities, was led into the bottom of the bottle via a Teflon tube, passed over the homogenate, and removed through a Tenax TA trapping column (same as above) at a flow rate of ca. 100 mL/min. The volume of gas passed through the outlet was measured, and gas flow was stopped at 3 L. Before the volatiles were trapped by Tenax TA column, 10 μL of β-phenylethyl acetate in methanol solution (1 mg/mL) was directly injected into the Tenax TA column as internal standard. During trapping, the sample was stirred with a magnetic stirrer. After collection of the volatiles, the Tenax column was purged with a stream of high-purity nitrogen (50 mL/min for 30 min) to remove water and methanol.

2. Dynamic Headspace Sampling of an Intact Ripe Peach Sample. Intact ripe peaches (nine pieces, total weight 1.86 kg) were placed in a 6-L Pyrex glass chamber. The high-purity air that was passed through the Tenax TA column (same as above) was led into the chamber via Teflon tube and passed over the peaches and out of the chamber through a Tenax TA trapping column (same as above) at a flow rate of ca. 100 mL/min. Gas flow was stopped at 6 L. The remaining procedures were the same as described above.

Gas Chromatography-Mass Spectrometry (GC-MS)

A GC-MSQP1000 system (Shimadzu, Kyoto, Japan) equipped with a 60-m × 0.25-mm (i.d.) DB-Wax column (J&W Scientific) was employed. The column temperature was programmed from 40 ℃ (5 min isothermal) to 200 ℃ at 3 ℃/min and then held at the upper limit. The helium carrier gas was used at a flow velocity of 29 cm/s. The injector and ion source were maintained at 260 and 250 ℃, respectively. The injection splitter SPL-G9 (Shimadzu) was used at a split ratio of 1:20. In all casses, the outlet of the column was directly coupled to

the ion source of the quadrupole mass spectrometer. In the electron-impact mode (EI), the mass spectrometer was scanned from *m/z* 20 to 300 in 2-s intervals. The instrument was operated at an ionization voltage of 70 eV. The methods of thermal desorption of volatiles from a Tenax TA and introduction to GC-MS were same as those previously described (Tatsuka et al. 1990). Identification of compounds was based on computer matching of mass spectra and coincidence for MS pattern of authentic compounds as well as coincidence for Kovats retention indices (Kováts, 1965).

Concentrations were calculated from total ion intensity of individual components and internal standard (IS) without a response factor correction by using a data processor GC-MS PAC2000S (Shimadzu). Concentration was calculated as follows: concentration (ng% for sample weight) = total ion intensity of peak × weight of IS (ng) × 100/total ion intensity of IS/weight of sample (g).

Assay for Emulsin

1. *Preparation of Enzyme Solution with and without High-Pressure Treatment.* The activity of emulsin was determined by monitoring the glucose amount produced by the decomposition of amygdalin. An enzyme solution was prepared with a 0.05% emulsin in 0.05 M citrate buffer (pH5.2). The enzyme solution was filled up in two 2-mL polyethylene tubes with screw-caps. The one was pressurized at a hydrostatic pressure of 400 MPa at 20 ℃ for 10 min, and the other was non-pressurized.

2. *Measurement of Enzyme Assay.* Citrate buffer (150 μL, 0.05 M) (pH 5.2) and 20 μL of 2.54 mg/mL amygdalin aqueous solution were mixed in a test tube (15-cm long, 1.5-cm i.d.). Sixteen test tubes with the mixed solution were placed in an ice bath. Thirty microliters of pressurized enzyme solution was added to eight test tubes, and 30 μL of non-pressurized enzyme solution was added into the other eight test tubes. Then, the 16 test tubes were transferred to a shaking bath (160 strokes/min) at 37 ℃ and incubated. One of the test tubes of both the pressurized and the nonpressurized reaction solutions was removed from the bath at 5, 10, 20, 30, 40, 50, 60, and 70 min and immediately immersed in a boiling water bath for 5 min to inactivate the enzyme. After the solutions had cooled to the room temperature, the glucose produced from amygdalin by the enzymic reaction was determined by the colorimetric mutarotase-glucose oxidase-peroxide method (Miwa et al., 1972). A glucose CII Wako kit was used as the reagents for the determination.

RESULTS AND DISCUSSION

The volatile constituents of peach were isolated by the dynamic headspace sampling methods and analyzed by GC-MS. The identification was considered tentative when it was based on mainly matching an unknown mass spectrum with a spectrum in the EPA/NIH (1983) or the Wiley/NBS (1989) collection. Compound identification was achieved by comparison of the Kovats index and mass spectral data with those of authentic reference compounds. Quantification of the volatile constituents was based on β-phenylethyl acetate as internal standard.

Fig. 1 shows total ion chromatograms

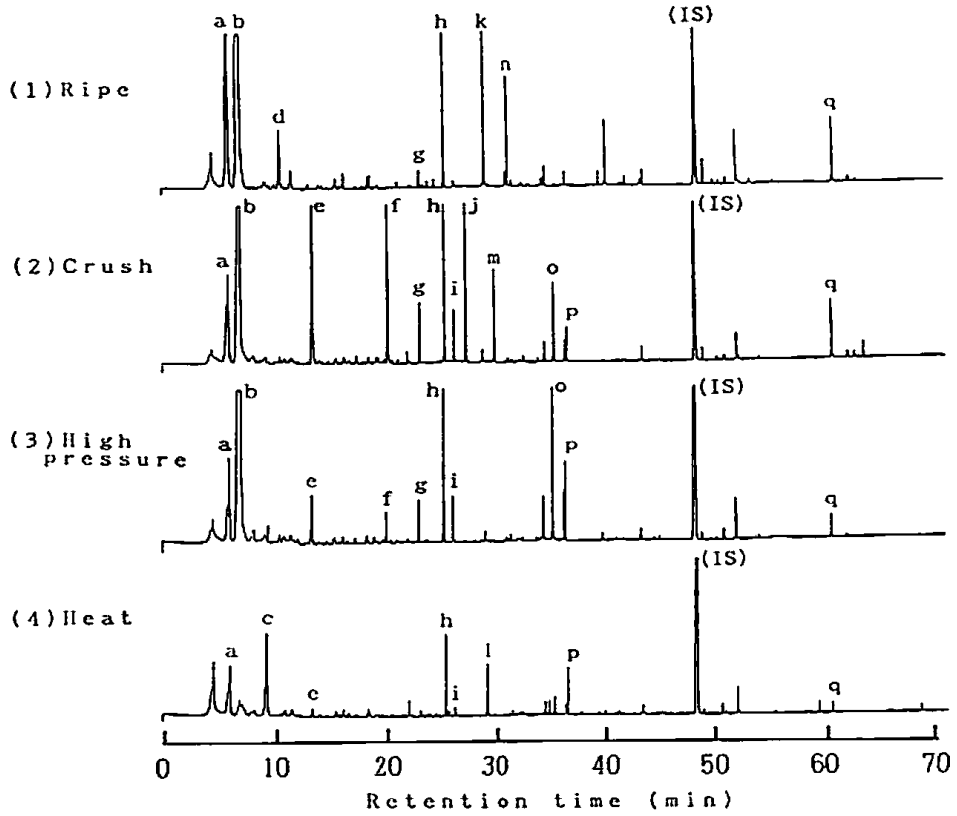

Fig. 1. Total ion chromatograms of headspace volatiles: (1) ripe peach, (2) crushed peach, (3) high pressure treated peach, and (4) heat-treated peach. Peaks: (a) methyl acetate; (b) ethyl acetate; (c) pentanal; (d) isobutyl acetate; (e) hexanal; (f) (*E*)-2-hexenal; (g) hexyl acetate; (h) (*Z*)-3-hexenyl acetate; (i) (*E*)-2-hexenyl acetate; (j) 1-hexanol; (k) methyl octanoate; (l) nonanal; (m) (*E*)-2-hexenol; (n) ethyl octanoate; (o) benzaldehyde; (p) linalool; (IS: internal standard) β-phenylethyl acetate; (q) γ-decalactone.

of headspace volatile compounds in peaches obtained immediately after various treatment, and Table 1 shows volatile compounds identified in the ripe peach and treated peaches by dynamic headspace sampring/GC-MS. Because of differences in the headspace sampling method between the ripe peach and other treated peaches, quantification data of the ripe peach could not be directly compared to the others. However, from the headspace experiments for the ripe peach, we knew the characteristic constituents of the volatiles. It is considered that the volatiles were directly related to organoleptic characters of the ripe peach.

Aldehydes and Alcohols

Various alchols and aldehydes were identified in C-peach, P-peach, and H-peach, but few were found in the ripe peach. Though most of the alcohols and aldehydes were found in small amounts, great amounts of 1-hexanol (1523.7 ng%), (*E*)-2-hexenol (453.9 ng%), hexanal (3086.5 ng%), and (*E*)-2-hexenal (3491.8 ng%) were found in the C-peach. These alcohols and aldehydes are found in smaller amounts in the P-peach than in the C-peach. These compounds were not detected in the ripe peach. (*E*)-2-Hexenal and (*Z*)-3-hexenol were not detected in the H-peach.

Table 1. Volatile Compounds Identified in Peach by Dynamic Headspace Sampling/GC-MS.

RI[K]	volatiles	concentrations (ng%) ripe	crushed	high-pressure	heat
		Aldehydes			
912	2-methylbutanal	—	+[b]	+[b]	—
978	pentanal	—	—	—	1558.3
1081	hexanal	—	3086.5	462.2	107.1
1183	heptanal	—	—	—	(114.5)[m]
1219	(*E*)-2-hexenal	—	3491.8	205.5	—
1289	octanal	—	—	14.2	26.6
1394	nonanal	0.6	15.6	51.6	300.1
1466	furfural	—	—	—	10.6
1530	benzaldehyde	0.5	495.0	2305.5	132.0
		Ketones			
900	2-butanone	+[b]	+[b]	+[b]	314.4
978	2-pentanone and/or 3-pentanone	3.2	87.8	113.4	—
1206	(4-methyl-2-heptanone)[f]	—	—	—	15.3
1286	3-hydroxy-2-butanone[n]	—	15.2	14.8	—
1326	(2-methyl-3-octanone)[f]	—	—	—	53.6
1339	6-methyl-5-hepten-2-one	0.5	9.3	10.6	20.6
1518	3-nonen-2-one	—	—	—	84.7
1660	1-phenylethanone	0.5	13.8	12.8	33.7
1854	(dihydoro-α(or β)-ionone)[f]	—	—	—	30.7
1956	β-ionone	0.8	8.0	—	—
		Alcohols			
1093	2-methyl-1-propanol	1.3	46.4	26.1	—
1110	3-pentanol[n]	0.7	35.3	35.9	16.5
1149	1-butanol	—	38.9	25.7	37.5
1164	1-penten-3-ol	0.5	(70.7)[m]	(45.3)[m]	21.1
1206	3-methyl-1-butanol	—	40.8	33.6	—
1256	1-pentanol	—	—	—	98.0
1361	1-hexanol	—	1523.7	13.5	10.0
1389	(*Z*)-3-hexenol	0.6	65.8	12.8	—
1411	(*E*)-2-hexenol	—	453.9	10.3	7.2
1469	6-methyl-5-hepten-2-ol	—	31.0	15.0	9.9
1494	2-ethylhexanol	—	15.3	18.8	13.4
1557	linalool	—	174.6	336.9	239.7
1632	(α (or β)-ionol)[f]	—	14.3	37.2	24.2
1671	1-nonanol[n]	—	9.5	10.4	—
1705	α-terpineol	—	5.5	12.9	11.8
1932	(β-phenylethanol)[i]	3.0	161.5	193.6	189.4
		Esters			
829	methyl acetate	128.3	1737.6	1284.3	1005.1
890	ethyl acetate	547.1[b]	10271.4[b]	16885.7[b]	319.4
968	propyl acetate	(3.2)[m]	—	(113.4)[m]	—
978	methyl *n*-butyrate	0.7	—	—	—
1013	2-methyl-1-propyl acetate	21.9	66.1	81.0	29.4
1051	ethyl 2-methylbutyrate	—	—	46.4	—
1072	*n*-butyl acetate	1.6	19.9	28.9	—
1123	3-methyl-1-butyl acetate	(3.1)[m]	(84.4)[m]	(109.9)[m]	—
1164	ethyl crotonate	—	(70.7)[m]	(45.3)[m]	—
1176	pentyl acetate	—	25.7	12.0	—
1187	methyl hexanoate[n]	2.8	—	—	—
1238	ethyl hexanoate[n]	1.1	30.4	23.9	—
1256	3-methyl-2-butenyl acetate	—	20.9	4.9	—
1275	hexyl acetate	3.4	345.4	236.5	—
1291	methyl heptanoate[n]	1.2	—	—	—
1309	((*E*)-3-hexenyl acetate)[f]	—	—	8.4	—
1320	(*Z*)-3-hexenyl acetate	35.1	1831.6	1886.0	502.1

Table 1. (Continued)

RI[K]	volatiles	concentrations (ng%) ripe	crushed	high-pressure	heat
1337	(*E*)-2-hexenyl acetate	(1.2)[m]	258.3	211.6	54.4
1337	ethyl heptanoate[n]	(1.2)[m]	—	—	—
1377	heptyl acetate	0.4	—	11.1	—
1392	methyl octanoate	77.7	—	—	—
1434	(methyl(*Z*)-4-octenoate)[f]	4.0	—	—	—
1466	ethyl octanoate	16.2	16.9	21.2	—
1466	(*E*)-3-hexenyl butyrate	0.7	—	—	—
1480	octyl acetate[n]	0.2	—	3.3	—
1632	methyl benzoate	0.3	—	—	—
1635	(methyl(*Z*)-4-decenoate)[n,t]	11.5	—	—	—
1665	((*Z*)-3-hexenylhexanoate)[n,t]	0.3	—	—	—
1738	benzyl acetate	—	13.4	11.7	9.5
1837	*β*-phenylethyl acetate[IS]	**	**	**	**
		Lactones			
1708	*γ*-hexalactone	3.5	82.0	71.3	67.5
1817	(*γ*-hexalactone)[f]	—	10.5	6.2	—
1934	*γ*-octalactone	0.6	34.2	11.1	12.7
2158	*γ*-decalactone	12.9	396.7	124.6	79.12
2210	*δ*-decalactone	0.9	52.8	10.8	—
		Hydrocarbons			
940	benzane[a]	0.7	—	171.8	106.2
1000	decane[a]	1.6	13.5	20.7	—
1022	chloroform	—	49.7	79.6	118.5
1040	toluene[a]	7.8	49.8	78.4	102.9
1100	undecane[a]	1.3	14.2	12.8	8.2
1125	ethylbenzane[a]	(3.1)[m]	(84.4)[m]	(109.9)[m]	53.41
1134	*p*-xylene[a]	1.3	15.9	21.4	19.9
1141	*m*-xylene[a]	3.8	57.5	56.9	74.2
1183	*o*-xylene[a]	2.8	43.0	(89.0)[m]	(114.5)[m]
1198	limonene	(1.1)[m]	—	9.1	11.1
1200	dodecane	1.0	—	7.1	17.1
1226	4-ethyltoluene	0.8	(20.7)[m]	7.4	(19.7)[m]
1246	1,3,5-trimethylbenzene[a]	—	—	—	14.4
1234	(2-pentylfuran)[f]	0.4	—	—	—
1258	(bicyclo[4.2.0]octa-1,3,5-triene)[f]	0.3	—	33.8	3.8
1265	2-ethyltoluene	0.3	—	—	—
1280	1,2,4-trimethylbenzene[a]	0.9	9.5	14.4	12.3
1300	tridecane	1.5	—	(11.4)[m]	—
1300	1,4-diethylbenzene	—	—	(11.4)[m]	(32.2)[m]
1337	1,2,3-trimethylbenzene[a]	(1.2)[m]	—	—	—
1400	tetradecane	0.6	—	9.3	6.1
1500	pentadecane	1.5	—	16.3	16.6
1700	heptadecane	1.2	—	—	—
1751	naphthalene	—	14.0	25.0	21.2
1927	2,6-di-*tert*-butyl-*p*-cresol	8.1	—	5.7	12.7
		Other			
1183	pyridine	—	—	(89.0)[m]	(114.5)[m]
1446	*p*-dichlorobenzene	1.3	20.7	33.0	31.3
1459	acetic acid	0.4	26.0	37.2	28.9
2015	phenol	—	9.9	9.6	18.1

IS = internal standard. [a]Artifacts from Tenax TA (MacLeod et al. 1986). [b]Overlapped peak; ethyl acetate (major constituent), 2-butanone and 2-methylbutanal (minor constituents). [f]Impurity in internal standard in parentheses. [m]Total amount of overlapped peaks in parentheses. [n]Previously identified in nectarine (Takeoka et al., 1988; Engel et al., 1988). [K]Kovats index (Kováts, 1965). [t]Tentative identification (in parentheses).

These alcohols and aldehydes were produced by the enzyme-induced oxidation of unsaturated fatty acid (mainly linoleic acid and linolenic acid). Horvat et al. (1990) reported that six compounds, such as hexanal, (*E*)-2-hexenal, benzaldehyde, linalool, C_{10} γ-lactone, and C_{10} δ-lactone, are major contributors to the ripe peach aroma. However, it may be considered that the two compounds, hexanal and (*E*)-2-hexenal, are not original aroma constituents but enzyme-induced compounds produced during sample preparations. Large amounts of pentanal, nonanal, and 1-pentanol were found in the H-peach, but the mechanism of the formation is unclear.

Benzaldehyde

The changes in the concentration of benzaldehyde placed in storage at 25 and 40 ℃ are shown in Table 2. A pronounced increase in concentration of benzaldehyde was observed in P-peaches. The concentrations of benzaldehyde ranged from 2305.5 ng% to a maximum of 41675.3 ng% after 1 week at 25 ℃ and 27827.8 ng% after 2 weeks at 40 ℃, and then gradually decreased. Spoilage in P-peaches and H-peaches by microorganisms was not observed during the experiments.

It is well-known that benzaldehyde arises from cyanogenic glycoside, amygdalin, and prunasin, the typical constituents of many *Prunus* species. Amygdalin consists of two molecules of glucose and one molecule of mandelonitrile. Prunasin consists of one molecule each of glucose and mandelonitrile. They yield benzaldehyde, hydrogen cyanide, and glucose by the action of β-glucosidase and mandelonitrile lyase (Cheetham, 1992). Only

Table 2. Concentration Changes of Benzaldehyde in High Pressure Treated and Heat-Treated Peaches in Storage at 25 and 40 ℃, Respectively.

	concentration (ng%)			
	high pressure treated		heat treated	
weeks	25℃	40℃	25℃	40℃
0	2305.5	2305.5	126.1	126.1
1	41675.3	13478.0	160.5	63.4
2	25366.5	27827.8	177.8	193.8
4	21215.5	18820.5	57.7	53.5
6	17523.3	13786.5	62.8	106.1
8	12339.0	8716.7	44.4	32.5

prunasin was detected in the flesh of *P. percica* L. as a cyanogenic glycoside; amygdalin was not detected in it (Mizutani et al., 1979). A large difference in concentration of benzaldehyde was found between C-peaches (495.0 ng%) and P-peaches (2305.5 ng%). It is reasonable to consider that benzaldehyde may be enzymically released from prunasin by disruption of fruit tissue during the pressurizing. The temperature came up from 20 ℃ to 28 ℃ by pressurizing for 3 min. The temperature rise may contribute to the acceleration of the enzymic reactions. In order to survey the effect of high-pressure treatments for the enzyme activity of emulsin, the activities of pressurized and nonpressurized emulsins were assayed by measuring the amount of glucose liberated from amygdalin. Fig. 2 shows the relationship between incubation time and glucose amount released from amygdalin by the pressurized and nonpressurized emulsins. The liberation of glucose from amygdalin by the pressurized emulsin indicates that the activity of the enzyme still remains after the high-pressure treatment (400 MPa, 20 ℃, 10 min). It may be considered that

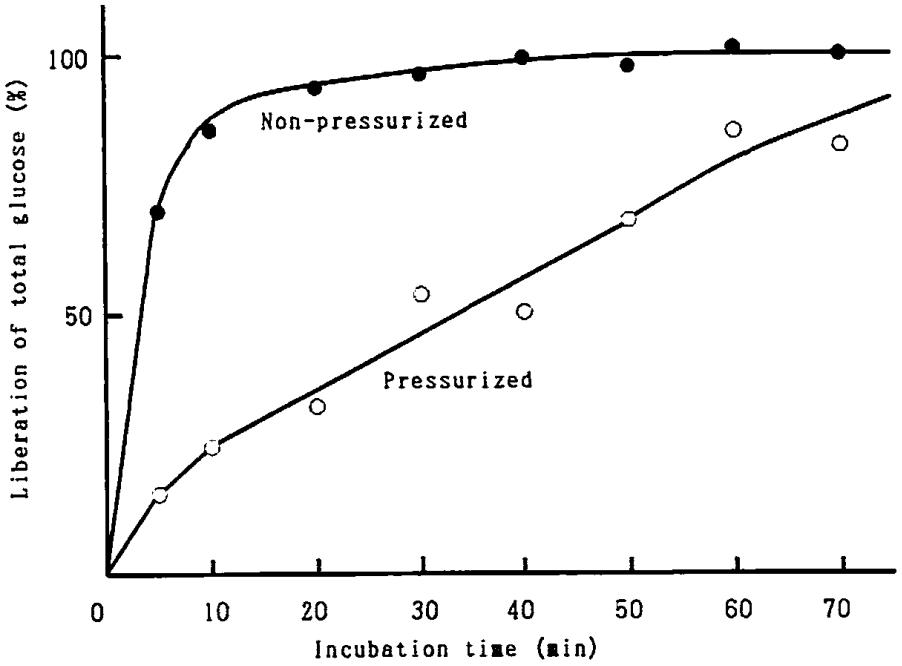

Fig. 2. Liberation of glucose from amygdalin by pressurized (400 MPa, 20℃, 10min) emulsin and nonpressurized emulsin.

the increase to the maximum amount of benzaldehyde shown in Table 2 depends upon the enzyme activity remaining. The gradual decreasing of benzaldehyde from maximum points were observed in storage at 25 and 40 ℃. The factors of the decrease of benzaldehyde is not clear. An amount of hydrogen cyanide equivalent to that of benzaldehyde may be produced from prunasin. Hydrocyanic acid produced by the action of emulsin on the flesh of the peach was detected by cyanide electrode methods after steam-generated distillation (Stoewsand and Anderson, 1973). A concentration of 0.69 ppm of hydrocyanic acid was detected in enzyme-acted peach flesh. The amount of hydrocyanic acid is assumed to be toxicologically insignificant. It is considered that the very small amounts of benzaldehyde detected in the H-peaches were produced by the enzymic hydrolysis of prunasin during heat processing (Vŏldrich and Kyzlink, 1992). The benzaldehyde simultaneously produced may contributed to the flavor quality of P-peaches. Although the H-peach does not have the characteristic smell of benzaldehyde, a faint smell was emitted from the H-peach after emulsin action.

Lactones

It is known that γ-decalactone plays a character impact compound role in peach flavor. Ho et al. (1990) reported that γ-decalactone was glycosidically bound in pineapple; however, in peach, it was not identified in the bound fraction but rather found in the free fraction. The amounts of γ-decalactone of C-peaches and P-peaches were 396.7 ng% and 124.6 ng%, respectively. Table 3 shows the concentration changes of γ-decalactone in P-peaches for 8 weeks. Remarkable concentration changes of γ-decalactone were not observed in P-peaces during storage. This is in agreement with the results that γ-decalactone was found in the free fraction and not detected in the

Table 3. Concentration Changes of γ-Decalactone in High Pressure Treated and Heat-Treated Peaches in Storage at 25 and 40 ℃, Respectively.

	concentration (ng%)			
	high pressure treated		heat treated	
weeks	25℃	40℃	25℃	40℃
0	124.6	124.6	79.1	79.1
1	277.6	239.8	143.8	89.5
2	215.1	136.9	178.1	205.5
4	185.6	146.9	80.5	131.0
6	109.2	185.0	74.0	153.2
8	154.0	222.3	98.8	54.2

Table 4. Concentration Changes of (*Z*)-3-Hexenyl Acetate in High Pressure Treated and Heat-Treated Peaches in Storage at 25 and 40 ℃, Respectively.

	concentration (ng%)			
	high pressure treated		heat treated	
weeks	25℃	40℃	25℃	40℃
0	1886.0	1886.0	502.1	502.1
1	582.0	441.3	1040.7	1026.8
2	389.9	218.5	1383.0	1368.0
4	111.5	104.8	660.4	673.9
6	29.1	33.8	562.7	514.3
8	15.0	12.6	437.1	186.1

bound fraction. Furthermore, the concentration differences between P-peaches and H-peaches were not large, as is shown in Table 3. This also supports the finding that the γ-decalactone is not the glycosidically bound fraction in the peach fruit.

Esters

The esters detected in the peaches were mainly acetates. The major esters found in C-peaches and P-peaches were methyl acetate, ethyl acetate, hexyl acetate, (*Z*)-3-hexenyl acetate, and (*E*)-2-hexenyl acetate. Table 4 shows the changes in the amount of (*Z*)-3-hexenyl acetate in P-peaches and H-peaches in storages at 25 and 40℃. The concentrations cleary decreased in P-peaches, but smaller changes were observed in H-peaches.

Seven esters, methyl hexanoate, ethyl hexanoate, methyl heptanoate, ethyl heptanoate, *n*-octyl acetate, methyl (*Z*)-4-decenoate (tentative identified), and (*Z*)-3-hexenyl hexanoate (tentative identified), found in the ripe peach have not been identified in the white peach. These esters were reported in nectarines (Takeoka et al., 1988; Engel et al., 1988).

Volatiles of the Intact Ripe Peach

Mookherjee et al. (1986) reported the defference in composition of the aroma between living and picked peaches. In this study, we attempted to compare the volatile compounds of ripe fruit and those of crushed fruit. Most large differences were found in the enzyme-induced volatile compounds such as C_6 alcohols, C_6 aldehydes, and benzaldehyde. The ripe fruit emitted the mild fruity peach aroma, but the C-peach has a relatively strong "green" odor. Methyl octanoate was only detected in the ripe peach, which has sweet fruit odor. Mookherjee et al. (1988) reported that methyl octanoate was more predominant in living peaches than picked peaches. This compound has not been found in the volatile compounds obtained from peach (*P. persica* L.) by dynamic headspace sampling (Narain et al. 1990). It can be considered that esters mainly contributed to the fruity and floral note and lactone to the peachy backgraund.

Flavor Quality and Preservation

P-peaches were not spoiled during 2 months strange at 40 ℃. A higher benzaldehyde concentration in P-peaches may contribute to good flavor quality. On the basis of these results, it is probable that high-pressure treatment of peaches will become a useful method for food processing.

LITERATURE CITED

Chapman, G. W., Jr, Horvat, R. J. and Forbus, W. R., Jr.: Physical and chemical changes during the maturation of peaches (Cv. Majestic). *J. Agric. Food Chem.*, 39, 867-870 (1991).

Cheetham, P. S. J.: Novel specific pathways for flavour production. In *Bioformation of Flavours*; Patterson, R. L. S., Charlwood, B. V., MacLeod, G., Williams, A. A., Eds.; The Royal Scoiety of Chemistry: Cambridge, U. K., 1992; pp 101-102

Do, J. Y., Salunkhe, D. K. and Olson, L. E.: Isolation, identification and comparison of the volatiles of peach fruit as related to harvest maturity and arificial ripening. *J. Food Sci.*, 34, 618-621 (1969).

Engel, K. H., Flath, R. A., Buttery, R. G., Mon, T. R., Ramming, D. W. and Teranishi, R: Investigation of volatile constituents in nectarines. 1. Analytical and sensory characterization of aroma components in some nectarine cultivars. *J. Agric. Food Chem.*, 36, 549-553 (1988).

Ho, C. T., Sheen, L. Y., Wu, P., Kuo, M. C., Hartman, T. G. and Rosen, R. T.: Glycosidically bound aroma compounds in pineapple and peach. In *Flavour science and technology*; Bessiere, Y., Thomas, A. F., Eds.; Wiley: Chichester, U. K., 1990; pp 77-80.

Horie, Y., Kimura, K., Ida, M., Yosida, Y. and Ohki, K.: Jampreparation by pressurization. *Nippon Nogeikagaku Kaishi*, 65, 975-980 (1991).

Horvat, R. J. and Chapman, G. W.: Comparison of volatile compounds from peach fruit and leaves (cv. Monroe) during maturation. *J. Agric. Food Chem.*, 38, 1442-1444 (1990).

Horvat, R. J., Chapman, G. W., Jr., Robertson, J. A., Meredith, F. I., Scorza, R., Callahan, A. M. and Morgens, P.: Comparison of the volatile compounds from several commercial peach cultivars. *J. Agric. Food Chem.*, 38, 234-237 (1990).

Jennings, W. G. and Sevenants, M. R.: Volatile components of peach. *J. Food Sci.*, 29, 796-801 (1964).

Josephson, D. B., Lindsay, R. C. and Stuiber, D. A.: Volatile compounds characterizing the aroma of fresh atlantic and pacific oysters. *J. Food Sci.*, 50, 5-9 (1985).

Kováts, E.: Gas chromatographic characterization of organic substances in the retention index system. *Adv. Chromatogr.*, 1, 229-247 (1965).

Krammer, G., Winterhalter, P., Schwab, M. and Schreier. P.: Glycosidically bound aroma compounds in the fruits of *Prunus* species: apricot (*P. armeniaca*, L.), peach (*P. persica*, L.), yellow plum (*P. domestica*, L. spp. Syriaca), *J. Agric. Food Chem.*, 39, 778-781 (1991).

Lim, L. and Romani, R. J.: Volatiles and the harvest maturity of peaches and nectarines. *J. Food Sci.*, 29, 246-253 (1964).

MacLeod, G. and Ames, J. M.: Comparative assessment of the artefact background on thermal desorption of Tenax GC and Tenax TA. *J. Chromatogr.*, 355, 393-398 (1986).

Miwa, I., Okuda, J., Maeda, K. and Okuda, G.: Mutarotase effect on colorimetric determination of blood glucose with β-D-glucose oxidase. *Clin. Chim. Acta.*, 37, 538-540 (1972).

Mizutani, F., Yamada, M., Sugiura, A. and Tomana, T.: The distribution of prunasin and amygdalin in *Prunus* species. *Memories of the College of Agriculture*; Kyoto Univ.: Kyoto, Japan, 1979; Vol. 113, pp 53-65.

Mookherjee, B. D., Trenkle, R. W., Wilson, R. A., Zampino, M., Sands, K. P. and Mussinan, C. J.: Fruit and flowers: live vs dead-which do we want? In *Flavours and Fragrances: A World Perspective*; Proceedings of 10th International Congress of Essential Oils, Fragrances and Flavors, Washington, DC, Nov 16-20, 1986; Lawrence, B. M., Mookherjee, B. D., Willis, B. J., Eds.; Elsevier Publishers: New York, 1988, pp 415-424.

Narain, N., Hsieh, T. C. Y. and Johnson, C. E.: Dynaminc headspace concentration and gas chromatography of volatile flavor components in peach. *J. Food Sci.*, 55, 1303-1307 (1990).

Robertson, J. A., Horvat, R. J., Lyon, B. G., Meredith, F. I., Senter, S. D. and Okie, W. R.: Comparison of quality characteristics of selected yellow-and white-freshed peach cultivars. *J. Food Sci.*, 55, 1308-1311 (1990a).

Robertson, J. A., Meredith, F. I., Horvat, R. J. and Senter, S. D.: Effect of cold storage and maturity on the physical and chemical characteristics and volatile constituents of peaches (Cv. Cresthaven). *J. Agric. Food Chem.*, 38, 620-624 (1990b).

Sevenants, M. R., Jennings, W. G.: Volatile components of peach. II. *J. Food Sci.*, 31, 81-86 (1966).

Spencer, M. D., Pangborn, R. M. and Jennings, W. G.: Gas chromatographic and sensory analysis of volatiles from cling peaches. *J. Agric. Food Chem.*, 26, 725-732 (1978).

Stoewsand, G. S. and Anderson, J. L.: Hydrocyanic acid in canned sweet cherries. *J. Food Sci.*, 38, 1256 (1973).

Takeoka, G. R., Flath, R. A., Güntert, M. and Jennings, W.: Nectarine volatiles: vacuum steam distillation versus headspace sampling. *J. Agric. Food Chem.*, 36, 553-560 (1988).

Tatuka, K., Suekane, S., Sakai, Y. and Sumitani, H.: Volatile constituents of kiwi fruit flowers: simultaneous distillation and extraction versus headspace sampling. *J. Agric. Food Chem.*, 38, 2176-2180 (1990).

Vŏldrich, M. and Kyzlink, V.: Cyanogenesis in canned stone fruits. *J. Food Sci.*, 57, 161-162 (1992).

Watanabe, M., Arai, E., Kumeno, K. and Honma, K.: A new method for producing a non-treated jam sample: the use of freeze concentration and high-pressure sterilization. *Agric. Biol. Chem.*, 55, 2175-2176 (1991).

Received for review July 13, 1993. Revised manuscript received December 1, 1993. Accepted December 17, 1993.⊗

Registry No. Supplied by Author:

2-Methylbutanal, 96-17-3; pentanal, 110-62-3; hexanal, 66-25-1; heptanal, 111-71-7; (*E*)-2-hexenal, 6728-26-3; octanal, 124-13-0; nonanal, 124-19-6; furfural, 98-01-1; benzaldehyde, 100-52-7; 2-butanone, 78-93-3; 2-pentanone, 107-87-9; 3-pentanone, 96-22-0; 4-methyl-2-heptanone, 6137-06-0; 3-hydroxy-2-butanone, 513-86-0; 2-methyl-3-octanone, 923-28-4; 6-methyl-5-hepten-2-one, 110-93-0; 3-nonen-2-one, 14309-57-0; 1-phenylethanone, 98-86-2; dihydro-α-ionone, 31499-72-6; dihydro-β-ionone, 17283-81-7; β-ionone, 14901-07-6; 2-methyl-1-propanol, 78-83-1; 3-pentanol, 584-02-1; 1-butanol, 71-36-3; 1-penten-3-ol, 616-25-1; 3-methyl-1-butanol, 123-51-3; 1-pentanol, 71-41-0; 1-hexanol, 111-27-3; (*Z*)-3-hexenol, 928-96-1; (*E*)-2-hexenol, 928-95-0; 6-methyl-5-hepten-2-ol, 1569-60-4; 2-ethylhexanol, 104-76-7; linalool, 78-70-6; α-ionol, 25312-34-9; β-ionol, 22029-76-1; 1-nonanol, 143-08-8; α-terpineol, 98-55-5; β-phenylethanol, 60-12-8; methylacetate, 79-20-9; ethyl acetate, 141-78-6; propyl acetate, 109-60-4; methyl n-butyrate, 623-42-7; 2-methyl-1-propyl acetate, 110-19-0; ethyl 2-methylbutyrate, 7452-79-1; *n*-butyl acetate, 123-86-4; 3-methyl-1-butyl acetate, 123-92-2; ethyl crotonate, 10544-63-5; pentyl acetate, 628-63-7; methyl hexanoate, 106-70-7; ethyl hexanoate, 123-66-0; 3-methyl-2-butenyl acetate, 1191-16-8; hexyl acetate, 142-92-7; methyl heptanoate, 106-73-0; (*E*)-3-hexenyl acetate, 3681-82-1; (*Z*)-3-hexenyl acetate, 3681-71-8; (*E*)-2-hexenyl acetate, 2497-18-9; ethyl heptanoate, 106-30-9; heptyl acetate, 112-06-1; methyl octanoate, 111-11-5; methyl (*Z*)-4-octenoate, 21063-71-8; ethyl octanoate, 106-32-1; (*E*)-3-hexenyl butyrate, 53398-83-7; octyl acetate, 112-14-1; methyl benzoate, 93-58-3; methyl (*Z*)-4-decenoate, 7367-83-1; (*Z*)-3-hexenyl hexanoate, 31501-11-8; benzyl acetate, 140-11-4; β-phenylethyl acetate, 103-45-7; γ-hexalactone, 695-06-7; γ-heptalactone, 105-21-5; γ-octalactone, 104-50-7; γ-decalactone, 706-14-9; δ-decalactone, 705-86-2; benzenze, 71-43-2; decane, 124-18-5; chloroform, 67-66-3; toluene, 108-88-3; undecane, 1120-21-4; ethylbenzene, 100-41-4; *p*-xylene, 106-42-3; *m*-xylene, 108-38-3; *o*-xylene, 95-47-6; limonene, 7705-14-8; dodecane, 112-40-3; 4-ethyltoluene, 622-96-8; 1,3,5-trimethylbenzene, 108-67-8; 2-pentylfuran, 3777-69-3; bicyclo [4.2.0] octa-1,3,5-triene, 694-87-1; 2-ethyltoluene, 611-14-3; 1,2,4-trimethylbenzene, 95-63-6; tridecane, 629-50-5; 1,4-diethylbenzene, 105-05-5; 1,2,3-trimethylbenzene, 526-73-8; tetradecane, 629-59-4; pentadecane, 629-62-9; heptadecane, 629-78-7; naphthalene, 91-20-3; 2,6-di-*tert*-butyl- *p*-cresol, 128-37-0; pyridine, 110-86-1; *p*-dichlorobenzene, 106-46-7; acetic acid, 64-19-7; Phenol, 108-95-2.

⊗Abstract published in *Advance ACS Abstracts*, February 1, 1994.