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Light-Induced Off-flavor Development in Cloudy Apple Juice

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Cloudy apple juice has been found to develop off-flavors during storage in daylight. The development of off-flavors and volatile compounds was monitored in reconstituted juice prepared from 'Golden Delicious' and 'Fuji' apple concentrates stored in glass bottles under fluorescent light (3000 lx, 8 °C). A strong metallic off-flavor was formed by photooxidation. A major contributor to the off-flavor was identified as 1-octen-3-one by gas chromatography–olfactometry. In addition, six volatile compounds, pentanal, 2-methyl-1-penten-3-one, hexanal, (*E*)-2-heptenal, 6-methyl-5-hepten-2-one, and (*E*)-2-octenal, increased significantly after light exposure and could contribute to the off-flavor. Except for pentanal and hexanal, these volatiles were found only after light exposure. Higher levels of volatiles were observed in juice from 'Golden Delicious' apples than in juice from 'Fuji' apples, and this difference was consistent with higher levels of suspended solids. When the suspended solids were removed by centrifugation, the development of volatiles on exposure to light was reduced significantly.

KEYWORDS: Apple juice; off-flavor; photooxidation

INTRODUCTION

Food products displayed on shelves in convenience stores, which may be open 24 h per day and 365 days per year, are constantly exposed to fluorescent light, and stores are tending to increase the brightness of the lighting. Furthermore, technical developments in the processing of foods allow the expiration date to be extended and, therefore, the light exposure of products in stores has increased. Recent developments in the storage of food products have, therefore, increased concern about the influence of light. Light is known to enhance oxidation of food components, causing deterioration of fats and vitamins and changes in color and flavor (*1*). Beverage companies have sometimes found that fruit juices have developed a metallic or mushroom-like flavor after light exposure. Undesirable oxidative flavors in dairy products induced by light exposure have been studied since the 1960s. Stark and Forss (*2*) identified the component contributing a metallic off-flavor in oxidized butter as 1-octen-3-one, which was likely to be derived from linoleic or arachidonic acids. Downey (*3*) suggested that fluorescent light could induce oxidative off-flavors, and other researchers have reported light-induced off-flavors in dairy products more recently (*4–8*). However, there are few reports of off-flavor development in fruit juices. In one study, Umekawa (*9*) found metallic off-flavor present in grapefruit juice stored in a PET bottle and detected 1-octen-3-one, 3-methoxy-1-butanol, anisaldehyde, and α-cardinol as volatile components. Pfannhauser et al. (*10*) reported the changes in light-exposed orange lemonades in which α- and β-pinene, mycrene, linalool, and γ-terpinene reduced in concentration and α-terpineol, carvone, and *trans*-carveol increased.

Fats and lipids are possible precursors of light-induced off-flavors. They are present as phospholipids derived from plant cells, as wax from the peel, and as triacylglycerols of seeds, and small amounts of those lipids from fresh fruit may be extracted into squeezed juice. According to the nutritional information, commercial fruit juice contains approximately 0.1 g of fat in 100 mL. The odor threshold value of 1-octen-3-one in water is 0.1 μg L^{-1} (*11*), and 1-*cis*-5-octadien-3-one, derived from the oxidation of fats and known to be a metallic flavored compound, has the very low threshold of 1.2×10^{-3} μg L^{-1} in water (*12*). Thus, degradation of fats and lipids present in low concentrations in fruit juice might cause undesirable flavors. Terpenes are also possible precursors. Monoterpenes such as limonene and citral extracted from lemon (*Citrus limon*) decomposed after exposure to UV radiation and caused off-flavors (*13, 14*). Anet (*15, 16*) and Rowan and co-workers (*17, 18*) suggested that 6-methyl-5-hepten-2-one was formed by the autoxidation of α-farnesene (sesquiterpene), which was induced by physiological disorders including superficial scald of fresh apples. In addition, some tetraterpenes, β-carotene and lycopene, may undergo oxidative cleavage to form 6-methyl-5-hepten-2-one (*19*).

A FAS/USDA report (*20*) estimated that apple juice production in the world was 1.4 million metric tons for the market year 2004/2005. The flavor of apples has been widely studied.

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In the early 1980s Dimick and Hoskin (*21*) published a comprehensive review of apple flavor. Almost 200 compounds have been listed in 22 references as flavor components of apple juice (*22*). It is known that processing (e.g., pasteurization, filtration) can influence the flavor of apple juice (*23*). We have observed consistently over a number of years the development of an off-flavor in cloudy apple juice that was not apparent in clear juice. We do not believe that the development of such light-induced flavor changes in apple juice has been reported previously. In this study, this off-flavor development in cloudy apple juices prepared from concentrates was investigated for two apple cultivars, namely 'Golden Delicious' and 'Fuji'.

MATERIALS AND METHODS

Apple Juice. Cloudy apple juices used in the experiments were reconstituted from concentrate. Unlike clear apple juice, the cloudy juice is not subjected to enzyme treatment before concentration. Concentrated juices ('Golden Delicious' and 'Fuji') were obtained commercially in 2005, transported, and stored in a frozen condition until use (for a maximum of 1 year). Reconstituted cloudy apple juices were adjusted to 12.0 °Brix with an RFM 80 digital refractometer (Bellingham + Stanley Ltd., Tunbridge Wells, U.K.) with deionized water at room temperature. Suspended solids were calculated on the basis of wet weight (percent) separated by centrifuging 1.5 mL samples at 7200*g* for 10 min ($N = 10$) by a Force Digital Microcentrifuge (Labnet International Inc., Windsor, U.K.). Aliquots of the reconstituted apple juices were centrifuged at 9500*g* for 15 min to reduce suspended solids using a Sorvall RC-6 centrifuge. A commercial product of cloudy apple juice was obtained from a local market and used for the sensory evaluation.

Chemicals. Bromobenzene (≥99.5%) and pyridinium chlorochromate (98%) were purchased from Sigma-Aldrich Co. Ltd. (Poole, U.K.). 2-Methyl-1-penten-3-ol (99%) was purchased from Alfa Aesar (Heysham, U.K.). The following compounds were used for identification: pentanal (97%), 1-penten-3-one (97%), butyl acetate (99%), hexanal (98%), 2-methylbutyl acetate (99%), (*E*)-2-pentenal (95%), 1-butanol (95%), 1-pentanol (99+%), (*E*)-2-heptenal (98%), 6-methyl-5-hepten-2-one (99%), (*E*)-2-octenal (94%), and (*E*,*E*)-2,4-heptadienal (90%) from Sigma-Aldrich Co. Ltd.; (*E*)-2-butenal (98+%), heptanal (97%), 1-octen-3-one (97%), and 1-octen-3-ol (98%) from Alfa Aesar; hexyl acetate (98+%) from IFF (Suffolk, U.K.); benzaldehyde (98+%) from Fisher Scientific UK Ltd. (Loughborough, U.K.). Solvents used were methanol (AnalaR grade), dichloromethane (AnalaR grade), and diethyl ether (AnalaR grade) from Merck Ltd. (Poole, U.K.).

Synthesis of 2-Methyl-1-penten-3-one. This was prepared by oxidation of 2-methyl-1-penten-3-ol (100 mg) with pyridinium chlorochromate in dichloromethane using the method described by Corey and Suggs (*24*). After reaction, the product was dissolved in diethyl ether and washed with 0.01 M sodium bicarbonate and saturated sodium chloride solution. The organic layer was dried with anhydrous sodium sulfate and analyzed by GC-MS. The linear retention index (LRI) of synthesized 2-methyl-1-penten-3-one was 1069 on the INNOWAX column (i.d. 0.25 mm, 0.25 μm, Agilent, Palo Alto, CA); mass spectrum: *m*/*z* (%) 29 (18), 39 (35), 41 (95), 57 (17), 69 (100), 98 ([M^+] 35).

Storage of Apple Juice with Light Exposure. Soon after adjustment of the concentration according to Brix value, each 100 g sample was stored in a glass bottle with 30% air headspace. Then samples were continuously exposed to fluorescent light (3000 ± 100 lx) and kept at 8 °C in a cold room for up to 72 h. Apple juice samples were taken from the cold room every 12 h for flavor analysis. Simultaneously, equivalent samples were stored in the dark as a reference control (0 h). The centrifuged samples were similarly treated by exposure to fluorescent light or storage in the dark.

Headspace Concentration. Solid-phase microextraction (SPME) was performed on the headspace above the apple juices using a 75 μm carboxen/polydimethylsiloxane (PDMS) fiber mounted in an SPME manual holder assembly (Supelco, Poole, U.K.). Prior to extraction, the fiber was conditioned for >30 min in the injection port of the GC-MS at 250 °C. Cloudy apple juice (20 g), containing bromobenzene (750 ng in 1.5 μL of methanol) as an internal standard and a stirring bar, was placed in a 40 mL amber vial and capped with a PTFE septum. The vial was incubated for 10 min, before the SPME fiber was exposed to the sample headspace for 45 min. Then it was retracted into the needle for 5 min and removed from the vial. Sample temperature was maintained at 35 °C during the extraction of volatiles. Each sample was extracted in triplicate.

Gas Chromatography–Mass Spectrometry (GC-MS). Analysis was carried out by a Hewlett-Packard 5890 series II gas chromatograph connected to a 5972 series mass selective detector and a G1701AA Chemstation with a 60 m INNOWAX column (i.d. 0.25 mm, 0.25 μm, Agilent). A section of column nearest to the injection port was cooled in a beaker of powdered solid carbon dioxide to cryofocus the volatiles. Volatile compounds were desorbed from the SPME fiber onto the front of column for 3 min. The injection port was in splitless mode, and split flow was programmed to turn on after 0.5 min. The temperature of the injector was 250 °C. After fiber desorption, the solid carbon dioxide was removed and the GC program started. The oven temperature was kept at 40 °C for 2 min and programmed to increase at 4 °C min^{-1}. The final temperature was set at 250 °C and held for a further 10 min. Helium was used as carrier gas with a flow rate of 1.0 mL min^{-1}. The mass spectrometer was operated in electron impact mode at 70 eV. Scan range and scan speed were *m*/*z* 29–400 and 2.05 scans s^{-1}, respectively. The LRI values of detected compounds were determined by comparison of retention times with those for a series of *n*-alkanes (C_6–C_{25}), which were analyzed in a separate analysis under the same conditions. The compounds were identified by comparison of mass spectra and LRI with those from authentic compounds.

The approximate quantities of all identified compounds were estimated by comparing the peak areas in the total ion chromatogram with that of the internal standard. Seven selected compounds, which were increased more significantly than other compounds, were estimated every 12 h (up to 72 h), and two ions from each compound were used [*m*/*z* 44 and 58 for pentanal, *m*/*z* 69 and 98 for 2-methyl-1-penten-3-one, *m*/*z* 56 and 82 for hexanal, *m*/*z* 70 and 83 for 1-octen-3-one, *m*/*z* 83 and 112 for (*E*)-2-heptenal, *m*/*z* 108 and 126 for 6-methyl-5-hepten-2-one, and *m*/*z* 83 and 97 for (*E*)-2-octenal]. The first ion of each compound and the ion *m*/*z* 158 of bromobenzene were used to estimate each compound. The relative peak areas of seven compounds were estimated by comparing the peak areas in the selected ion chromatogram with that of the internal standard (*m*/*z* 158), and the proportion of each compound (percent) was calculated relative to the amount present after 48 h of exposure.

Sensory Evaluation. Nine trained Japanese panelists who were experienced in the sensory evaluation of apple juices were used. Initially the panelists were asked to describe the characteristics of the light-induced off-flavors in cloudy apple juice obtained from a local market. These descriptions were made in Japanese and translated to English for presentation in this paper. Then the panelists evaluated by tasting the cloudy apple juices ('Golden Delicious' and 'Fuji') exposed to light for 0, 12, 24, and 48 h and scored the intensities of the off-flavor of each sample on a 9-point scale. No off-flavor detected was given a score of 1, and very strong off-flavor was given a score of 9. All samples (approximately 40 mL) were served in transparent plastic cups at cooled temperature (8–15 °C) in random order and coded with random numbers. The same test was repeated the next day to duplicate the data.

Gas Chromatography–Olfactometry (GC-O). This was performed on a Hewlett-Packard 5890 series II gas chromatograph using a 60 m Rtx-5MS column (i.d. 0.25 mm, 0.25 μm, Thames Restek, Buckinghamshire, U.K.). The detectors were an ODO II odor port (SGE International Pty Ltd., Ringwood, Australia) and a flame ionization detector (FID), which were connected to a column flow splitter (50/50). Nine panelists described the odor of each individual compound eluting from the odor port. Only descriptions that were repeated twice by the same assessor or that three or more panelists agreed upon were used as valid. Injection method, oven temperature, and other conditions were the same as used for GC-MS except for a final temperature of 350 °C. GC-MS was performed with a similar nonpolar column (VF 5ms, 60 m, i.d. 0.25 mm, 0.25 μm, Varian, Oxford, U.K.) to determine relevant compounds for each description by comparison of LRI.

Table 1. Mean Light-Induced Off-flavor Intensity Scores by Trained Panelists for Cloudy Apple Juice Exposed to Fluorescent Light at 8 °C for Different Time Periods[a]

light-exposed period (h)	'Golden Delicious'	'Fuji'
0	1.4 a	1.2 a
12	4.8 cd	2.8 b
24	6.3 d	4.7 c
48	7.9 e	6.1 d

[a] Means with different letters are significantly different ($P < 0.05$).

Statistical Analysis. The data obtained for quantities of flavor compounds were processed by SPSS 14.0 using one-way analysis of variance (ANOVA) and post hoc range tests by least significant difference (LSD). The probability for statistical significance was set at $P < 0.05$. For the sensory data two-way ANOVA was used with treatment and panelist as variables.

RESULTS AND DISCUSSION

The flavors of the cloudy apple juices ('Golden Delicious' and 'Fuji') that had been exposed to light were described by the sensory panel as metallic, plastic-like, oxidized, rotten, and waxy. None of these descriptions were used for the unexposed samples. **Table 1** shows the sensory evaluation scores for the overall off-flavor in 'Golden Delicious' and 'Fuji' apple juices that were exposed to fluorescent light (3000 lx) for 0, 12, 24, and 48 h. Exposure to light at 3000 lx for 48 h was considered to be equivalent to holding at 300 lx (typical of the lighting level in a food store) for 20 days. The score for the intensity of light-induced off-flavor increased with increasing time of exposure. The score for 'Golden Delicious' apple juice was higher than that for 'Fuji' for the same period of exposure. All panelists perceived light-induced off-flavor in 'Golden Delicious' juice exposed to fluorescent light for 12 h and in 'Fuji' juice exposed for 48 h.

The headspace from light-exposed reconstituted cloudy apple juices ('Golden Delicious' and 'Fuji') showed the presence of a number of lipid degradation products, including alkenals, an alkadienal, and alkenones, which were absent from the unexposed juices (**Table 2**). Indeed, the unexposed juices showed very few compounds above the detection limit (0.1% total ion chromatogram peak area of internal standard). Some or all of these compounds were considered to contribute to the light-induced off-flavor. Although many esters have been reported in other apple juices, only butyl acetate, 2-methylbutyl acetate, and hexyl acetate were identified in cloudy 'Golden Delicious' apple juice. This may reflect the relatively small sample size used and the mild volatile extraction conditions used. However, thermal processing for concentration may cause the loss of these flavor components.

GC-O was carried out to determine the relative importance of the headspace volatiles to the off-flavor (**Table 3**). This showed that several compounds had unpleasant odors including unsaturated aldehydes and ketones, which have been associated previously with lipid oxidation off-flavors (*11*, *12*). In particular, 1-octen-3-one, which has a metallic, mushroom-like flavor, is probably a major contributor to the light-induced off-flavor. This odor was detected by all nine assessors in the GC-O. However,

Table 3. Odors Detected by GC-O in Headspace Extract of Cloudy Apple ('Golden Delicious') Juice with Off-flavor

odor description	LRI[a]	relevant compound[b]	frequency[c]
rubber, sulfur, sweaty, wooden	748	2-methyl-1-penten-3-one	6
cut grass, fresh, green apple	801	hexanal	9
apple-like, fruity, pungent	849	–	4
biscuit, caramel fatty, grassy, sweet	959	(*E*)-2-heptenal	7
metallic, moldy, mushroom	978	1-octen-3-one	9
bad, earthy, geranium, spicy, unpleasant,	989	6-methyl-5-hepten-2-one	6
almond, fatty, frying oil, oily	1073	(*E*)-2-octenal	4
fatty, nutty, roasted nut	1144	–	4

[a] Linear retention index on a Rtx 5MS column. [b] Relevant compound was determined by the comparison of LRI between GC-O and GC-MS; (–) shows unknown compound. [c] Number of assessors observing odor.

Table 2. Approximate Quantities[a] of Volatile Compounds Identified in Cloudy Apple Juice, Comparing Two Varieties and the Effect of Removing Suspended Solids by Centrifugation

		not centrifuged				centrifuged			
		'Golden Delicious'		'Fuji'		'Golden Delicious'		'Fuji'	
compound	LRI[b]	cont[c]	exp[d]	cont[c]	exp[d]	cont[c]	exp[d]	cont[c]	exp[d]
pentanal	978	16 c	58 f	5 a	24 d	16 bc	31 e	4 a	11 b
1-penten-3-one	1020	–	5 d	–	3 c	–	2 b	–	1 a
(*E*)-2-butenal	1050	–	2.0 a	–	–	–	–	–	–
2-methyl-1-penten-3-one	1069	–	37 c	–	12 b	–	13 b	–	4 a
butyl acetate	1075	6 a	10 b	–	–	–	–	–	–
hexanal	1081	22 bc	63 e	11 a	36 d	24 c	24 c	10 a	15 ab
2-methylbutyl acetate	1128	0.8 a	0.8 a	–	–	–	–	–	–
(*E*)-2-pentenal	1134	–	1.3 a	–	–	–	–	–	–
1-butanol	1146	6 b	6 b	0.5 a	1.0 a	7 b	–	–	–
heptanal	1186	–	1.6 a	–	–	–	–	–	–
1-pentanol	1244	1.4 b	2.4 c	0.5 a	1.2 b	–	–	–	–
hexyl acetate	1269	0.7 a	0.9 b	–	–	–	–	–	–
1-octen-3-one	1305	–	40 d	–	22 c	–	20 b	–	7 a
(*E*)-2-heptenal	1332	–	52 d	–	26 c	–	20 b	–	9 a
6-methyl-5-hepten-2-one	1338	–	12 d	–	5 c	–	4 b	–	1 a
(*E*)-2-octenal	1425	–	11 d	–	5 c	–	3 b	–	1 a
1-octen-3-ol	1451	–	1.7 b	–	0.9 a	–	–	–	–
(*E*,*E*)-2,4-heptadienal	1497	–	2.5 b	–	1.1 a	–	–	–	–
benzaldehyde	1530	–	1.3 b	–	1.0 a	–	–	–	–

[a] Approximate quantities (ng) in headspace from 20 g of sample were estimated by comparison with 750 ng of bromobenzene internal standard; mean values of triplicate analyses are given; compounds identified below 0.5 ng are reported as not detected (–). [b] Linear retention index on an INNOWAX column. [c] Control sample stored in the dark at 8 °C. [d] Light-induced sample exposed to fluorescent light for 48 h at 8 °C. Means with different letters within a row are significantly different ($P < 0.05$). All compounds were identified by comparison of mass spectrum and LRI with those of authentic compounds.

it is likely that some or all of the other unsaturated compounds contributed to the light-induced off-flavor in the apple juices. Hammond and Hill (*25*) suggested that in the off-flavor of oxidized milk fat the overall odor comprised contributions from several different aldehydes and ketones. Unsaturated fatty acids occur at a total concentration of about 0.1 mg mL^{-1} in cloudy apple juice from concentrate (*26*). (*E*)-2-Heptenal and (*E*)-2-octenal are known autoxidation products of linoleic acid (*11*). 1-Octen-3-one may be formed from arachidonic acid (*11*), but arachidonic acid was not reported as a component of apple juice (*26*), and it is more likely that it is formed by photooxidation of linoleic acid. Two other unsaturated ketones, 6-methyl-5-hepten-2-one and 2-methyl-1-penten-3-one, both containing methyl branched chains, were also likely contributors to the light-induced off-flavor. 6-Methyl-5-hepten-2-one may have been formed from α-farnesene, which is a significant terpene in fresh apples. However, most α-farnesene is lost during processing, and only trace amounts of α-farnesene were reported in processed juice (*27*); therefore, it is difficult to explain the apparent formation on exposure of the processed juice to light. 2-Methyl-1-penten-3-one, which had an unpleasant odor described as rubber, sulfur, sweaty, or wooden (**Table 3**), has previously been reported as a volatile component in blackberry, strawberry, kiwi fruit, and rehydrated French beans (*28*–*32*). It contains a methyl branch and therefore is not an expected oxidation product from normal straight-chain lipids. The compound was not commercially available and, therefore, it was synthesized to confirm its identity in the cloudy apple juice.

The total amount of volatile compounds in the cloudy 'Golden Delicious' juice was higher than that in cloudy 'Fuji' juice (**Table 2**). In addition, 'Golden Delicious' juice after light exposure contained significantly more lipid oxidation volatiles than the 'Fuji' juice (**Table 2**). These differences between varieties could be explained by the amount of suspended solid in each juice; suspended solids in the juices were 1.91 ± 0.18 and 1.16 ± 0.26% in the 'Golden Delicious' and 'Fuji' juices, respectively. This indicates that the insoluble fraction could contain precursors of the lipid-derived flavor components. Gheyas et al. (*33*) reported that dietary fiber in the apple flesh of 'Fuji' is present at a lower concentration than in 'Golden Delicious', and Kakiuchi et al. (*27*) reported that the amount of pulp in pasteurized cloudy juice from 'Fuji' apples is lower than that from 'Golden Delicious' apples. To confirm that the suspended solids were the source of the off-flavor, volatile compounds were analyzed after centrifugation of the cloudy apple juices (**Table 2**). This resulted in a significant decrease in all of the unsaturated aldehydes and ketones, clearly demonstrating that their precursors were associated with the suspended solids.

Quantities of off-flavor compounds were lower in 'Fuji' juice than in 'Golden Delicious' juice (**Table 2**). When changes in the volatiles were monitored over a period of 72 h, differences between the varieties were found in the rates of volatile formation and in the behavior of individual volatiles (**Figures 1**–**3**). It was found that the unsaturated aldehydes and ketones in 'Fuji' juice did not increase after 60 h. The development of volatiles on exposure to light showed different behavior for alkanals (**Figure 1**), (*E*)-2-alkenals, and vinyl ketone (**Figure 2**) and unsaturated methyl-branched ketones (**Figure 3**). Hexanal and pentanal were detected in the control sample (stored in the dark) and increased gradually before achieving an equilibrium (**Figure 1**); they reached the maxima at 36 and 60 h for 'Golden Delicious' and 'Fuji' juices, respectively. On the other hand, 1-octen-3-one, (*E*)-2-heptenal, and (*E*)-2-octenal increased

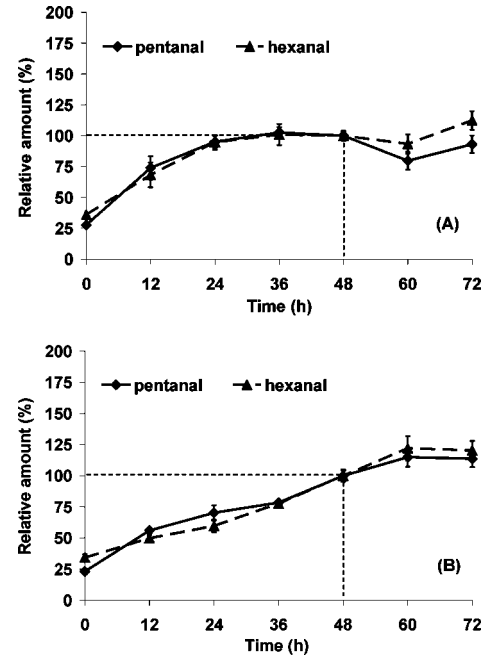

Figure 1. Formation of alkanals in cloudy apple juice under fluorescent (3000 lx) light at 8 °C: (**A**) 'Golden Delicious'; (**B**) 'Fuji'. Relative amount (percent) was calculated on the amount present after 48 h of exposure (equal to 100%), based on the comparison of peak area with 750 ng of bromobenzene used as an internal standard. Error bars show standard deviation from three replicate analyses.

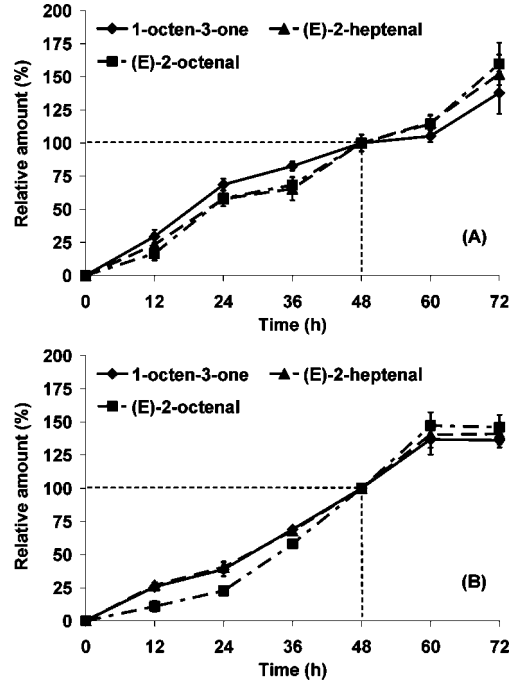

Figure 2. Formation of 1-octen-3-one and (*E*)-2-alkenals in cloudy apple juice under fluorescent (3000 lx) light at 8 °C: (**A**) 'Golden Delicious'; (**B**) 'Fuji'. Relative amount (percent) is calculated on the amount after 48 h of exposure (equal to 100%), based on the comparison of peak area with 750 ng of bromobenzene used as an internal standard. Error bars show standard deviation from three replicate analyses.

rapidly (**Figure 2**) and continued to increase for up to 72 h in 'Golden Delicious' juice. After 72 h, these amounts were approximately 50% higher than those after light exposure for 48 h. **Figure 3** shows that 2-methyl-1-penten-3-one and 6-methyl-5-hepten-2-one were not detected at 0 h, and formation of

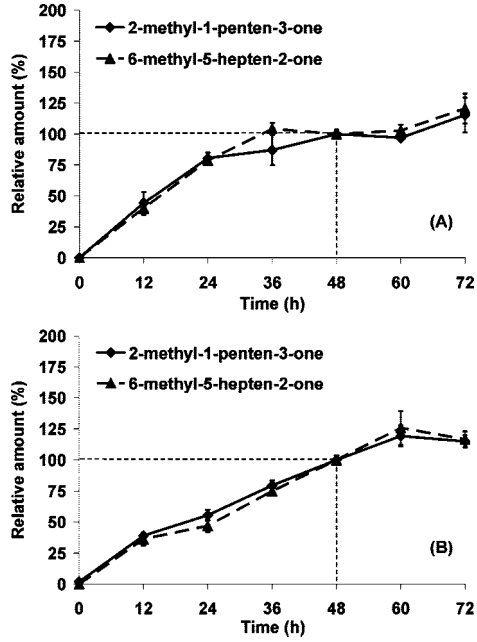

Figure 3. Formation of unsaturated methyl-branched ketones in cloudy apple juice under fluorescent (3000 lx) light at 8 °C: (**A**) 'Golden Delicious'; (**B**) 'Fuji'. Relative amount (percent) is calculated on the amount after 48 h of exposure (equal to 100%), based on the comparison of peak area with 750 ng of bromobenzene used as an internal standard. Error bars show standard deviation from three replicate analyses.

these compounds had nearly stopped by 36 h in 'Golden Delicious' juice and by 60 h in 'Fuji' juice.

The three patterns of off-flavor development suggest a different mechanism for the formation of these groups of components. Unsaturated fatty acids are well-known precursors of straight-chain aldehydes and ketones. On the other hand, 6-methyl-5-hepten-2-one is known to be formed from the oxidation of terpenes such as α-farnesene and lycopene. Therefore, the formation of volatiles by exposure to light is thought to proceed by more than one mechanism.

In summary, off-flavor volatiles were induced in cloudy apple juice after it was exposed to fluorescent light. Comparison between 'Golden Delicious' and 'Fuji' showed that the amount of off-flavors was higher in the former. When suspended solids in cloudy apple juice were reduced by centrifugation, the formation of light-induced off-flavors was significantly decreased, indicating that these solids were the source of the off-flavor.

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