Influence of Packaging on the Aroma Stability of Strawberry Syrup during Shelf Life

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Different types of packaging (glass bottle, PVC, and PET) were compared for the preservation of aroma quality of a strawberry syrup during shelf life. Esters, alcohols, and aldehydes were analyzed by solid-phase micro-extraction (SPME) and solvent extraction. During storage, hydrolysis of esters in acids and alcohols led to a modification of the aroma profile which can be explained by the replacement of "fruity" and "fresh" notes by "dairy note" in the syrup. Aroma compounds that are responsible for fruity notes, such as methyl cinnamate, methyl anthranilate, and methyl dihydro-jasmonate, were strongly reduced after 90 days. This could be explained by a selective interaction of these compounds with the polymer matrix (PET or PVC). After 330 days, a later and important decrease of the "fruity notes" occurred in both PETs; so PVC2 and the glass bottle were found to be able to maintain a balanced aroma for long-term storage.

Keywords: *Aroma; packaging; strawberry; syrup; PET; PVC; SPME*

INTRODUCTION

In Europe, fruit syrups are very popular drinks, especially for children, because of their relatively low sugar and high aroma content. For these syrups, thermoplastic packaging displays many advantages: among them, it is cheap, and it is easily processed and formed.

Strawberry syrup is one of those most consumed by children. The characteristic strawberry aroma is due to a well-balanced and complex composition of numerous volatile compounds (aldehydes, alcohols, and esters) (*1, 2*) in particular with typical sensory notes ("fresh strawberry " and "wood strawberry "). Sorption of aroma compounds by polymers may induce weakening of both flavor and taste intensities (*3*), and because of selectivities of volatile compounds relative to polymer, this leads to unbalanced aroma during syrup shelf life. Within studies of this topic, degradation of the quality of citrus juices packed in polymers has been the subject of intensive research (*4–7*). In recent years, Feigenbaum et al. (*8*), showed that sorption of labile compounds such as terpens could have positive effects, by preventing the formation of undesirable reaction products.

The purpose of our research was to compare PVC and PET for the preservation of aroma quality of a strawberry syrup during shelf life, taking into account aroma reactivity. In this first paper, we report on methods for evaluation of aroma reactivity in the fruit syrup as well as the influence of the polymer. The aroma and packaging material interactions will be reported later.

MATERIALS AND METHODS

Strawberry Syrup. Strawberry syrup was obtained by mixing a saccharose syrup (°Brix: 64.5 ± 1) and fruit juices (strawberry, elder, and lemon juices). Aromatization was made with nature-identical flavoring substances. The pH of the strawberry syrup was 2.65 ± 0.2 and its shelf life was 18 months.

Packaging Materials. Strawberry syrups were conditioned in nonplastified PVC (PVC1 and PVC2: thickness, 1 mm) and in amorphous PET (PET1 and PET2: thickness, 0.75 mm) and were stored at 20 °C. The ratio of surface area/volume in dm^2/L was approximately 5.

An additional sample was conditioned in a glass bottle (GL) as a reference to test the stability of the syrup without the influence of polymer interaction.

Solvent Extraction. Volatile compounds in the strawberry syrup were extracted three times with dichloromethane. Syrup (200 mL), 200 mL of Milli-Q ultrapure water (Millipore, Bedford, MA), and 500 μL of tridecane solution (as internal standard, 25 μL/50 mL) were mixed in 1-L flasks with 80, 30, and 30 mL of distilled dichloromethane for 30 min, 15 min, and 15min, respectively, at 0 °C while stirring. Organic phases were separated from aqueous phases and pooled.

The dichloromethane extracts were dried over anhydrous Na_2SO_4 and concentrated with the use of a Kuderna-Danish column.

Headspace–Solid-Phase Micro-Extraction (HS–SPME) Analysis. Volatile compounds in the strawberry syrup headspace were extracted using a 100-μm solid-phase micro-extraction (SPME) fiber (Supelco Co., Bellefonte, PA) coated with poly (dimethylsiloxane) (PDMS). Syrup (5 g) was mixed with 5 mL of Milli-Q ultrapure water and 2.23 g of NaCl into a Mininert-valve-capped 20-mL vial (Supelco, PA). A solution (100 μL) of ethyl pentanoate in methanol (160 μL/L) was added as internal standard. The vial was placed into a water bath regulated at 50 °C and a magnetic stirrer was used for gentle sample mixing.

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Table 1. Aroma Compounds of the Strawberry Syrup Identified in SPME and Solvent Extracts

volatile compound	code	sensory note	method[a]	Kovats index FFAP[b]	C_o mg/L[c]
ethyl butanoate	BE	fruity	1	1040	
ethyl 2-methylbutanoate	2MBE	fruity, strawberry	1, 2	1045	257.5
ethyl 3-methylbutanoate	3MBE	fruity, apple	1, 2	1060	166.8
3-methyl-1-butanol	3M1OL	herbaceous	2	1206	
butyl butanoate	BB	fruity	1, 2	1216	24.6
ethyl hexanoate	HE	fruity, strawberry	1, 2	1232	167.5
3-methylbutyl butanoate	B3MB	unpleasant	1, 2	1262	
hexyl acetate	AcH	fruity, light	1, 2	1272	152.5
3-methylbutyl-3-methylbutanoate	3MB3MB	fruity, synthetic	1, 2	1293	134.5
3(Z)-hexenyl acetate	Ac3H	fruity, unpleasant	1, 2	1317	142.2
1-hexanol	HOH	herbaceous	2	1354	110.0
3(E)-hexen-1-ol	3HOHc	mentol	1, 2	1384	687.0
hexyl butanoate	BH		1, 2	1413	
3(Z)-hexenyl butanoate	B3H	fruity, light	1, 2	1459	75.3
furfural	FURal	roasted peanut	2	1465	
octyl acetate	AcO	sweet	1, 2	1477	
benzaldehyde	Bzal		2	1510	
linalool	LIOL		2	1552	
1-octanol	OCT		2	1560	
octyl butanoate	BO	fruity, rose	1, 2	1615	
butanoic acid	AB	unpleasant, cheese	2	1630	
ethyl benzoate	BzE	wildstrawberry	1, 2	1653	47.5
3 and 2-methylbutanoic acid	AMB	unpleasant	2	1671	63.8
α-terpineol	AT		2	1689	
ethyl salicylate	2OHBzE	fruity, wildstrawberry	1, 2	1791	120.4
hexanoic acid	AH	unpleasant, cheese	2	1847	53.4
phenymethanol	PHME	flower, synthetic	2	1871	
methyl cinnamate	CIME	strawberry jam	1, 2	1946	
maltol	MAOL	nougat, roasted	2	1954	205.0
1-(2furyl)-2-hydroxyethanone	FHEON		2	1989	
2,5-dimethyl-4-hydroxy-(2H)-furan-3-one (furaneol)	FURA	caramel, strawberry	2	2031	
dimethyl anthranilate	DMAN		2	2050	120.0
methyl cinnamate	CIME2	fruity, flower	1, 2	2062	530.5
γ-decalactone	GDL	fruity, peach apricot	1, 2	2126	339.2
methyl anthranilate	ANME	sweet, honey	2	2225	
methyl dihydrojasmonate	DHJM	fruity, wildstrawberry	2	2274	72.8
2-hydroxymethy-furfural	HMFUR		2	2505	
vanillin	VANI	fruity, rose	2	2553	

[a] 1, SPME; 2, solvent. [b] Retention indices on FFAP except for BE on C20M. [c] Co, initial concentration of the main aroma compounds in the solvent extract.

The sample was equilibrated for 60 min. The SPME fiber was then inserted through the valve into the headspace for 2 min and then removed for GC analysis. Two bottles were analyzed at each tested time. Volatile sampling was done in duplicate for each bottle.

GC analysis of SPME extraction was performed using a Girdel model 30 with a FID detector. Volatiles were desorbed from the SPME fiber during 3 min into the splitless injector. Separations were performed on a Supelcowax fused-silica capillary column (0.32 mm × 30 m; 0.5 μm; Supelco, Bellefonte, PA). GC analysis of the SPME extraction was performed with a flame ionization detector. Hydrogen was used as the carrier gas (linear flow velocity, 40 cm/sec). Signal was treated with a data acquisition software (Borwin Version 1.2, JMBS Developments, Le Fontanil, France) for quantification.

Gas Chromatography Analysis and Gas Chromatography−Olfactometry (GC−O) Analysis of Solvent Extracts. The analysis was carried out using a Fisons gas chromatograph equipped with a split-spitless injector, a flame ionization detector, a sniffing port, and a fused-silica capillary column (30 m × 0.32 mm i.d.) coated with DB−FFAP (J&W Scientific-Chromoptic, 0.25 μm film thickness).

Hydrogen was used as the carrier gas. The temperatures of the injector and detector were set at 240 °C and 250 °C, respectively. The oven temperature was programmed from 40 °C (for 5 min) to 240 °C at 3 °C/min.

Sniffing of the extracts was realized by 3 trained panelists who were told to evaluate the odor of the eluted compounds.

Mass Spectra Analysis. Identifications of the constituents were made by gas chromatography−mass spectrometry (GC−MS). The GC−MS system consisted of a Fisons GC-8000

chromatograph and a MD 800 mass spectrometer (Fisons Instruments, Les Ulis, France). Separations were performed on a Supelcowax fused-silica capillary column (0.32 mm × 30 m; 0.5 μm; Supelco, Bellefonte, PA). Linear flow velocity of helium was 32 cm/sec. The column was held at 30 °C for 10 min and then programmed to 240 °C for SPME analysis and 260 °C for solvent extracts at 5 °C/min. Split-splitless injector was at 230 °C. Samples were injected in splitless mode for SPME fiber and in splitless/split for solvent extract (split valve was closed 30 s). Electron-impact mass spectra were recorded with the following conditions: capillary direct interface, 250 °C; ion source, 200 °C; ionization voltage, 70 eV; mass range, 29−300 m/z; electron multiplier voltage, 450 V; scan rate 3 scans/s.

Mass spectral matches were made by comparison of NIST and INRAMASS mass spectra libraries. Kovat's Indices of authentic compounds compiled in INRAMASS library were used to confirm identification.

RESULTS AND DISCUSSIONS

Identification of the Aroma Compounds. To take into account any distortion of the chromatographic profile of the syrup due to a specific analytical procedure, two methods were used in parallel: extraction of volatiles on a solid-phase microextraction fiber (SPME) — a quick method, and solvent extraction. Thirty-eight volatile compounds were identified in the strawberry syrup with a majority of esters. The initial concentrations (C_o) of the main aroma compounds were deter-

Table 2. Repeatability of the SPME Analysis According to Temperature and Salt Addition

compound	pure syrup 50 °C (% RSD)	pure syrup 70 °C (% RSD)	NaCl diluted syrup (% RSD)
ethyl butanoate	16	19.7	6
ethyl 2-methylbutanoate	13.7	21.7	4
ethyl 3-methylbutanoate	14.1	25.1	5
ethyl hexanoate	15.4	19.4	6
3-methylbutyl butanoate	13.7	21	6
hexyl acetate	16	20.8	8
3-methylbutyl 3-methylbutanoate	13.9	15.8	6
3(Z)-hexenyl acetate	19.6	17.2	8
1-hexanol	5	11.5	16
3(E)-hexen-1-ol	15.9	11.1	15
3(Z)-hexenyl butanoate	12.5	13.5	4
ethyl benzoate	5	11.7	11
ethyl salicylate	4.8	8.5	9
methyl cinnamate	4.8	9	13
γ-decalactone	4.9	14.7	13
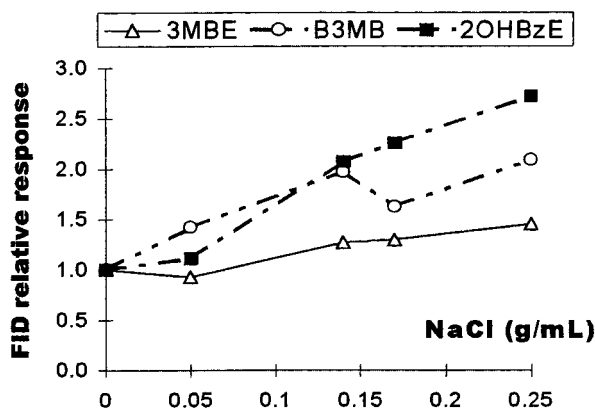
Figure 1. Effect of salt addition on FID response of some of the flavor compounds analyzed by SPME adsorption. See Table 1 for codes.

mined by internal calibration in the solvent extract of the syrup conditioned in the glass bottle, just after its production (~7 days) (Table 1).

SPME Optimization. It is well-known that experimental conditions, such as the temperature of equilibration of volatile compounds between the headspace and the fiber, the concentrations of added salts have critical effects, and must be carefully adjusted for each type of substrate. (*9–11*)

In most cases, SPME analysis sensitivity changed with increasing salt concentration. Increasing salt concentrations gave rise to three groups of behavior (Figure 1), which were respectively represented by ethyl 3-methylbutanoate, 3-methylbutyl butanoate, and ethyl salicylate: very volatile group (ethyl 3-methylbutanoate, ethyl butanoate, ethyl 2-methylbutanoate, hexyl acetate, 1-hexanol, and 3(E)-Hexen-1-ol); intermediate group (3-methylbutyl butanoate, ethyl hexanoate, 3-methylbutyl 3-methylbutanoate, and 3(Z)-hexenyl butanoate); and highest-boiling-point compounds group (ethyl salicylate, ethyl benzoate, methyl cinnamate, and γ-decalactone). FID responses increased up to a factor of 3 between 0 and 0.25 g/mL of NaCl. The upper concentration tested in this study was 0.25 g/mL; this corresponded to the saturation limit in the diluted syrup.

The major effect was noticed for high-boiling-point compounds such as ethyl salicylate. Generally, the presence of an electrolyte in an adsorption system can influence the adsorption by decreasing the solubility of hydrophobic compounds in the aqueous phase. As ionic strength increased, Henry's law constants of volatile organic compounds increased, which in turn favored the partitioning of hydrophobic compounds into the air phase, in particular for the high-boiling-point compounds (*12*).

As the best sensitivity was obtained with 0.25 g of NaCl/L, this optimized NaCl concentration was used for further analysis.

Two equilibration temperatures were tested: 50 °C and 70 °C. Increasing temperature leads to an increased sorption of the high-boiling-point compounds such as methyl cinnamate and γ-decalactone. However, the repeatability is better at 50 °C, in particular for very volatile compounds (Table 2). At 70 °C, a larger desorption of these volatiles from the SPME fiber occurred.

The precision of the method with the retained conditions was estimated by performing five replicate adsorption–desorptions on SPME fiber (Table 2). The corresponding standard deviation (expressed as percent relative standard deviation, % RSD) values ranged between 4 and 18%; for most compounds, it was below 10%.

Comparison of the Scope of SPME and Solvent Extraction Methods. The two methods gave complementary GC profiles of the most important aroma compounds (Figure 2). The SPME method favored the determination of the most volatile compounds such as acetates or branched esters (3(Z)-hexenyl butanoate and 3-methylbutyl 3-methylbutanoate). In the solvent extract, hydrophilic (acids and alcohols) and high-boiling-point compounds are well represented. These two methods were used simultaneously to evaluate the evolution of volatiles in glass packaging.

Stability of Aroma Compounds during Time in Glass Packaging. Evolution of the aroma compounds in the glass bottle was evaluated by both extraction methods.

By SPME analysis, the behaviors of the more volatile compounds can be classified into three groups (Figure 3): Group A, which includes butyl butanoate **BB**, hexyl butanoate **BH**, 3-(E)-hexenyl butanoate **B3H**, octyl butanoate **BO**, 3-methylbutyl butanoate **B3MB**, and ethyl hexanoate **HE**; Group B, which consists of ethyl 2-methylbutanoate **2MBE**, ethyl 3-methylbutanoate **3MBE**, 3-methylbutyl 3-methylbutanoate **3MB3MB**; and Group C, which includes ethyl butanoate **BE**, hexyl Acetate **AcH**, 3-(E)-hexenyl acetate **Ac3H**, and octyl acetate **AcO**. Similar results were obtained by solvent extraction.

The decrease of volatile compound concentrations during 225 days storage ranged between 40% (Group B) and 80% (Group C). The stability decreased in the
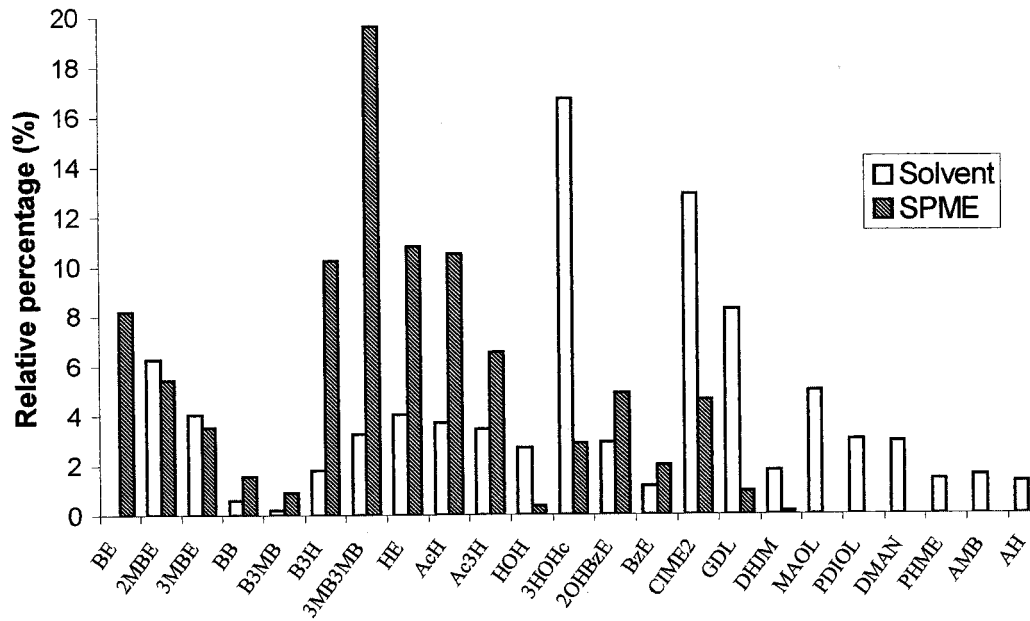
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Figure 2. Comparison of the strawberry syrup extracts obtained by solvent and SPME analysis.
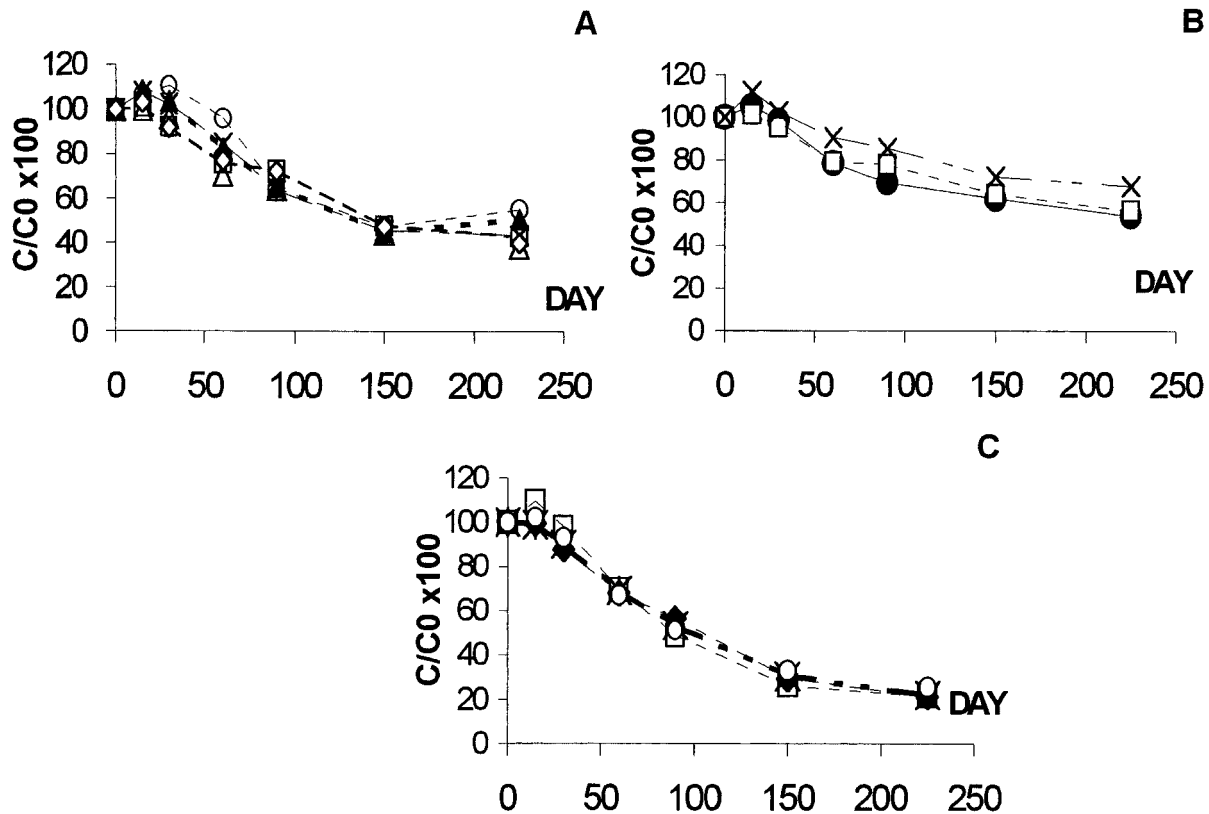

Figure 3. Effect of storage time on the relative concentration of volatile compounds (SPME analysis) of the strawberry syrup. See Table 1 for codes. Group A: BB(□), BH (▲), B3H (X), BO (O), B3MB (△), HE (□). Group B: 2MBE (●), 3 MBE (□), 3MB3MB (X). Group C: BE (O), AcH (■), Ac3H (∗), AcO (♦)

following sequence: B > A > C. The regression of Ln (C/Co) against time (Table 3) for the three groups showed that the degradation rate displayed a first order kinetic. The larger reactivity of group C esters can be explained by the low steric hindrance around their carboxyl group (acetic acid esters, methyl or ethyl esters), in contrast to linear longer chain esters (group A) and especially to branched esters (group B), which are much more resistant to hydrolysis. Fast decreasing of esters, especially for hexyl acetate was already noticed

for strawberry juice (*8*), and in deep frozen strawberries (*14*).

The general decrease of the ester concentrations could be explained by their hydrolysis and formation of the corresponding acids and alcohols (Figures 4A and 4B). These formations were followed by solvent extraction, as only this method allowed the quantification of the more polar and the less volatile compounds. For example, the amounts of hexyl butanoate (BH) and 3-methylbutyl butanoate (B3MB) significantly decrease,
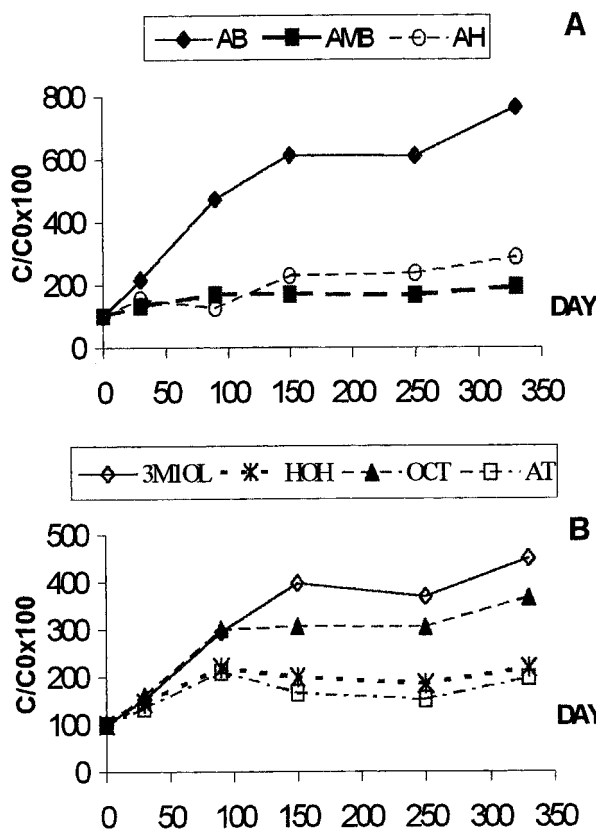
Figure 4. Formation of acids (A) and alcohols (B) in the strawberry syrup stored in glass bottle during time, solvent extraction.

Table 3. Degradation Rates of Volatiles from Groups A, B, and C in Glass Packaging: Regression of Ln (C/CO) as a Function of Storage Time (day) (See Table 1 for Code)

	compound	slope	intercept	r^2
group A	BB	−0.0042	0.017	0.96
	B3MB	−0.0048	0.015	0.96
	BH	−0.0041	0.0438	0.84
	B3H	−0.0046	0.065	0.91
	BO	−0.0041	0.091	0.89
	HE	−0.0045	0.0371	0.97
group B	2MBE	−0.0031	0.0113	0.92
	3MBE	−0.0027	0.0023	0.96
	3MB3MB	−0.0022	0.0579	0.91
group C	BE	−0.0067	0.0351	0.97
	ACH	−0.0075	0.0564	0.98
	AC3H	−0.0073	0.0513	0.98
	ACO	−0.008	0.0948	0.95

and the concentrations of butanoic acid (AB) and hexanol (HOH) or 3-methyl butanol (3M1OL) increase. These variations explain the lower perception of fruity notes and higher perception of dairy notes in the syrups during storage.

The typical strawberry note found in fresh syrups may be due to methyl cinnamate, ethyl salicylate, methyl dihydrojasmonate, and ethyl benzoate. These compounds decreased (Figure 5) during the storage. The corresponding sensory notes detected by sniffing in the extracts (fresh attribute, strawberry, and wild strawberry) were not detected by the panelists after 90 days of storage.

Furanic compounds such as furfural, furaneol, 1-(2−furyl)-2-hydroxyethanone, and hydroxymethyl-2-furancarboxaldehyde were produced during storage (Figure 6). These compounds are responsible for cooked, cara-
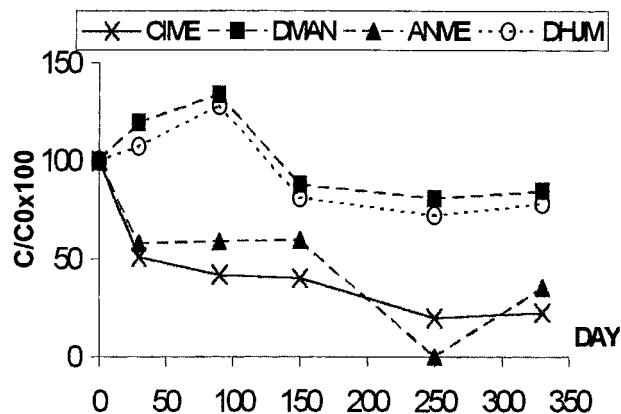

Figure 5. Effect of storage time in glass bottle on the relative concentration of "wild strawberry and fresh note" aroma, solvent extraction.
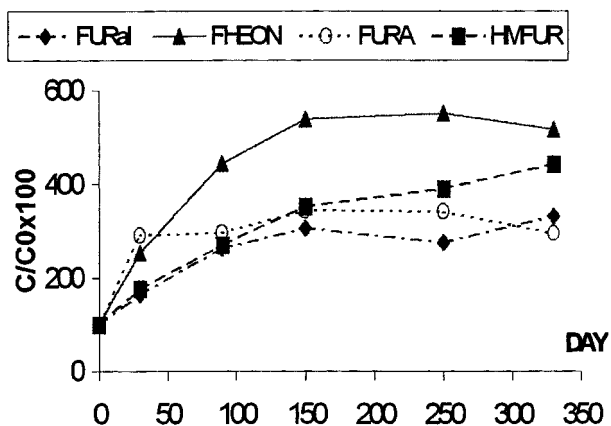

Figure 6. Formation of furanic compounds in the strawberry syrup stored in glass bottle during time, solvent extraction.

mel, and dairy notes, and they have also been found in strawberry jam (*15*).

The concentrations of vanillin and maltol are stable during storage.

Effect of Packaging on the Stability of Aroma Compounds during Storage Time. During the 5 first months of storage, only a few compounds showed significant differences in their amounts in the syrups stored in the different packagings. However, after 250 and 330 days of storage, 19 compounds showed significant differences at a probability level of 5% by Student Newman Keuls test. Table 4 shows the classification for each significant compound from the highest to the lowest value for the different packagings.

At 250 days, esters were present in greater concentrations in both PET samples than in the glass bottle and PVC 1. In glass bottle, degradation of esters was greater and the compounds formed according to Maillard reaction, such as furaneol, were more abundant.

At 330 days, the classification of the different packagings was different from that obtained at 250 days. This can be explained by a later degradation of esters in both PETs, in comparison with the two PVCs. Most of the esters giving the sensory note "fresh strawberry", such as methyl cinnamate, methyl dihydrojasmonate, and dimethyl anthranilate were found in greater amounts in glass bottles and in lower amounts in PVC 1.

A PCA carried out with these 19 variables shows a good discrimination between the packagings on the principal plane (Figure 7) and summed up the results

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Table 4. Classification of the 19 Significant Compounds by Student Newman Keuls Test from the Highest to the Lowest Value for the Different Packaging Types (GL, Glass Bottle) at 250 and 330 Days

code	Student Newman Keuls test after 250 days	Student Newman Keuls test after 330 days
2MBE	PET1 PET2 PVC2 PVC1 GL	PVC2 GL PET2 PET1 PVC1
3MBE	PET1 PET2 PVC2 PVC1 GL	PVC2 GL PET2 PET1 PVC1
HE	PET1 PET2 PVC2 PVC1 GL	PVC2 GL PET2 PET1 PVC1
3MB3MB	PET2 PET1 PVC2 GL PVC1	PVC2 PET2 GL PET1 PVC1
3HOHt	PVC2 PET2 PET1 PVC1 GL	PVC2 PET2 PVC1 PET1 GL
BH	PET2 PET1 PVC2 PVC1 GL	PET2 PET1 PVC2 PVC1 GL
Bzal	PVC2 PVC1 PET2 PET1 GL	PVC2 PVC1 PET1 PET2 GL
BzE	PET1 PET2 PVC2 GL PVC1	PVC2 GL PET2 PET1 PVC1
AT	PET2 PET1 PVC2 GL PVC1	GL PVC2 PET PET2 PVC1
2OHBzE	PET2 PET1 PVC2 GL PVC1	PVC2 GL PET2 PET1 PVC1
AH	PET1 PET2 PVC2 GL PVC1	PVC2 GL PET2 PET1 PVC1
CIME	PVC1 PET2 PET1 PVC2 GL	PET2 PVC2 PET1 PVC1 GL
FURA	GL PET2 PET1 PVC2 PVC1	GL PET1 PET2 PVC2 PVC1
DMAN	PET2 PET1 GL PVC2 PVC1	GL PVC2 PET1 PET2 PVC1
CIME2	PET2 PET1 PVC2 GL PVC1	GL PVC2 PET1 PET2 PVC1
GDL	PET2 PET1 PVC2 PVC1 GL	PVC2 GL PET2 PET1 PVC1
ANME	PVC2 PVC1 PET1 PET2 GL	PET2 PET1 PVC1 PVC2 GL
DHJM	PET2 PET1 PVC2 GL PVC1	PVC2 GL PET1 PET2 PVC1
ACIN	PET1 PET2 GL PVC2 PVC1	PVC2 GL PET1 PVC1 PET2

of the previous variance analysis. After 250 days of storage, esters are present in lower amounts in syrups stored in glass or PVC1 than those in PETs, except methyl anthranilate (ANME) which is present in a greater amount in PVC1. The proportions of these compounds in the different syrups mainly explains the separation of the packagings along axis 1 (Figure 7). Furaneol (FURA) is formed by Maillard reaction in the syrups and is present in a greater amount when glass was used as the packaging. Its concentration increases for the different packagings up to 150 days, then decreases more rapidly when syrups were stored into PVC1. Benzaldehyde (Bzal) was formed during storage in a greater amount when PVC1 was used. The amounts of these two compounds mainly explain the separation of the packagings along axis 2.

After 330 days of storage, the representation of the samples on the principal plane of PCA is quite different (Figure 8). This could be explained by a later degradation of the esters in the syrups stored in PETs than in those stored in PVC1. At this time of storage, syrups stored in glass contain a greater amount of most of the flavor compounds except for benzaldehyde and methyl anthranilate. The greater amount of furaneol in glass packaging can be the result of a better stabilization of

these compounds in this packaging. This volatile compound is a keynote in the flavor of strawberry (*16*), and it has a very low threshold level of 0.03 ppb in water (*17*). This compound has a strawberry-like aroma at low concentration and caramel-like aroma at higher concentration.

CONCLUSION

The main phenomenon observed during the storage of syrup is the hydrolysis of esters in acids and alcohols. This modification explained the replacement of "fruity note" by "dairy note".

Disappearance of "wild strawberry note" detected by sniffing at the very beginning of the storage could be explained by the decrease of methyl cinnamate and methyl anthranilate. After 90 days, aroma compounds that are responsible of fruity notes, such as methyl salicylate, dimethyl anthranilate, and methyl dihydrojasmonate, were strongly reduced. The difference in the oxygen transfer through amorphous PET and rigid PVC cannot explain this result, as they are quite similar, respectively 4.4×10^{-11} cm^2 sec^{-1} Pa^{-1} and 3.4×10^{-11} cm^2 sec^{-1} Pa^{-1} (*18*). This could be explained by a selective interaction of these compounds with the poly-
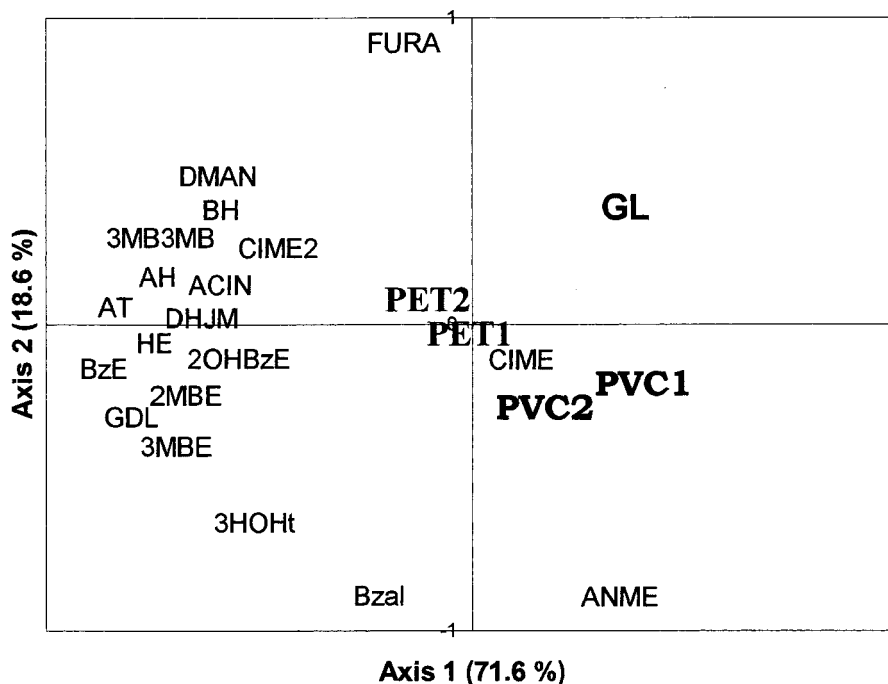
Figure 7. PCA of the 19 significant volatile compounds at 250 days for the three kinds of packaging. See Table 1 for codes.
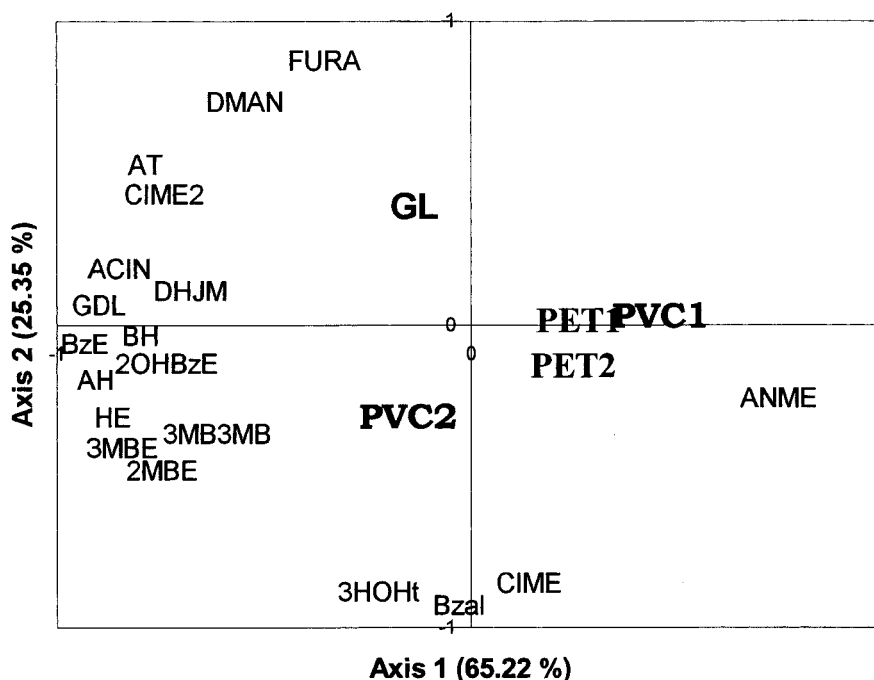

Figure 8. PCA of the 19 significant volatile compounds at 330 days for the three kinds of packaging. See Table 1 for codes.

mer matrix (PET or PVC). These interactions took place together with the degradation of the aroma compounds into the syrup, as we can see in glass bottle. The interactions of the volatile compounds and the different packaging materials will be reported in a later paper.

Until 250 days, strawberry syrups stored in both PET samples were the richest in aroma compounds in comparison with those stored in glass bottle and PVC2. Syrups conditioned in PVC1 were very poor in aroma compounds.

After 330 days and due to a late and important decrease of the "fruity notes" in the two PETs, PVC2 and glass bottle proved to be good enough packagings to maintain an acceptable strawberry aroma.

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