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Quality changes in yogurt during storage in different packaging materials

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Abstract

The influence of packaging polymers (polypropylene or polystyrene) on the sensory and physicochemical characteristics of flavoured stirred yogurts with either 0% or 4%-fat content was investigated during the 28 days of storage at 4 °C. Regardless of the packaging type, complex viscosity and thickness perception increased during storage due to exopolysaccharide production, whereas the pH of yogurts decreased. Packaging type had a greater impact on 0%-fat yogurts than on 4%-fat yogurts for both sensory and physicochemical characteristics. During storage, 0%-fat yogurt conditioned in glass displayed the lowest aroma quantity decrease of the three types of packaging, in accordance with the olfactory properties. However, between the two polymer types, polystyrene packaging seemed to be preferable for limiting aroma compound losses and subsequent fruity note intensities, and for avoiding the development of odour and aroma defects. Less significant packaging effect was observed for 4%-fat yogurts.

Keywords: Yogurt; Packaging polymer; Sensory profile; Aroma release

1. Introduction

Yogurt is a very popular fermented milk product, widely consumed all over the world. To preserve its inherent quality during storage and, in particular, its physicochemical and sensory characteristics, packaging is essential. However, due to the short storage time and low-temperature storage conditions, the influence of polymer properties on the evolution of fresh dairy products has not been adequately studied and was often based on model systems in the past (Van Willige, Linssen, & Voragen, 2000). Linssen, Verheul, Roozen, and Posthumus (1992) studied the sorption of aroma compounds from flavoured drink yogurts by packaging material (polyethylene). Even at low temperatures (4 °C), these authors observed a decrease of aroma compounds.

More studies have been devoted to products with a long storage time, such as orange juice (Berlinet, Ducruet, Brillouet, Reynes, & Brat, 2005). The sorption of aroma compounds by polymeric packaging (or "flavour scalping") may alter the organoleptic quality of products, and results in a decrease of the olfactory intensity or a modification of the olfactory profile (Nielsen & Jagerstad, 1994; Sajilata, Savitha, Singhal, & Kanetkar, 2007; Van Willige, Schoolmeester, van Ooij, Linssen, & Voragen, 2002). Different factors can influence this sorption of aroma compounds by packaging: the type of packaging material, the nature of aroma compounds, the composition of the food matrices and the external environment (temperature, storage time, humidity, etc.) (Ducruet, Fournier, Saillard, Feigenbaum, & Guichard, 2001; Van Willige, Linssen, Legger-Huysman, & Voragen, 2003). For example, polar polymer materials

Abbreviations: G, glass; PP, polypropylene; PS, polystyrene; SPME, solid-phase microextraction; PDMS, polydimethylsiloxane; M, mouth; O, odour; A, aroma; T, taste; ANOVA, analysis of variance; PCA, principal component analysis; SNK, Student–Newman–Keuls.

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such as polycarbonate or polyethylene terephthalate can absorb smaller quantities of apolar terpenes (limonene and myrcene) than non-polar polymer materials such as linear low-density polyethylene or oriented polypropylene (Van Willige et al., 2002). The structure of a packaging polymer has an influence on the sorption of aroma compounds because sorption is mainly possible in the amorphous area of the polymer. Thus, sorption of aromas by a polymer decreases with the increase of crystalline regions (Van Willige et al., 2002). Only a few studies have investigated the influence of packaging on sensory properties (Pieper, Borgudd, Ackermann, & Fellers, 1992; Van Aardt, Duncan, Marcy, Long, & Hackney, 2001). Among these studies, it was shown that an orange juice stored in a glass bottle at 4 °C for 24 weeks could not be differentiated from a juice packaged in a low-density polyethylene packaging material, even though a reduction of D-limonene of up to 50% by absorption into the packaging was observed (Pieper et al., 1992).

Regardless of the packaging material, some changes in the quality characteristics of yogurt may also appear during storage. A decrease in the pH and sourness of fresh dairy products was observed during storage and was often associated with an increase of yogurt viscosity explained by post-acidification (Abu-Jdayil & Mohameed, 2002; Lubbers, Decourcelle, Vallet, & Guichard, 2004; Martin, Skokanova, Latrille, Beal, & Corrieu, 1999; Salvador & Fiszman, 2004). Aroma compound composition can also be modified. For example, it was shown that aldehydes, terpenes and esters decreased during storage in the headspace of flavoured dairy bases (Harasawa et al., 1998; Lubbers et al., 2004). The decrease of aroma compound release in the headspace has been explained by an increase of the yogurt viscosity during storage and thus by the stronger interactions between the aroma compounds and the matrix network. But pH modification could also modify the physicochemical interactions between the aroma compounds and the matrix during storage.

Although the yogurt perception has been extensively studied in the literature (Sodini, Remeuf, Haddad, & Corrieu, 2004), to our knowledge the study of the influence of packaging type on flavoured dairy products has been limited. In this context, the aim of the present study was to investigate the influence of the type of packaging material: (i) a semi-crystalline polymer (polypropylene, PP) and (ii) a totally amorphous and vitreous polymer (polystyrene, PS), on both physicochemical and sensory characteristics of flavoured stirred yogurts during storage. To do so, yogurts with either 0% or 4%-fat content flavoured with the same strawberry aroma were investigated. The aroma release, the rheological properties and the olfactory and texture perceptions of yogurts were monitored on the 2nd, 14th and 28th days of storage at 4 °C on both yogurts (0% and 4%-fat), and compared to yogurts stored under the same conditions in glass packaging.

2. Materials and methods

2.1. Yogurt production

Two flavoured stirred yogurts were studied with either 0% or 4%-fat content. The premix compositions for the two yogurts are given in Table 1.

For 4%-fat yogurt, the first stage of yogurt production was the reconstitution of the milk base starting from an emulsion with a two-stage homogeniser (APV1000, APV, France). After this step, sucrose was added in the mix. For 0%-fat yogurt, skim milk powder and sucrose were mixed with water to reconstitute the milk. The two milk bases were then heated at 92 °C for 5 min. Fermentation was carried out in a 7-l fermenter (SGI, France) and thermostated at 44 °C. The milks were inoculated with *Lactobacillus delbrueki* sp. *bulgaricus* (LB18 incorporated into 0.005% v/v in milk) and *Streptococcus thermophilus* (ST7 and ST143 in 0.01% v/v), provided by Chr Hansen (Arpajon, France). Fermentation was stopped when the yogurt pH reached 4.6 and then stored at 4 °C.

Yogurts were flavoured 24 h after fermentation with 0.1% (w/w) strawberry aroma containing 17 aroma compounds mixed with propylene glycol (Aldrich, France). Concentrations of aroma compounds in yogurts are presented in Table 2. These concentrations ranged from 1.01 to 32.53 mg/kg of yogurt. The flavouring step was performed with a food processor (Kenwood, United States) under controlled conditions (2 kg of yogurt per batch, 30 s, 2.5 power). More details on fermentation and flavouring are given in Saint-Eve, Lévy, Martin, and Souchon (2006).

After flavouring and starting from the same batch, the yogurts were immediately conditioned in three different kinds of commercial packaging: glass used as a reference (G), polystyrene (PS, consisting of high impact PS and crystal PS at a 50/50 ratio) and polypropylene (PP) (Danone, France). Especially, polystyrene packaging (Coexpan SA France, Beaucouze) thickness was 1.3 mm and its density 1.06. Polypropylene packaging was provided by Graham Packaging (Villecomtal). Its thickness was 0.35 mm and its weight was 7.5 g.

Each type of yogurt pot was sealed with an adapted lid: multilayer aluminium and polyethylene for glass and PP; multilayer polyethylene and polypropylene for PS. The

Table 1
Premix composition for yogurt preparation (% in w/w)

Ingredients (suppliers)	Mix composition for 4%-fat yogurt	Mix composition for 0%-fat yogurt
Water (Volvic, France)	1 l	1 l
Low heat skim milk powder (Ingredia, France)	135 g	135 g
Anhydrous milk fat (Lactalis, France)	0 g	40 g
Sugar (sucrose) (Daddy, France)	50 g	50 g
Dry matter (w/w)	18.50%	22.50%

Table 2
Aroma compound composition of strawberry aroma mixed with propylene glycol, their concentrations (mg/kg) in yogurts and their hydrophobic constant

Aroma compounds (Aldrich, France)	Concentration in yogurt (mg/kg)	log P[a,b]
Butanoic acid	2.21	0.79
Decanoic acid	1.11	4.09
Hexanoic acid	1.12	1.92
Diacetyl	4.34	−1.34
Ethyl acetate	17.88	0.73
Ethyl butyrate	27.24	1.85
Ethyl hexanoate	22.44	2.83
Ethyl octanoate	1.14	3.81
Methyl cinnamate	2.2	2.62
4-Hydroxy-2,5-dimethyl-3(2H)-furanone	18.47	0.82
g-decalactone	2.52	2.72
Hexanal	1.01	1.78
Z-3-hexenol	23.68	1.61
Limonene	2.23	4.57
Linalol	1.88	2.97
3-Hydroxy-2-methyl-4H-pyran-4-one	32.53	0.09
Vanillin	15.72	1.21

[a] log P = log of the partition coefficient of the compound between water and octanol – calculated values.
[b] EPI estimation programs interface v3.10.

conditioning effect was associated with a packaging effect since the mass-transferring surface of the lids was relatively weak compared to the direct contact surface of the product with the main part of the yogurt pot. A domestic iron was used to thermo-seal the lids. Each pot contained 125 g of yogurt and 10 ml of headspace between the yogurt and the lid. The yogurts were then stored at 4 °C.

2.2. Sensory profiles

2.2.1. Subjects

The subjects were 15 members of the laboratory staff (six women and nine men, from 22 to 41 years old) recruited according to their motivation and availability to pursue a four-month study with two sessions per week. Six subjects had previous experience in sensory evaluation of dairy products, but all 15 subjects were trained in sensory profiling in preliminary sessions for this specific study. The panel was separated into two groups: Group 1 (eight subjects), who evaluated 0%-fat yogurts; Group 2 (seven subjects), who evaluated 4%-fat yogurts with an exception on the 2nd day of storage when both groups evaluated the yogurts at the two levels of fat content (0% and 4%). The panel was separated into two groups, in order to take experimental constraints into account and to avoid a yogurt production repeatability effect. We choose, thus, to use products coming from a same fermentation batch. Nine training sessions were carried out and were described in Saint-Eve, Juteau, Atlan, Martin, and Souchon (2006).

2.2.2. Generation of attributes

Generation of the attributes used for the sensory profile was carried out during a specific session where the 0% and 4%-fat flavoured stirred yogurts packaged in glass designed for the study were presented. A list of 58 attributes was established. In a subsequent session, the subjects agreed on a reduced list of 30 attributes (Table 3) related to texture-in-mouth (M), odour (O), aroma (A) and taste (T). Flavour is defined as the combination of olfactory, gustatory and trigeminal sensations perceived during tasting (NF ISO 5492, 1995). In our study, the term ‘odour’ refers to the direct olfactory component of flavour (orthonasal perception), and the term ‘aroma’ to the organoleptic attribute perceptible by the olfactory organ via the back of the nose, i.e., retronasal olfactory perception when tasting (NF ISO 5492, 1995).

2.2.3. Sensory procedure

Before each sensory evaluation, yogurt samples were served in white isothermal pots (40 g/pot) closed with a cover cap and stored one night at 4 °C. The yogurts were presented by a three-digit code. The samples were at approximately 10 °C when they were tested. Subjects had mineral water and plain crackers as palate cleansers between samples. Sessions were carried out in an air-conditioned room under white lighting in individual booths. Data acquisition was assisted by Fizz software (Biosystèmes®, 1999).

The samples were presented in a monadic way and tasted according to a Latin square experimental design for each subject for the descriptive analysis on the 2nd, 14th and 28th days of storage. For Group 1 and Group 2 sessions, the reference product conditioned in glass was replicated within the session on the 14th and 28th day of storage, which means that four products (glass, doubled glass, PP and PS products) were tested. The subjects evaluated the perceived intensity for each attribute on an unstructured scale anchored with the terms “very weak”

Table 3
List of the 30 attributes used for the descriptive analyses

Odour attributes	Aroma attributes	Taste attributes	Texture-in-mouth attributes
O-overall intensity	A-overall intensity	T-sweet	M-thick
O-lacteous	A-lacteous	T-sour	M-unctuous
O-fruity	A-fruity		M-astringent
O-solvent	A-strawberry		
O-butter	A-kiwi		
O-caramel	A-pineapple		
O-vanillin	A-apple		
O-animal	A-peach		
O-defect	A-solvent		
O-green	A-green		
	A-caramel		
	A-vanillin		
	A-butter		
	A-animal		
	A-defect		

O, odour (orthonasal perception); A, aroma (retronasal perception); T, taste; M, texture-in-mouth.

and "very intense". The attributes were evaluated in the following order: odour, aroma, taste and texture-in-mouth. For a single subject, the order of presentation of the products was the same, regardless of the replication. The yogurt pots were distributed one by one to the subjects in order to limit product heating. A replication was performed for the session on the 14th day of storage.

2.3. Physicochemical analysis

2.3.1. pH measurement

The yogurt pH was measured at 4 °C with a pH-metric probe (Mettler Toledo, France). Each measurement was carried out at the same date as the sensory analysis sessions (2nd, 14th and 28th days of storage).

2.3.2. Rheological properties

The complex viscosity of yogurts was measured using a controlled-stress rheometer (model RS1, Haake, Germany), equipped with a cone and plane geometry (60-mm diameter, 2° angle and 117-μm gap). Rheological measurements were taken during a sweeping in constraint in harmonic mode. A slope of constraints ranging between 0.1 Pa and 100 Pa, with a frequency of 1 Hz, was exerted. Measurements were carried out at 10 °C on the same date as the sensory analysis sessions. Details were given in Saint-Eve et al. (2006).

2.3.3. Aroma compound release

Aroma release measurements were performed at 4 °C, corresponding to the storage temperature of yogurts. The solid-phase microextraction (SPME) method was used to quantify the aroma compounds of the strawberry released in the vapour phase above the different yogurts.

Headspace (HS) vials filled with 5 g/vial of product and previously stored overnight at 4 °C were placed in the HS sample tray maintained at 4 °C. A gas chromatograph flame ionisation detector (GC-FID HP6890, Germany) combined with an automatic headspace sampler, CombiPal (CTC Analytics, Switzerland), was used. A 2h-extraction with a polydimethylsiloxane fibre (PDMS, 100-μm film thickness) was performed (details given in Saint-Eve et al., 2006). The aroma compounds were separated on a polar column (BP20 Carbowax, Interchim, France). The oven temperature was programmed from 50 °C to 70 °C at 4 °C/min, and from 70 °C to 170 °C at 5 °C/min and from 170 °C to 220 °C (maintained for 6 min) at 8 °C/min. Results obtained from SPME were expressed as area units. Each headspace analysis was done in triplicate.

2.4. Product codes

In order to make the results as clear as possible, products were coded according to the following letters – f, p and tx – where "f" was the level of fat content (0 for 0% or 4 for 4%), "p" was the packaging type (g for glass, PP for polypropylene and PS for polystyrene) and "tx" was the time of storage (t2 for the 2nd day of storage, t14 for the 14th day of storage and t28 for the 28th day of storage).

2.5. Data analysis

All data analyses were performed using SAS software package, version 9.1 (SAS® User's Guide: Statistics, 1990).

The fat content effect was investigated on yogurt conditioned in glass on the 2nd day by a one-way analysis of variance (ANOVA) (product) on the physicochemical data, and by a three-way ANOVA (product, group, subject (group)) on the sensory data. The influence of packaging and storage time was assessed on the sensory data by a three-way analysis of variance (ANOVA) (time, packaging, and subject) with interactions in which subjects were treated as a random effect. The influence of packaging effect and storage time on a physicochemical data set (pH, aroma release and complex viscosity) was analysed by a two-way ANOVA (packaging, time), including interaction. When significant differences were revealed ($p < 0.05$), mean partition coefficients were compared using the Student–Newman–Keuls (SNK) multiple comparison test.

Principal component analysis (PCA) was performed to visualise the yogurt sample differences and the variable correlations from the discriminant sensory and instrumental data resulting from ANOVA.

3. Results and discussion

The presentation of results in this paper was organised as follows: (i) first, the effect of fat content on yogurt quality was introduced. This effect on flavour release and perception has been extensively studied in the literature. The objective of this first part was to quantify the difference in release and perception of the two yogurts (0% and 4%-fat) at the initial time of storage; (ii) second, the effect of storage and packaging on 0%-fat stirred yogurts was presented, and (iii) followed by the results for the 4%-fat yogurts.

3.1. Influence of fat content on the sensory properties and flavour release of yogurt on the second day of storage

Fat content had a considerable influence on the sensory and instrumental characteristics of yogurt as shown by the one-way ANOVA (Table 4). A significant effect of fat content was obvious on nine sensory attributes and on seven aroma compounds released in yogurts packaged in glass on the 2nd day of storage.

The low-fat yogurts were perceived as being less intense in lacteous and butter aroma than the 4%-fat yogurts. On the contrary, the low-fat yogurts were perceived as being more intense in green odour, overall intensity aroma, fruity aroma and solvent aroma than the 4%-fat yogurts. The variation of fruity note intensities between yogurts with and without fat were about 15–60%, with percent (%) variation defined as follows:

Table 4
Significant effect of fat content (0% and 4%) on the sensory attributes (3-way ANOVA (product, panel, subject (panel)) and aroma compound release variables (2-way ANOVA (product, repetition)) on the 2nd day of storage, conditioned in glass

Sensory variables	*p*-value	0%-fat	4%-fat
Intensity means			
O-lacteous	0.032	1.96 (2)[A] b	3.48 (2.51) a
O-green	0.041	3.37 (2.8) a	1.38 (2.07) b
A-overall intensity	0.043	6.59 (1.22) a	5.73 (2.37) b
A-fruity	0.038	6.52 (2.25) a	4.7 (2.12) b
A-kiwi	0.001	5.76 (3.03) a	3.11 (2.85) b
A-solvent	0.031	3.43 (2.87) a	1.93 (2.52) b
A-butter	0.062	0.83 (1.06) b	1.75 (1.85) a
M-thick	0.055	1.09 (1.31) a	0.39 (0.42) b
M-unctuous	0.0403	2.66 (2.28) a	1.75 (2.12) b
Aroma compounds	***p*-value**	**0%-fat**	**4%-fat**
Area peak means			
Ethyl acetate	0.048	159 (5.3) a	126.4 (10.5) b
Ethyl butyrate	0.003	1952.4 (20) a	1459.1 (14.4) b
Ethyl hexanoate	0.029	10334.5 (430.3) a	3416.7 (20.2) b
Ethyl octanoate	0.006	938.4 (16.5) a	103.5 (20.6) b
Hexanal	0.003	4562.6 (28.7) a	292.2 (3.9) b
Limonene	0.031	523.2 (32.9) a	161.5 (7.2) b
Linalol	0.041	221.7 (4.1) a	95.4 (11.4) b

Probability levels associated with means and SNK comparison test.The letters a and b indicate means that significantly differ at $p < 0.05$ (SNK test).
[A] (Standard deviation) value.

$$\frac{\text{0\%-fat yogurt intensity} - \text{4\%-fat yogurt intensity}}{\text{0\%-fat yogurt intensity}} \times 100$$

These results were in agreement with the aroma compound release above the yogurts: seven aroma compounds were significantly less released in the presence of fat in yogurt (Table 4). Differences in flavour release between 0% and 4%-fat yogurt were dependant on hydrophobic properties of aroma compounds. For hydrophilic aroma compounds, ethyl acetate presented a small variation of aroma release between the two levels of fat in yogurt (20% variation), and no significant effect of fat content was observed for diacetyl. On the contrary, the most hydrophobic aroma compounds presented wide variations: an aroma quantity decrease of more than 60% variation was observed in 4%-fat yogurts in comparison to 0%-fat yogurts for ethyl butyrate, ethyl hexanoate, ethyl octanoate, hexanal, limonene and linalool.

These results were in agreement with several authors (Brauss, Linforth, Cayeux, Harvey, & Taylor, 1999; De Roos, 1997; Folkenberg & Martens, 2003; Nongonierma, Springett, Le Quere, Cayot, & Voilley, 2006). One interpretation is that fat acts as a solvent, reducing the aroma compound volatility and therefore causing a decrease in the amounts released. However, these effects depend on the physicochemical characteristics of the aroma compounds. The modification of aroma compound release when adding 4%-fat to yogurt was at the origin of the olfactory perception decrease and, in particular, the decrease of fruity notes.

3.2. Low-fat yogurts: storage and packaging effects

3.2.1. Effect of storage on sensory and physicochemical properties of low-fat stirred yogurts, regardless of the packaging

Modifications of the rheological properties of yogurts were observed during the time of storage. A 71% increase of the complex viscosity was observed for the low-fat yogurts between the 2nd and the 28th day of storage. In parallel, the low-fat yogurts were perceived as being thicker during storage (63% increase between the 2nd and the 28th day of storage). The increase of complex viscosity during storage can thus explain the increase in thickness perception of yogurts (Table 5).

The complex viscosity increase can be explained by post-acidification, which occurs during yogurt storage. The residual activity of the microorganisms in the product leads to a reinforcement of the strength of the protein network by: (i) acidification of the product due to the increase in lactic acid; and (ii) by the possible ability of strains to produce exopolysaccharides. The consequences of post-acidification on rheological properties and texture observed in this study confirmed the results of several authors (Barrantes, Tamime, Muir, & Sword, 1994; Barrantes, Tamime, Sword, Muir, & Kalab, 1996; Biliaderis, Khan, & Blank, 1992). As was the case for Barrantes et al. (1994) and Martin et al. (1999), we observed that major texture changes occurred during the first week of storage. Post-acidification activity was confirmed with the pH decrease from 4.3 to 4.1 during storage. Even if a decrease of pH was observed, the yogurts were not discriminated by the sour characteristics. At the sensory level, the pH decrease did not directly result in perceived sourness but, instead, seemed to be expressed by sweet/sour balance: sweet tastes decreased with storage time (by 25% between the 2nd and the 28th day of storage for low-fat yogurts).

Aroma release and olfactory perception of low-fat stirred yogurts changed during storage at 4 °C, as illustrated in the principal component analysis (PCA) (Fig. 1). The first factorial plot of PCA showed that the fruity note perception and the aroma compound quantity decreased from the 2nd to the 14th day of storage. Indeed, the perceived olfactory intensities significantly declined during the first 14 days of storage for kiwi aroma, apple aroma and solvent aroma (Fig. 2). In parallel, several aroma compounds had a significant and similar evolution during storage: ethyl acetate, 4-hydroxy-2,5-dimethyl-3(2H)-furanone and limonene significantly decreased during the 28 days of ageing (Table 5). For example, a 53.2% loss was observed for limonene from the 2nd to the 28th day of storage with% variation defined as:

$$\frac{\text{peak area on the 28th day} - \text{peak area on the 2nd day}}{\text{peak area on the 2nd day}} \times 100$$

(Table 5). Other aroma compounds such as ethyl butyrate, ethyl octanoate, ethyl hexanoate and γ-decalactone also presented a significant decrease during storage (Fig. 2),

Table 5
Significant influence of storage time (2nd, 14th and 28th day of storage) on (a) sensory attributes averaged by packaging and subject intensities for low-fat stirred yogurt; and (b) aroma compounds released (in peak area) and measured by the SPME method at 4 °C

Sensory variables	*p*-value	2nd day	14th day	28th day
Intensity means				
O-animal	0.03	0.65 (1.4)[A] a	0.44 (0.9) b	0.95 (1.97) a
A-kiwi	0.00	4.43 (3.2) a	3.16 (2.2) b	3.04 (2.6) b
A-apple	0.041	2.7 (2.6) a	2.42 (2.3) b	2.5 (2.3) b
A-defect	0.0001	0.89 (1.7) b	0.75 (1.7) b	2.4 (3.4) a
M-thick	0.037	0.73 (1.0) b	3.26 (2.2) a	3.43 (2.3) a
Aroma compounds	***p*-value**	**2nd day**	**14th day**	**28th day**
Area peak means				
Hexanoic acid	0.0007	7.75 (4.1) b	9.47 (9.6) b	20.82 (5.2) a
Ethyl acetate	0.0003	159.00 (5.4) a	116.57 (10.8) b	152.42 (26.4) a
Limonene	<0.0001	523.15 (32.9) a	375.40 (52.1) b	244.97 (34.9) c
4-Hydroxy-2,5-dimethyl-3(2H)-furanone	0.0002	13.25 (6.3) a	1.02 (0.5) b	1.97 (0.3) b

The letters a,b and c indicate means that significantly differ at $p < 0.05$ (SNK test).
[A] (Standard deviation) value.

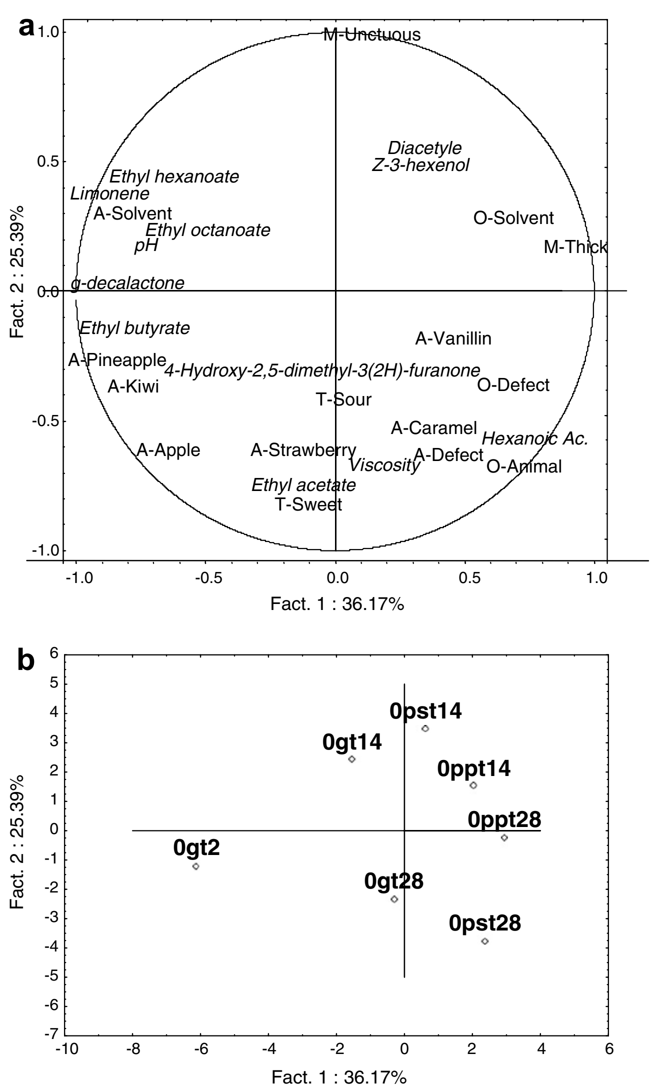

Fig. 1. PCA biplot on the descriptive quantitative analysis scores of the 0%-fat yogurts. (a) Variable map (sensory and *physicochemical* variables); (b) product map.

but this decrease depended on the packaging effect, as discussed in the Section 3.2.2. Moreover, the aroma release decreases during the first 14 days of storage were at the origin of the olfactory perception differences of low-fat yogurts. These results corroborated the findings of Lubbers et al., who observed a decrease of some aroma compounds (esters) in the headspace during the ageing of flavoured yogurts (Lubbers et al., 2004). According to these authors, the changes in rheological properties observed during ageing could partly explain the results in aroma release. In addition, the hypotheses of bacterial digestion of some aroma compounds (aldehydes reduced to alcohols) in yogurt was proposed by Harasawa et al. (1998) and could explain the aroma decrease during storage.

The 2nd axis of PCA mainly illustrated the evolution of yogurt between the 14th and the 28th day of storage (Fig. 1). Hexanoic acid quantity increased considerably (+121% variation) and significantly ($p < 0.05$) between the 14th and the 28th day (Table 5). This increase could be related to the increase of animal odour and defect aroma perception, especially between the 14th and the 28th day of storage (Fig. 2). These results were in agreement with those of Harasawa et al., who observed a decrease of aldehyde, ester and terpene release and an increase of acid release (hexanoic, octanoic and decanoic acids) during yogurt storage (Harasawa et al., 1998). Moreover, Yazici and Akgun observed that the storage time had a negative impact on the flavour scores in yogurts. The most widely observed defect was acidity and rancid flavour for all samples at the end of the storage period (Yazici & Akgun, 2004).

Correlations between sensory attributes showed negative texture–aroma correlations: thickness–kiwi aroma ($r^2 = -0.8$), thickness–pineapple aroma ($r^2 = -0.78$), thickness–apple aroma ($r^2 = -0.76$). These results could be explained by physicochemical interactions between the aroma compounds and the exopolysaccharides, which increased during storage. On the contrary, solvent odour was positively correlated with the thickness character

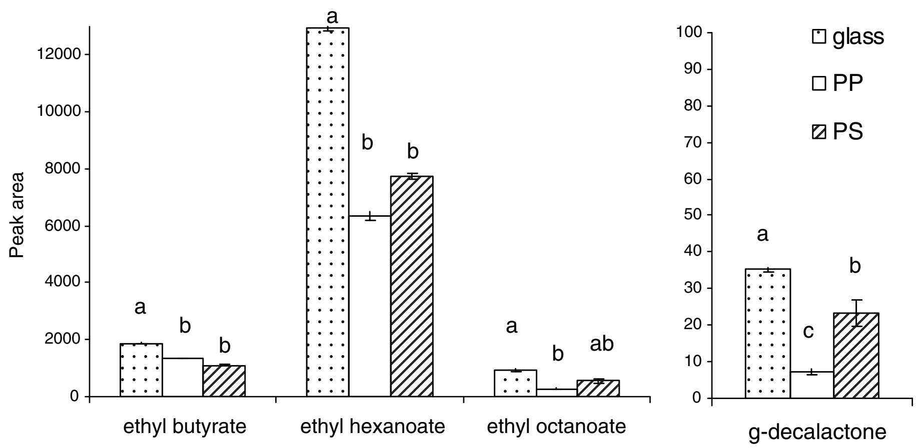

Fig. 2. Significant influence of packaging type (glass, PS and PP) on aroma compounds released (in peak area) and measured by the SPME method at 4 °C on the 14th day of storage for low-fat stirred yogurt. Letters a, b and c indicate that significantly differ at $p < 0.05$ (SNK test).

($r^2 = 0.83$). This could be explained by the increase of complex viscosity and the released quantity of hexanoic acid over the course of time, and subsequent thickness and perceived solvent odour increase. In addition, taste–aroma correlations were observed: sweet–strawberry aroma ($r^2 = 0.71$), sweet–apple aroma ($r^2 = 0.71$) and sour–animal odour ($r^2 = 0.78$). A negative correlation was also observed between sweetness and unctuous characters ($r^2 = -0.81$). These results corroborated the impact of aroma and taste on texture perception already observed, and sensory interactions between aroma and taste (Frank & Byram, 1988; Saint-Eve, Paci Kora, & Martin, 2004).

3.2.2. Effect of the type of packaging on sensory and physicochemical properties of low-fat stirred yogurts during storage

Aroma compound quantities above the low-fat yogurts decreased during storage, regardless of the packaging. However, yogurts conditioned in glass presented the least decrease of the three packaging types (Fig. 1). The highest aroma quantities released above the yogurts were observed for yogurts conditioned in glass, especially for ethyl butyrate, ethyl hexanoate, ethyl octanoate and g-decalactone, as illustrated on the 14th day of storage in Fig. 2. This result confirmed that glass is an almost perfect barrier, is inert, and does not interact with the packaged food to any considerable extent (Nielsen & Jagerstad, 1994).

Concerning polymer packaging, the significant effects were dependent on the time effect. Between the 2nd and the 14th day of storage, the loss of some aroma compounds (ethyl butyrate, ethyl octanoate, ethyl hexanoate and g-decalactone) was greater in yogurts conditioned in polypropylene than in yogurts conditioned in polystyrene (Fig. 1). A global stabilisation of aroma compound release was observed for yogurts conditioned in polypropylene between the 14th and the 28th day of storage, while a decrease, particularly for diacetyl and *Z*-3-hexenol, was observed for yogurt in PS over the same time period (Fig. 1). The properties of the polymers could explain the differences in the evolution of the flavoured yogurts over the course of time. At 4 °C, polystyrene is totally amorphous in a vitreous state, while polypropylene is a semi-liquid crystalline polymer in a rubbery state. Thus, these differences in the structure could explain why the kinetics of aroma compound sorption were slower in polystyrene packaging than in polypropylene packaging (Sajilata et al., 2007).

Concerning the influence of packaging on sensory properties beyond 14 days, stabilisation of the olfactory properties of the flavoured yogurt was only observed when the latter was packed in a polypropylene pot. These sensory results were in agreement with the small change after the 14th day of storage of the aroma release above the yogurts conditioned in a polypropylene container.

In addition, the quantity of hexanoic acid increased after the 14th day of storage, especially in yogurt conditioned in polystyrene. At the end of storage, yogurts conditioned in PS thus presented less loss of aroma compounds responsible for fruity notes, but greater quantities of aroma compounds such as acids than yogurts conditioned in polypropylene. Moreover, yogurts conditioned in PS and glass developed similar odour and aroma defects during storage time. Defect notes appeared at the end of the storage time, mainly for yogurts conditioned with polystyrene (Fig. 1). Defect notes in yogurt conditioned in polystyrene could thus be explained by the considerable quantity of hexanoic acid measured on the 28th day of storage.

Thus, packaging polymers had a different influence on aroma release and olfactory perception depending on their properties. For low-fat yogurts, polystyrene packaging seems to be preferable to polypropylene packaging for avoiding a decrease in fruity note perception.

3.3. 4%-fat stirred yogurts: effect of storage and packaging on sensory and physicochemical properties

Less significant effects of storage and packaging were observed for yogurts with 4%-fat content than for 0%-fat yogurts. Indeed, only ten sensory attributes significantly differed for 4%-fat yogurts, whereas 17 differed for low-fat yogurts. Stabilisation due to the physicochemical interactions between aroma compounds and fat, and to the slow diffusion of aroma compounds in fat, could explain this result that was in agreement with those of other authors (Brauss et al., 1999) with regard to fresh dairy products.

Because of the lipophilic character of many aroma compounds, yogurt with 4%-fat content could lose less aroma compounds by absorption into packaging than the 0%-fat yogurt. These results were in agreement with Van Willige et al., who observed that very small amounts of oil added to an aqueous system can significantly decrease the absorption of the aroma compounds by linear low-density polyethylene packaging (Van Willige et al., 2000).

A PCA (Fig. 3) was performed on the set of significantly discriminant sensory attributes and physicochemical variables. The first two principal components accounted for 69.5% of the data variance. Yogurts were discriminated along the first axis according to their aroma compound release and their texture perception. Some aroma compounds responsible for fruity notes (limonene, linalool and hexanal), solvent odour and sweet taste were opposed to the thickness perception and the lacteous odour. The first factorial axis exhibited a ranking of the samples conditioned in glass according to storage time. The majority of aroma compounds presented the highest quantities in yogurt on the 2nd day of storage. A decrease of aroma compound quantities and an increase of lacteous odour during ageing were then observed, as already shown for the low-fat yogurts. In addition, yogurt thickness increased during storage and could be due to post-acidification by lactic bacteria.

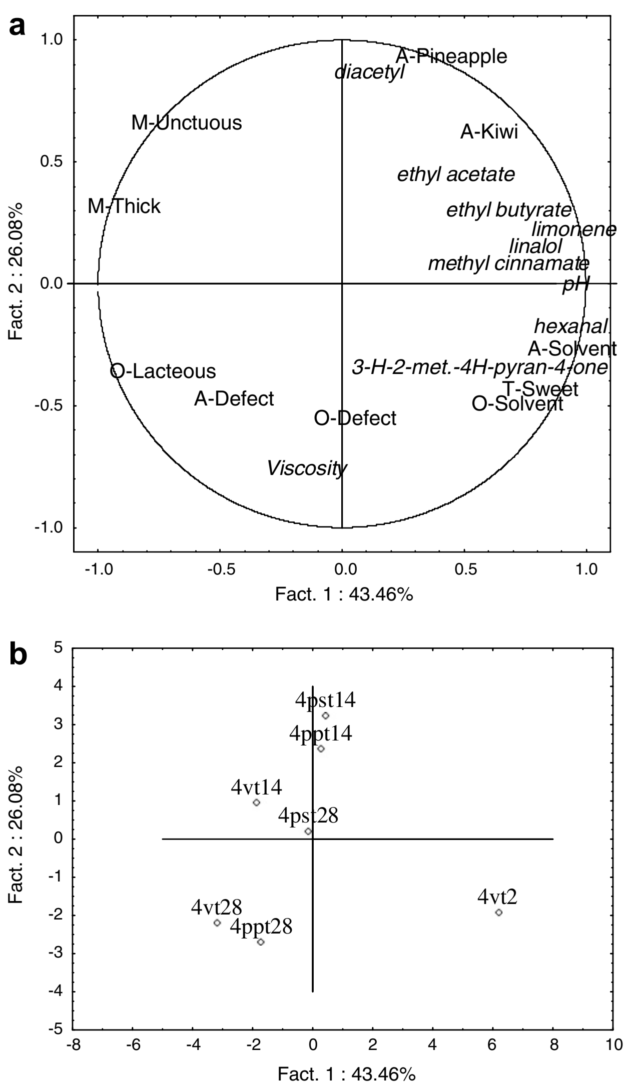

Fig. 3. PCA biplot on the descriptive quantitative analysis scores of the 4%-fat yogurts. (a) Variable map (sensory and *physicochemical* variables); (b) product map.

The second factorial axis of PCA showed that between the 14th and the 28th day of storage, the pineapple aroma intensity and the diacetyl quantity decreased, whereas the yogurt complex viscosity increased (67% variation). These results confirmed those already observed in low-fat yogurts and by some authors in the literature. Moreover, the yogurts conditioned in polymers, on the 14th and the 28th day of storage, were differentiated. On the 28th day, the yogurt conditioned in polystyrene had a greater quantity of diacetyl and a more intense pineapple aroma than the two others yogurts (PP and G), and was perceived as being less intense in odour and aroma defects.

Thus, polystyrene packaging seems to be preferable for avoiding the loss of fruity notes and for hindering the development of odour and aroma defects in the flavoured yogurts used in the present study.

The decrease of fruity notes for the 4%-fat yogurt was observed between the 14th day and the 28th day of storage, rather than between the 2nd day and the 14th day of storage for the 0%-fat yogurt. Fat thus plays a protective role in the fruity quality of the yogurts.

4. Conclusion

This work shows the influence of the storage and the type of packaging on flavoured stirred yogurt quality, whereas fat content and storage time had greater consequences on physicochemical and sensory properties. The analyses of the yogurts over the course of time at 4 °C for all kinds of packaging revealed a rapid evolution of the low-fat yogurts during the first 14 days at the physicochemical and sensory levels. For the 4%-fat yogurts, a decrease in fruity notes was observed between the 14th day and the 28th day of storage. However, less significant effects were observed for yogurts with 4%-fat content than for low-fat yogurts. The fat acts as an aroma solvent and reduces interaction with packaging. Concerning the packaging effects, polystyrene packaging seems to be preferable for avoiding the loss of fruity notes for 0% and 4%-fat yogurts and for limiting the development of odour and aroma defects, particularly for 4%-fat yogurts. The physicochemical results (complex viscosity, pH values and aroma release) are in agreement with the sensory properties of the yogurts.

This study contributes to a better understanding of the impact of packaging on the physicochemical and sensory properties. It shows the need for integrating the packaging type into the formulation of flavoured dairy products, in particular for low-fat yogurt, even if yogurt has a short conservation time and is stored at low temperatures.

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