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Free fatty acids and volatile compounds of low-fat Feta-type cheese made with a commercial adjunct culture

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Abstract

The effect of a commercial adjunct culture (CR-213), containing *Lactococcus Lactis* subsp. *lactis* and *Lactococcus Lactis* subsp. *cremoris*, added at the level of 0.06 and 0.09% (w/w) to cheese milk, on lipolysis and formation of volatile compounds was studied. Two controls, a full-fat (~22% fat) and a low-fat cheese (~7% fat) were also prepared. The results indicated that the adjunct-treated low-fat cheeses had higher total free fatty acid (TFFA) levels than the low-fat control cheese but lower than the full-fat control cheese. The full-fat cheese had significantly higher levels of TFFA than the low-fat control. Almost the same volatile compounds were identified in the four cheeses. The adjunct culture containing low-fat cheeses had higher levels of acetaldehyde, 2-butanone, ethanol and acetoin than low-fat control cheese and even higher than the full-fat cheese.

Keywords: Low-fat cheese; Feta cheese; Adjunct culture; FFA; Volatile compounds

1. Introduction

Fat has been associated with an increased risk of obesity, certain forms of cancer, atherosclerosis, coronary heart disease, elevated blood pressure and tissue injury diseases associated with lipid oxidation. This has created an increased consumer awareness and a dramatic increase in the supply of, and demand for low-fat foods, including cheese (Dexheimer, 1992; Fenelon & Guinee, 2000).

Generally, reduced fat cheeses are considered to be less acceptable to consumers than their full-fat counterparts due to texture and flavour defects. The usual textural defects of low-fat cheeses are increased firmness, rubberiness, hardness, dryness and graininess (Emmons, Kalab, Larmond, & Lowrie, 1980; Olson & Johnson, 1990) while the usual flavour defects are low intensity of typical cheese taste and aroma, bitterness, astringency and unclean flavours (Banks, Brechany, & Christie, 1989; Banks, Muir, Brechany, & Law, 1992; Lee, Johnson, & Marth, 1992). It is not clear whether the lack of flavour is due to the lack of precursors from the fat or the lack of the solvent power of the fat, thus allowing essential flavour compounds to escape, or to the different physical structure of the reduced fat cheese which inhibits certain enzymatic reactions essential for the formation of flavour compounds (Urbach, 1997). Flavour development in cheese is a complex combination of microbial and biochemical activities throughout the ripening period which leads to the formation of a heterogeneous mixture of volatile and non volatile compounds (Fox & Wallace, 1997). The ripening of most cheeses is accompanied by lipolysis, i.e. the hydrolysis of triglycerides to produce free fatty acids (FFA) with chain length >C4. Also FFA can be produced from the metabolism of carbohydrates and amino acids by bacteria (Fox & Wallace, 1997; Urbach, 1993). FFA contribute to cheese flavour and serve as precursors for a variety of other compounds, such as alcohols, esters, aldehydes, ketones and lactones (Fox & Wallace, 1997; Langsrud & Reinbold, 1973; Urbach, 1993). Especially for some cheese varieties, e.g. hard Italian and blue type cheeses, FFA are the major contributors to the development of their characteristic flavour (Fenelon & Guinee, 2000). Feta cheese is the most popular white brined cheese in Greece. Very few attempts have been made to manufacture a low-fat white brined cheese similar to

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Feta (Katsiari & Voutsinas, 1994; Mondal, Gough, Ryan & Adkinson, 1989). However, the results of these studies were contradictory. Thus, Mondal et al. (1989) reported that the fat level (2.0, 3.5 and 5%) in the milk had no significant effect on the flavour, body and texture scores of Feta cheese and that the best Feta was that made from 2.0% fat milk. On the other hand, Katsiari and Voutsinas (1994) found that body, texture and flavour scores of Feta cheeses were adversely affected by the decreases in the amount of milk fat (6.0, 4.5, 3.0 and 1.5%), but significant differences in these characteristics were observed between cheeses only at 180 days of storage for the former and throughout storage for the latter.

Several approaches have been investigated to improve the flavour of the low-fat cheeses such as (1) alteration of cheesemaking procedure (Drake & Swanson, 1995; Katsiari & Voutsinas, 1994), (2) the addition of fat mimetics to the milk (Fenelon & Guinee, 1997; Suriyaphan, Drake, & Cadwallader, 1999), (3) the use of novel starter cultures (Lee et al., 1992; Rodriguez, Requena, Valero, Martinez-Castro, Lopez-Fandino, & Huarez, 1997), (4) the use of starter adjuncts in conjunction with normal starter cultures (Fenelon & Guinee, 2000), and (5) the use of enzyme preparations (Fenelon & Guinee, 2000).

Voutsinas, Katsiari, Kondyli, and Alichanidis (2001) investigated the use of commercial enzymes or adjunct cultures for improving the sensory quality of a low-fat (6.67% fat) Feta-type cheese. Their results showed that the low-fat cheese made with an adjunct culture consisting of *Lc. Lactis* subsp. *cremoris* and *Lc. Lactis* subsp. *lactis* received significantly higher total score (overall acceptability) than the low-fat control cheese, but lower than the full-fat control cheese.

The objective of the present study was to determine and compare lipolysis (acid degree value and FFA) and volatile compounds in the low-fat Feta-type cheese, made with or without adjunct culture, to those of full-fat cheese.

2. Materials and methods

2.1. Milk

Fresh bulk ewe's milk was obtained from the herd of the Agricultural Research Station of Ioannina.

2.2. Cheesemaking

The milk was standardized, by separation to 6.0% (full-fat control) or 1.5% fat (low-fat control). Cheese manufacture was carried out at the pilot plant of the Institute on a 30 kg scale according to the procedure followed by the Greek cheese factories (Katsiari & Voutsinas, 1994), all conditions being kept as similar as possible. Each batch of milk was pasteurized in a double walled stainless-steel vat at 63 °C for 30 min and then cooled to 35° C. Normal starter culture (Dry-Vac lactic culture no. CH-1, Chr. Hansen's Laboratorium A/S, Copenhagen, Denmark) was added at the rate of 0.75% in all cheeses. Adjunct culture CR-213, a mixture of three *Lc. Lactis* strains (two are *ssp. lactis* and the third is ssp. *cremoris*) (Chr. Hansen's Laboratorium A/S, Copenhagen, Denmark), was added at the rate of 0.06 and 0.09% (w/w) and both cultures allowed to ripen for 30 min. $CaCl_2$ solution 40% (50 ml/100 kg milk for the 6% fat cheesemilk and 25 ml/100 kg milk for the 1.5% fat cheesemilk) was then added, this being followed by the addition of powdered calf rennet (HA-LA, Hansen's Laboratorium A/S, Copenhagen, Denmark), dissolved in cold water. Coagulation was achieved in about 45 min at 35 °C. After coagulation, the curd was cut into cubes of 2-cm side and was left to rest for 10 min. The sliced curd was then transferred into two perforated rectangular moulds for draining. The moulds were then turned upside down three times during the first 3 h of draining and then left at rest overnight (16–18 °C) to complete draining. The next morning, the curd of each mould was cut into four blocks, each weighing about 1.5 kg. The cheese blocks were placed into individual cans, and granular recrystallized NaCl, equivalent to 2.5% of the weight of the cheese, was added. After 1 day, the salty aqueous phase was removed and replaced by a 7% NaCl solution in a ratio of brine volume to cheese weight of 1:5. The cans were sealed and left in the ripening room (16–18 °C) until the pH of cheese dropped to a value of ~4.6. Subsequently, the cans were transferred into the storage room (3–4 °C) and remained there for up to 6 months. Three cheesemaking trials were carried out.

2.3. Acid degree value (ADV)

The ADV was determined according to Deeth and Fitz-Gerald (1976).

2.4. FFA analysis

Extraction of cheeses lipids, isolation of FFA and determination of FFA concentration by gas chromatography were performed as described by De Jong and Bandings (1990).

A Shimadzu model GC-17A gas chromatograph, equipped with an on-column injector and a flame ionization detector (FID) was used with a fused silica capillary column (length 15 m, inner diameter 0.53 mm) coated with free fatty acid phase OV-351 (bonded polyglycol-nitroterephthalic, film thickness 1.0 μm). Direct on-column injection took place at 60 °C; the injector temperature was raised from 60 to 230 °C at a rate of

35 °C min^{-1}, and then held at 230 °C for 40 min. Oven temperature was programmed from 60 to 70 °C at a rate of 1 °C min^{-1}, after a two min hold at 60 °C, and then to 220 °C at a rate of 10 °C min^{-1} and a 18 min hold at 220 °C. The FID temperature was 225 °C. The carrier gas (helium) flow rate was 8.8 ml min^{-1}. The identification of the individual fatty acids of the cheese samples was based on a comparison of the retention times of the unknown FFA with those obtained from known FFA standards (Sigma, Steinheim, Germany) under identical conditions. The quantitation of the FFA of cheese samples was performed using the internal standardization technique with $C_{9:0}$ as an internal standard and processing the chromatograms with the CLASS-VP™ Chromatography Laboratory Automated Software System (Shimadzu Scientific Instruments Inc., Columbia, MD, USA).

2.5. Analysis of volatile compounds by GC/MS

The headspace volatile compounds were isolated and detected by a dynamic headspace autosampler Perkin-Elmer HS40 coupled to a GC/MS-Q 5050 system (Shimadzu). The cheese samples were grated and 5 g were weighed into 20 ml vials; then the vials were sealed with aluminium-rubber septa. The vials with samples were thermostatted at 75 °C for 15 min, purged and pressurised with 35 ml/min helium and then the volatile compounds driven through the thermostat via the 90 °C transfer line and injected into the GC/MS.

The volatile compounds were separated on a HP Innowax capillary column (60 m length × 0.25 mm i.d., 0.25 μm film thickess) under the following conditions: injector temperature 200 °C; carrier gas helium 0.6 ml/min; temperature programme: from 35–80 °C at a rate of 5 °C/min, held for 3 min and then up to 200 °C at a rate of 8 °C/min. The GC column was directly connected without splitting to the ion source of a QP 5050 quadrupole mass spectrometer (interface line 250 °C), operating in the scan mode within a mass range of m/z 40–300 at 2 scans/s. Ionization was done by electronic impact at 70 eV, and calibration by autotuning.

Identification of the compounds was carried out by computer-matching of mass spectral data with those in the Shimadzu NIST62 Mass spectral Database and by comparing their retention times and mass spectra to those of some standard compounds (when available). Quantitation was performed by integrating the peak areas of total ion chromatograms (TIC) by the Shimadzu Class 500 software.

2.6. Statistical analysis

The data of ADV and FFA analyses were subjected to one-way analysis of variance (ANOVA) to test the differences among the four cheeses at each sampling age using the software Statgraphics (Statistical Graphics Corp., Rockville, MD, USA). When significant ($P<0.05$) differences were found among treatments, means were separated by Tukey's test.

3. Results and discussion

3.1. Acid degree value

The extent of lipolysis in the cheeses, expressed as acid degree value (ADV), at different sampling ages is shown in Table 1. The ADV in all cheeses increased continuously during aging. The rate and extent of lipolysis in the full-fat cheese was a little higher than in the low-fat control cheese. This observation is in agreement with the results of Katsiari and Voutsinas (1994) for Feta cheese. Other workers noted a reduction in the total free fatty acid (TFFA) level in other cheese varieties as the fat content was reduced (Aly, 1994; Banks et al., 1989). The low fat cheeses supplemented with the adjunct culture showed slightly higher levels of ADV compared to the untreated low-fat cheese. This increase in the ADV could be due to the formation of simple nitrogen compounds, especially free amino acids, which might serve as precursors for the formation of volatile fatty acids (Aly, 1994). Generally, the ADV values indicated low lipolytic activity in the four cheeses and this is in accordance with the findings of the FFA levels (see Table 2).

3.2. Free fatty acids

Table 2 shows the concentration of the even-numbered FFA in the full-fat (control) Feta cheese and the low-fat Feta-type cheeses at 120 and 180 days. Acetic ($C_{2:0}$) and palmitic ($C_{16:0}$) acids were the most abundant FFA in all cheeses at both sampling ages. Although acetic acid is not considered a product of lipolysis, but mainly a product of other biochemical pathways, probably the fermentation of lactate or the metabolism of

Table 1
Acid degree values (meq KOH/100 g fat) of full-fat Feta and low-fat Feta-type cheeses[a] made with or without adjunct cultures during aging

Age of cheese (days)	Cheese[b]			
	A	B	C	D
2	0.57	0.45	0.57	0.53
20	0.90	0.65	0.73	0.76
60	1.04	0.94	0.99	0.98
120	1.11	0.94	1.01	1.03
180	1.46	1.10	1.27	1.22

[a] Means of three trials.
[b] Cheese: A, full-fat (control); B, low-fat (control); C, low-fat with 0.06% adjunct culture; D, low-fat with 0.09% adjunct culture.
Means in each row without a letter did not differ significantly ($P>0.05$).

Table 2
Free fatty acids[a] (mg/100 g) of full-fat Feta and low-fat Feta-type cheese made with or without an adjunct culture and aged for 120 and 180 days

Free fatty acids	Age of cheese (days)							
	120				180			
	A[b]	B[b]	C[b]	D[b]	A[b]	B[b]	C[b]	D[b]
C2:0	81.9 a	83.3 ab	91.03 b	94.06 b	82.84 a	86.30ab	95.80 b	98.35 b
C4:0	1.48 b	0.74 a	1.46 b	1.27 b	1.70 b	0.83 a	1.60 b	1.78 b
C6:00	6.50	5.57	6.04	6.74	7.01	6.54	6.77	6.67
C8:0	2.57 b	1.83a	1.97a	1.88a	3.27 b	1.84 a	2.18 a	2.28 a
C10:0	3.86 b	1.29 a	1.69 a	1.48 a	5.41 b	1.70 a	1.96 a	1.86 a
C12:0	12.3	6.84	8.66	9.57	12.90 b	8.38 a	9.71 ab	10.4 ab
C14:0	11.2 b	4.31 a	4.76 a	5.37 a	12.8 b	5.55 a	6.16 a	6.11 a
C16:0	34.17 b	19.5 a	27.0 a	26.2 a	43.8 b	26.5 a	32.6 a	31.9 a
C18:0	10.2	6.07	6.64	6.48	11.7	8.45	8.76	9.87
C18:1	7.72 b	2.59 a	2.00 a	2.03 a	8.36 b	2.87 a	3.99 a	3.72 a
C18:2	1.44	nd	nd[c]	nd	1.47	nd	nd	1.68
Total	173b	131.96a	151ab	155ab	191.08b	149.02a	169.55ab	175ab
C4-C18:2	91.4b	48.9a	60.19a	61.0a	108.2b	62.7a	73.8a	76.3a

Means in a row and at the same age without a superscript or bearing a common letter did not differ significantly ($P > 0.05$).
[a] Means of three trials.
[b] Cheese: A, full-fat (control); B, low-fat (control); C, low-fat with 0.06% adjunct culture; D, low-fat with 0.09% adjunct culture.
[c] nd = not detected.

amino acids by bacteria, it contributes greatly to the final flavour of Feta cheese (Abd El Salam, Alichanidis, & Zerfiridis, 1993; Efthymiou, 1967; Fox, Law, Mc Sweeny, & Wallace, 1993). Acetic acid represented the 47.3% of total FFA (TFFA) present in the full-fat cheese and 60.2–63.1% of TFFA present in the low-fat cheeses made with or without adjunct culture at 120 days of age. Acetic acid concentration didn't differ significantly ($P > 0.05$) between the full-fat and low-fat control cheeses at both sampling ages. This is in accordance with the findings of Ardo (1993); Dimos, Urbach, and Miller (1996); El Neshawy, Abdel Baky, Rabie, and Ashour (1986), Kleinhenz and Harper (1997) who found no significant differences in the acetic acid concentration of other types of cheeses resulting from their fat contents. However, other authors reported higher values for acetic acid in low-fat cheeses than full-fat cheeses (Mc Gregor & White, 1990; Ohren & Tuckey, 1969). The low-fat cheeses supplemented with the adjunct culture showed significantly ($P < 0.05$) higher values for acetic acid than the full-fat cheese, while there were no significant differences among the three low-fat cheeses, although the experimental low-fat cheeses had higher values for acetic acid than the low-fat control. The increase of acetic acid in the adjunct culture-treated low-fat cheeses could be due to the peptidolytic activity of this particular culture, which resulted in the formation of simple nitrogen compounds, especially amino acids, which might have served as precursors for the formation of acetic acid and other volatile fatty acids.

Butyric acid had significantly ($P < 0.05$) lower values in the low-fat control cheese than in the other cheeses, indicating that the adjunct culture used had a slight lipolytic activity. The values of caproic acid did not differ significantly ($P > 0.05$) among the four cheeses, while the values for caprylic and capric acids were significantly ($P < 0.05$) higher in the full-fat cheese than in the low-fat cheeses.

Generally, the levels of butyric, caproic, caprylic and capric acids were low in all cheeses; this was an indication of the low lipolytic activity resulting exclusively from the starter microorganisms, since the natural lipase of milk was destroyed by the pasteurization process and no lipase was added during cheesemaking.

Lauric acid was significantly lower in the low-fat control than the full-fat cheese only at 180 days of sampling, while myristic, palmitic and oleic acids had significantly ($P < 0.05$) higher values in the full-fat than in the low-fat cheeses. Stearic acid content did not differ in all cheeses. The concentration of all individual FFA increased slightly between 120 and 180 days. The levels found for the FFA in the cheeses of the present study, represent amounts well above the typical flavour and aroma thresholds and therefore, would be expected to contribute to their organoleptic properties (Attaie & Richter, 1995).

Full-fat cheese had significantly higher values of TFFA than low-fat control cheese, while the experimental low-fat cheeses had intermediate values (Table 2). However, the total content of C_4–$C_{18:2}$, which is the actual index of cheese lipolysis, was significantly ($P < 0.05$) higher in the full-fat control cheese than in the low-fat ones. It seems, therefore, as expected, that the addition of the adjunct culture did not influence the production of FFA,

since this culture has mainly peptidolytic activity (Hoier, 2000).

3.3. Volatile compounds

Feta-type cheeses have a characteristic flavour, primarily due to their strong acidity (low pH) and high salt content (Efthymiou, 1967). The most abundant volatile compounds which contribute to the flavour of the cheeses at 180 days of ripening are listed in Table 3 and include alcohols (mainly short chain alcohols) aldehydes and ketones. These types of compounds have been found in many other cheese varietes (Bosset & Gaugh, 1993; Chin & Rosenberg, 1997; Meinhart & Schreier, 1986; Milo & Reineccius, 1997; Oumer, Fernandez-Garcia, Serrano, & Nunez, 2000). Many of these compounds were common in the four cheeses but they differed quantitatively. Ethanol was the most abundant volatile compound in all cheeses. This is in accordance with the results of Horwood, Lloyd, and Stark (1980) for full-fat Feta cheese. The full-fat cheese had a higher level of ethanol than the low-fat control, while the adjunct culture-treated low-fat cheeses had greater amounts of ethanol than the other two cheeses. Ethanol is a common terminal end-product in the breakdown of glucose (Langsrud & Reinbold, 1973) or it is produced from amino acid and aldehyde degradation or the reduction of acetaldehyde (Urbach, 1995). Keenan, Lindsay, Morgan, and Day (1966) demonstrated that *Lc. Lactis* subsp. *lactis* and *Lc. Lactis* subsp. *cremoris* produce ethanol and this is probably the explanation for the higher amount of ethanol found in the low-fat cheeses containing the adjunct culture. Urbach (1993), also reported higher concentrations of ethanol in cheeses made with enzymes or mutant starter along with the normal starter. Butan-2-ol was identified in all cheeses but at different levels. Keen, Walker, and Pederby (1974) suggested that the formation of butan-2-ol is probably due to the inclusion of some adventitious microorganisms in cheese during cheese-making. Pentanol was found only in the full-fat cheese, while 3-methyl butan-1-ol was identified in all cheeses. The full-fat and low-fat control cheeses had higher amounts of 3-methyl butan-1-ol. This branched chain alcohol is derived from leucine by Strecker degradation (Urbach, 1995). Acetaldehyde is the most common aldehyde found in fermented dairy products (Langsrud & Reinbold, 1973). Acetaldehyde was found in all cheeses and the full-fat and the low-fat controls had similar levels, while the low-fat cheeses containing the adjunct culture had greater levels than the controls. A possible explanation is that acetaldehyde is produced by 11 strains of *Lc. lactis* and *Lc. cremoris* as reported by Langsrud and Reinbold (1973) who also, found that *St. thermophilus* produces acetaldehyde under anaerobic conditions. Propanal, pentanal, hexanal and heptanal were present in all cheeses but at different levels, while butanal was identified only in the full-fat and low-fat control cheeses. The above aldehydes represent different smells, e.g. acetaldehyde is characteristic for its sweet, pungent odour and hexanal a green odour (Milo & Reineccius, 1997). 3-Methyl- butanal was found in all cheeses and the low-fat cheeses had larger amounts than the full-fat cheese. Especially the low-fat cheeses, containing the

Table 3
Volatile compounds (TIC[a] peak area) of full-fat Feta and low-fat Feta type cheeses made with or without adjunct culture at 180 days of age

Peak No.	Retention time (min)	Compound	Cheese[b]			
			A	B	C	D
1.	6.11	diethylether	975	572	652	772
2.	6.76	acetaldehyde	336	280	774	781
3.	8.01	propanal	613	804	755	607
4.	8.50	acetone	649	336	375	491
5.	9.80	butanal	61	116		
6.	9.96	butan-2-one	159	409	20,552	19,140
7.	10.16	ethyl acetate	507			
8	11.00	3-methyl, butanal	160	280	565	585
9.	11.40	ethanol	26,686	13,138	42,081	45,886
10.	12.90	pentanal	157	785	631	656
11.	13.00	pentan-2-one	630			
12.	13.82	butan-2-ol	6727	5189	5214	7866
13.	14.90	pentan-1-ol	312			
14.	16.11	3-hydroxy, butanal	52	72	98	128
15.	16.75	hexanal	357	821	548	737
16.	20.88	heptanal	289	710	809	422
17.	22.50	3-methyl, butan-1-ol	963	504	118	152
18.	24.60	3-hydroxy, butan-2-one	1477	1237	1887	1576

[a] Total ion chromatograph peak areas in arbitary units. Means of two trials.
[b] Cheese: A, full-fat (control); B, low-fat (control); C, low-fat with 0.06% adjunct culture; D, low-fat with 0.09% adjunct culture.

adjunct culture, had higher levels of this branched chain aldehyde than the other two control cheeses. This aldehyde is produced from leucine by the Strecker degradation (Urbach, 1993). This probably explains the higher levels of 3- methyl butanal, since the adjunct culture used in the manufacture of low-fat cheeses has mainly aminopeptidolytic activity and higher amounts of leucine were produced in these cheeses than in the controls (Voutsinas et al., 2001). Acetone is a normal constituent of milk and cheese (Urbach, 1993). It was found in all cheeses (Table 3) but at different levels. The low-fat control had the lowest level of acetone and the full-fat the highest, while the low-fat containing adjunct culture had intermediate values. This is in agreement with the results of Dimos (1992). Butan-2-one was identified in all cheeses and was found in higher concentrations in the low-fat experimental cheeses. Keen et al. (1974) suggested that the formation of butan-2-one, like butan-2-ol, arises also from the inclusion of some adventitious organisms in the cheesemaking process. Pentan-2-one, a methylketone related to lipolysis, was identified only in full-fat cheese. 3-Hydroxy, butan-2-one (acetoin), a compound which contributes buttery notes to Cheddar cheese (Chin & Rosenberg, 1997), was found in all cheese samples. The full-fat cheese had higher levels of acetoin than the low-fat control cheese. This is in accordance with the results of Chin and Rosenberg (1997) and Fenelon and Guinee (2000) who also reported higher acetoin levels in full-fat than in reduced-fat Cheddar cheese. The low-fat cheeses containing the adjunct culture had higher levels of acetoin than the other control cheeses. This is probably because the strains of the adjunct culture used in the manufacture of the low-fat cheeses produce the enzyme diacetyl-reductase which produces acetoin (Langsrud & Reinbold, 1973)

Diethylether was found in all cheeses at different levels. Diethylether is regularly found in the headspace of Cheddar cheese and swiss Emmental cheese and is not a contaminant (Urbach, 1995). Finally, ethyl acetate was identified only in the full-fat cheese. Horwood et al. (1981) also, found ethyl acetate in full-fat Feta cheese.

4. Conclusions

The results of the present study indicate that the use of the adjunct culture CR-213 in the manufacture of the low-fat Feta-type cheese, at both levels, had no significant effect on the total FFA content. On the other hand, the full-fat cheese had significantly higher TFFA content than the low-fat control cheese. The principal volatile compounds found in all cheeses were ethanol, acetoin, 2-butanol, 2-butanone and acetaldehyde. The low-fat adjunct-treated cheeses had higher levels of ethanol, 2- butanone and acetoin than the low-fat or the full-fat control cheeses.

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References

Abd, El-Salam, Alichanidis, E., & Zerfiridis, G. K. (1993). Domiati and feta type cheeses. In P. F. Fox (Ed.), *Cheese: chemistry, physics and microbiology, Vol 2* (pp. 301–335). London: Chapman & Hall.

Aly, M. E. (1994). Flavour enchancement of low-fat Kashkaval cheese using heat or freeze-shocked *Lactobacillus delbrueckii* var. *helveticus* cultures. *Die Nahrung*, *38*, 504–510.

Ardo, Y. (1993). Characterizing ripening in low-fat, semi-hard, round-eyed cheese made with undefined mesophilic DL-starter. *International Dairy Journal*, *3*, 345–357.

Attaie, R., & Richter, R. L. (1995). Formation of volatile free fatty acids during ripening of Cheddar-like hard goat cheese. *Journal Dairy Science*, *79*, 717–724.

Banks, J. M., Brechany, E. Y., & Christie, W. W. (1989). The production of low-fat Cheddar-type cheese. *Journal of the Society of Dairy Technology*, *42*, 6–9.

Banks, J. M., Muir, D. D., Brechany, E. Y., & Law, A. J. R. (1992). The production of low-fat hard ripened cheese. In T. M. Cogan, P. F. Fox, & P. Ross (Eds.), *Proceedings of the 3rd Cheese Symposium* (pp. 67–80). Fermoy, Co. Cork, Ireland: National Dairy Products Research Centre.

Bosset, J. O., & Gauch, R. (1993). Comparison of the volatile flavour compounds of six European 'AOC' cheeses by using a new dynamic headspace GC–MS method. *International Dairy Journal*, *3*, 359–377.

Chin, H. W., & Rosenberg, M. (1997). Accumulation of some flavour compounds in full- and reduced-fat Cheddar cheese under different ripening conditions. *Journal Food Science*, *62*(3), 468–474.

Dexheimer, E. (1992). On the fat track. *Dairy Foods*, *93*(5), 38–50.

Drake, M. A., & Swanson, B. G. (1995). Reduced and low-fat cheese technology: a review. *Trends in Food Science and Technology*, *6*, 366–369.

De Jong, C., & Bandings, H. T. (1990). Determination of free fatty acids in milk and cheese: procedures for extraction, clean up, and capillary gas chromatographic analysis. *Journal of High Resolution Chromatography*, *13*, 94–98.

Deeth, H. C., & Fitz-Gerald, C. H. (1976). Lipolysis in dairy products: a review. *Australian Journal of Dairy Technology*, *31*, 53–64.

Dimos, A. (1992). *A comparative study by GC–MS of the flavour volatiles produced during the maturation of full-fat and low-fat Cheddar cheese*. MSc thesis, Latrobe University, Bundoora, Victoria, Australia.

Dimos, A., Urbach, G. E., & Miller, A. J. (1996). Changes in flavour and volatiles of full-fat and reduced-fat Cheddar cheeses during maturation. *International Dairy Journal*, *6*, 981 - 995.

Efthymiou, C. (1967). Major free fatty acids in Feta cheese. *Journal of Dairy Science*, *50*, 20–24.

El-Neshawy, A. A., Abdel Baky, A. A., Rabie, A. M., & Ashour, M. M. (1986). An attempt to produce low-fat Cefalotyre (Ras) cheese of acceptable quality. *Food Chemistry*, *22*, 123–137.

Emmons, D. B., Kalab, M., Larmond, E., & Lowrie, R. J. (1980). Milk gel stucture. X. Texture and microstucture in Cheddar cheese made from whole milk and from homogenized low-fat milk. *Journal of Texture Studies*, *11*, 15–34.

Fox, P. F., Law, J., Mc Sweeny, P. L. H., & Wallace, J. M. (1993). Biochemistry of cheese ripening. In P. F. Fox (Ed.), *Cheese: chem-*

istry, physics and microbiology, Vol 2 (pp. 421–433). London: Chapman & Hall.

Fox, P. F., & Wallace, J. M. (1997). Formation of flavour compounds in cheese. *Advances in Applied Microbiology*, *45*, 17–85.

Fenelon, M. A., & Guinee, T. P. (1997). The composition, texture and maturation characteristics of reduced-fat Cheddar containing Dairy Lo $^{T.M.}$. *Milchwissenschaft*, *52*, 385–389.

Fenelon, M. A., & Guinee, T. P. (2000). Flavour development in low-fat cheese. In *Proceedings 6th Moorepark Cheese symposium* (pp. 31–42). Dublin: Teagasc/UCC.

Hoier, E. (2000). *Maturing cheese scientifically. Around the world, 5 (August)*. Denmark: Chr. Hansen A/S.

Horwood, J. F., Lloyd, G. T., & Stark, W. (1981). Some flavour components of Feta cheese. *Australian Journal of Dairy Technology*, *36*, 34–37.

Katsiari, M. C., & Voutsinas, L. P. (1994). Manufacture of low-fat Feta cheese. *Food Chemistry*, *49*, 53–60.

Keen, A. R., Walker, N. J., & Pederby, M. F. (1974). The formation of 2-butanone and 2-butanol in Cheddar cheese. *Journal of Dairy Research*, *41*, 249–257.

Keenan, T. W., Lindsay, R. C., Morgan, M. E., & Day, E. A. (1966). Acetaldehyde production by single strain lactic streptococci. *Journal of Dairy Science*, *49*, 10–14.

Kleinhenz, J., & Harper, W. J. (1997). Lower molecular weight free fatty acids in full-fat and low-fat Swiss cheese. *Milchwissenschaft*, *52*(11), 622–625.

Langsrud, T., & Reinbold, G. W. (1973). Flavour develpoment and microbiology of Swiss cheese—a review, III. Ripening and flavour production. *Journal of Milk Food and Technology*, *36*(12), 593–609.

Lee, S. K., Johnson, M. E., & Marth, E. H. (1992). Characteristics of reduced-fat Cheddar cheese made with added *Micrococcus species* LL3. *Lebensmittel Wissenschaft und Technologie*, *25*, 552–558.

Mondal, S., Gough, R. H., Ryan, J. J., & Adkinson, R. W. (1989). Manufacture and evaluation of a Feta cheese. *Cultured Dairy Products Journal*, *24*(4), 16 18,20.

Mc Gregor, J. U., & White, C. H. (1990). Effect of enzyme treatment and ultra filtration on the quality of low-fat Cheddar cheese. *Journal of Dairy Science*, *73*, 571–578.

Milo, C., & Reineccius, G. A. (1997). Identification and quantification of potent odorants in regular-fat and low-fat mild Cheddar cheese. *Journal of Agriculture and Food Chemistry*, *45*, 3590–3594.

Ohren, J. A., & Tuckey, S. L. (1969). Relation of flavour development in Cheddar cheese to chemical changes in the fat of the cheese. *Journal of Dairy Science*, *52*, 598–607.

Olson, N. F., & Johnson, M. E. (1990). Light cheese products: characteristics and economics. *Food Technology*, *44*(10), 93–96.

Oumer, A., Fernandez-Garcia, E., Serrano, C., & Nunez, M. (2000). Flavour of Hispanico cheese manufactured with *Lc. Lactis* ssp. *lactis* and *Lc. Lactis* ssp. *cremoris* as starter cultures. *Milchwissenschaft*, *55*(6), 325–328.

Rodriguez, J., Requena, T., Valero, E., Martinez-Castro, I., Lopez-Fandino, R., & Huarez, M. (1997). Proteolysis and volatile components of reduced-fat cheeses made from ultrafiltered milk and different starters supplemented with lactobacilli and Lac$^-$ Prt$^-$Lactococci. *Lait*, *77*, 717–728.

Suriyaphan, O., Drake, M. A., & Cadwallader, K. R. (1999). Identification of volatile off-flavours in reduced-fat Cheddar cheeses containing lecithin. *Lebensmittel Wissenschaft und Technologie*, *32*, 250–254.

Urbach, G. (1993). Relations between cheese flavour and chemical composition. *International Dairy Journal*, *3*, 389–422.

Urbach, G. (1995). Contribution of lactic acid bacteria to flavour compounds formation in Dairy products. *International Dairy Journal*, *5*, 877–903.

Urbach, G. (1997). The flavour of milk and dairy products. II. Cheese: contribution of volatile compounds. *International Journal of Dairy Technology*, *50*(3), 79–89.

Voutsinas, C. P., Katsiari, M. C., Kondyli, E., & Alichanidis, E. (2001). *Use of commercial enzymes or adjunct cultures for improving the sensory quality of a white brined cheese and a hard cheese of low-fat content. Final report of the research project DEMETRA 95 VI/7*. Greece: National Agricultural Research Foundation.