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Food Chemistry 88 (2004) 381–388
Food Chemistry
www.elsevier.com/locate/foodchem

Effect of some fat replacers on chemical, physical and sensory attributes of low-fat white pickled cheese ☆

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Received 17 November 2003; received in revised form 12 January 2004; accepted 12 January 2004

Abstract

Full-fat and low-fat white pickled cheeses were manufactured, by the traditional procedure, from bovine milk. Results indicated that, as the fat content of cheese milk decreased, fat in total solids, total solids and cheese yield of white pickled cheese significantly decreased but the moisture and total nitrogen values significantly increased. Total solids, salt, salt in total solids, pH and acidity values of cheese were not affected by the fat replacers in the cheese milk used. Sensory properties of cheese were adversely affected by the use of fat replacers in cheese making. From the rheological point of view, all the low-fat cheeses containing fat replacers were different from the full-fat cheese. Moreover, no off-flavour or bitterness was noted in any full-fat or low-fat cheese.

Keywords: Low-fat cheese; White pickled cheese; Composition; Fat replacers type; Fat mimetics

1. Introduction

Since the 1980s, the eating habits of consumers in North America and Europe have changed. Largely influenced by health-related concerns, there has been pressure to reduce the amounts of fat, sugar, cholesterol, salt and certain additives in diet (Drake & Swanson, 1995; Muir, Tamime, Shenana, & Dawood, 1999; Rodriguez, 1998; Tamime, Muir, Shenana, Kalab, & Dawood, 1999).

Food manufacturers have responded to consumer demand and there has been a rapid market growth of products with a healthy image (Mistry, 2001; Muir et al., 1999; Tamime et al., 1999).

Fat consumption by western populations has been shown to be associated with an increased risk of obesity, atherosclerosis, coronary heart disease, elevated blood pressure, and tissue injury diseases associated with lipid oxidation (Katsiari, Voutsinas, & Kondyli, 2002). This association has created an increased awareness and a dramatic increase in the demand and supply for, low-fat foods, including cheese varieties (Katsiari et al., 2002).

However, reduced-fat and low-fat cheeses, that exhibit the characteristics of conventional full-fat cheeses, are needed for consumer markets. Cheeses with reduced-fat content may exhibit dilute flavour and poor texture (Drake, Bolyston, & Swanson, 1996). For this reason, fat replacer compounds are used to fully or partially replace fat in reduced-fat foods (Drake et al., 1996). Fat replacers have been used to stimulate the functional and organoleptic properties of fat with a substantial reduction in calorific value (Drake & Swanson, 1995; Mistry, 2001; Muir et al., 1999; Rodriguez, 1998). Fat replacers are categorized as fat substitutes or fat mimetics. Fat mimetics are polar, water-soluble compounds used to partially replace the sensory and functional characteristics of fat. Also, fat mimetics may improve sensory and functional characteristics of low-fat cheeses by binding water and improving texture and yields (Drake et al., 1996).

The production of fat-free or reduced-fat foods has been a constant preoccupation of scientists and industry due to the desire to limit the fat intake by large segments of population. However, it is not easy to make low-fat

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doi:10.1016/j.foodchem.2004.01.054

or fat-free cheeses with good sensory properties. The main problem is the much higher protein content and the resulting possibilities of major cross linking. As fat content decreases, the protein matrix becomes more compact and the cheese texture is more chewy (Zalazar, Zalazar, Bernal, Bertola, Bevilacqua, & Zraitzky, 2002).

In recent years, many studies have been related to low-fat Mozzarella, Cheddar, Kashkaval, Edam, Kefalograviera type cheeses (Drake et al., 1996; Drake, Herrett, Bolyston, & Swanson, 1995; Katsiari & Voutsinas, 1994; Muir et al., 1999; Romeih, Michaelidou, Biliaderis, & Zerfiridis, 2002; Sipahioglu, Alvarez, & Solano-Lopez, 1999; Zalazar et al., 2002). However, other cheeses with higher levels of consumption, such as low-fat soft cheeses, have received much less attention (Zalazar et al., 2002). White pickled cheese, the subject of this study, is a very popular soft cheese in Turkey and constitutes more than 50% of the total cheese production. White pickled cheese is a soft white cheese with 20–25% fat, ripened in brine, with a typical salty and acidic taste. Conventional white pickled cheese is made using bovine's, sheep's or goat's milk or a mixture of these milks that imparts the characteristic flavour.

Therefore the objectives of this study were to determine the effects of fat reduction on composition, hardness and sensory properties of white pickled cheese and to evaluate the functionality of carbohydrate- and protein-based fat replacers as fat mimetics in low-fat white pickled cheese.

2. Materials and methods

2.1. Milk, culture, rennet and fat replacers

Fresh bovine milk was obtained from the Pınar Milk and Milk Products A.Ş. and processed at the pilot plant of the laboratory of the Dairy Technology Department. The milk was first standardized at a fat content of about 0.5%. Certain quantities whole of 60 kg milk and low-fat milk were kept as controls. All portions of milk were pasteurized at 74 °C for 1–2 s and cooled to 35 °C.

A freeze-dried cheese culture (Redi-Set MA-U014, TEXEL-Group Rhòne-Poulenc 86220 Dange'- Saint-Romain, France) of mixed mesophilic strains, containing *Lactococcus lactis subsp. lactis* and *Lactococcus lactis subsp. cremoris*, was used. The culture was reactivated and grown at 37 °C for 30 h, followed by refrigeration overnight before cheese production. The activated starter culture was added to cheese milk at a level of 0.5% v/v-10^{11} or/g. Powdered calf rennet (HA-LA, Hansen's Laboratorium, Copenhagen, Denmark), dissolved in tap water, was used; 25 ml single strength liquid rennet was added to each cheese milk.

The fat replacers used were Simplesse® D-100 (Nutra-Sweet KELCO Co., USA) and Dairy-Lo™ (Pfizer Inc., Groton, CT) which are microparticulated whey protein concentrates. The quantity of fat replacers used in cheese making was based on usage levels recommended by the manufacturers. Portions of 300 g of Simplesse® D-100 and Dairy-Lo™ were used in 60 kg of milk. Low-fat white pickled cheeses, formulated with carbohydrate-based fat mimetics, were made by adding 0.5% Perfectamyl gel MB (modified potato starch) (**P**) and 0.4% Satiagel ME 4 (**St**) (AVEBE STARCH Co.). The dispersion of fat replacers in milk was made according to the manufactures recommendations.

2.2. Cheesemaking and storage

Two batches of cheese were made as follows: a control vat of full-fat cheese (**F**), a control of low-fat cheese (**L**) and four vats of low-fat cheese containing fat replacers were formulated in each batch using 60 kg of milk for each vat (**S**, **D**, **St**, **P**).

After pasteurization, batches of 60 l of milk were cooled to 35 °C. The milk was then inoculated with a lactic starter culture of *Lc. lactis subsp. lactis* and *Lc. lactis subsp. cremoris* at a rate of 0.5% (w/w). This was followed by the addition of 40% (w/v) $CaCl_2$ solution (i.e. 0.02% v/v) to each batch. The milk was held at 35 °C for 30 min for starter maturation before the addition of rennet (0.04% v/v), then the rennet was added to the cheese milk. Then curd was allowed to set for 45 min and was then cut into approximately 1 cm^3 cubes with vertical and horizontal knives. After being cut, the curd was left to settle for 20–25 min. The curd was then transferred to molds ($30 \times 30 \times 30$ cm^3) and covered with cheese cloth. More curd was added to the molds as whey drained during the first 10–15 min and then pressed for 2 h. Following this period, cheese blocks ($8 \times 8 \times 8$) were cut, placed in vat and covered with brine (15% NaCl). This was followed by addition of the residual amount of dry salt on the upper surface of the cheese blocks. After 5 h, the cheese blocks were vacuum-packaged in clear poly-vacuum bags and stored at 5 °C for a ripening period of 90 days.

Samples from each cheese were taken 1, 15, 30, 45, 60 and 90 days after manufacturing, for assessment of compositions. The values reported are the means of the three cheese making trials.

2.3. Chemical analyses

Full and low-fat cheese milks were analysed for fat, total nitrogen and total solids (AOAC, 1995; Türk Standartları, 1990).

The fat content of cheese was determined by the Gerber method, whereas total solids and salt contents were determined according to the standard methods (IDF, 1982; Türk Standartları, 1978).

The pH of cheese was measured using a pH meter (Beckman Zeromatic SS3) by inserting a combined glass calomel electrode. The titratable acidity was determined by the Soxhlet Henkel method (Türk Standartları, 1995). Total nitrogen (TN) of cheese was determined by the Kjeldahl method (Öztürk & Metin, 2002) using approximately 1 g of grated cheese. The water-soluble fraction (WSN) was prepared essentially as described by Polychroniadou, Michaelidou, and Paschaloudis (1999), using 20 g of cheese with 100 ml H_2O. The mixture was homogenized for 5 min using an Ultraturrax IP 1842 model. Water-soluble N content of the cheese extract was determined by the Kjeldahl method, using 10 ml of cheese extracts (AOAC, 1995; Katsiari, Alichanidis, Voutsinas, & Roussis, 2001). Total free fatty acids (FFA) of cheese were determined as described by Katsiari, Alichanidis, Voutsinas, and Roussis (2000).

2.4. Hardness

Hardness was measured using an Instron Universal Testing Instrument Model 1140 (Instron Ltd., High Wycombe, Bucks, UK). Samples ($4 \times 4 \times 2$ cm^3) were prepared and analyzed as described by Prasad and Alvarez (1999).

2.5. Sensory evaluation

Organoleptic assessment of the cheeses, during the ripening period, was carried out by a five member panel of the Department's staff, selected on the basis of interest and experience in sensory evaluation of white-brined cheese products. Panellists assessed the cheese samples according to scheme by the International Dairy Federation (IDF, 1987) guide for the sensory evaluation of cheese. Samples of white-brined cheese were placed on white plates coded with three-digit random numbers. The samples were tempered at ambient temperature (18 ± 2 °C) for 1 h and then presented to the panellists in a random order for testing. Water was provided for mouth-washing between samples.

2.6. Statistical analysis

Experimental design was conducted to evaluate the influence of the six treatments, namely **F** (full-fat cheese), **L** (low-fat, without fat replacers), **S** (low-fat cheese, with Simplesse® D-100), **D** (low-fat cheese with Dairy-Lo™), **St** (low-fat cheese with Satiagel ME4), **P** (low-fat cheese with Perfecamyl gel MB) on the physico-chemical and sensory characteristics of the cheese. The experimental design was a split-plot design where the larger cheese sample was the whole plot and the smaller sample, one of the triplicate measurements, was the subplot. The whole plot experiment was a one-way treatment layout in a completely randomized design. Duncan's multiple comparison procedure was used to compare the means. The appropriate error term used in the multiple comparison was the random effect for the whole plot. The variables were total solids, fat, salt, fat in total solids, salt in total solids, total nitrogen, acidity, free fatty acids, hardness and sensory properties. A probability of <0.05 was used to establish statistical significance and the statistical data analysis was performed using the SPSS program (SPSS Inc. Chicago, USA, Sipahioglu et al., 1999).

3. Results and discussion

3.1. Milk composition

The average composition and some of the physico-chemical properties of standardized bovine milk used in evaluating the effect of fat replacers on the quality characteristics of low-fat white-brined cheese are given in Table 1. Reduction in the fat content of milk affected its total solids (TS%) and the casein/fat ratio increased as the fat content in the milk decreased; there was no effect on the pH of milk.

3.2. Compositional and physico-chemical properties of cheese

The effects of reducing the fat content of cheese milk on the mean values of composition and physico-chemical properties of manufactured white pickled cheese, during ripening and at the end of ripening, are shown in Table 2. The fat content of cheese milk significantly ($p < 0.05$) affected these parameters; the total solids content was inversely related to the fat content of cheese milk. The full-fat cheese had a higher total solids content than cheeses produced from low-fat milk ($p < 0.05$). These differences between the full-fat cheeses and the low-fat cheeses may be attributed to their total nitrogen contents. Furthermore, fat replacers are known for their water-binding capacity, which may in turn explain the lower total solids content found in the cheese containing the fat replacers than in the full and low-fat control cheeses.

Compared to full-fat cheeses (**F**), total nitrogen contents of low-fat cheeses increased significantly ($p < 0.05$)

Table 1
Composition and physico-chemical properties of milk used in the manufacture of low-fat white pickled cheese

Composition	Whole milk	Low-fat milk
Fat (%)	3.28	0.43
Protein (%)	2.82	2.37
Casein (%)	2.22	1.89
Casein/fat	0.67	4.39
Total solids (%)	11.12	8.63
PH	6.61	6.60

Table 2
Chemical composition and ripening indices of low-fat and full-fat cheeses during ageing

Sample no.	Age (days)						
		1	15	30	45	60	90
Full-fat cheese (**F**)	DM (%)[A]	42.07 ± 2.59[a]	45.00 ± 0.67[a]	45.22 ± 2.00[a]	45.92 ± 1.11[a]	44.95 ± 1.69[a]	45.43 ± 2.45[a]
	Fat (%)	24.00 ± 3.61[a]	23.50 ± 3.50[a]	24.00 ± 3.91[a]	21.17 ± 1.61[a]	21.83 ± 0.29[a]	22.17 ± 1.04[a]
	N (%)[B]	2.69 ± 0.50[a]	2.70 ± 0.43[a]	2.66 ± 0.43[a]	2.60 ± 0.43[a]	2.55 ± 0.45[a]	2.47 ± 0.45[a]
	WSN (%)[C]	0.40 ± 0.19[a]	0.55 ± 0.34[a]	0.65 ± 0.21[a]	0.72 ± 0.16[a]	0.79 ± 0.13[a]	0.88 ± 0.13[a]
	Salt (%)	2.20 ± 0.47[a]	2.04 ± 0.23[a]	2.04 ± 0.30[a]	2.46 ± 0.36[a]	2.46 ± 0.24[a]	2.54 ± 0.29[a]
	Acidity (SH)	50.5 ± 3.9[a]	63.2 ± 15.9[a]	81.0 ± 7.6[a]	78.0 ± 8.7[a]	81.0 ± 13.3[a]	93.3 ± 15.9[a]
	Acidity (pH)	5.18 ± 0.17[a]	5.20 ± 0.17[a]	5.27 ± 0.21[a]	5.23 ± 0.15[a]	5.30 ± 0.0001[a]	5.10 ± 0.26[a]
	FFA (%)[D]	5.01 ± 5.39[a]	1.19 ± 0.44[a]	1.27 ± 0.45[a]	1.85 ± 0.90[a]	1.75 ± 0.46[a]	2.76 ± 0.007[a]
	FDM[E]	56.98 ± 5.5	52.16 ± 7.87	52.88 ± 6.17	46.05 ± 2.37	48.58 ± 1.41	48.45 ± 1.11
	SDM[F]	5.19 ± 0.79	4.54 ± 0.57	4.53 ± 0.78	5.37 ± 0.91	5.48 ± 0.64	5.58 ± 0.82
Low-fat cheese (**L**)	DM (%)	35.60 ± 2.46[b]	36.52 ± 3.98[b]	38.30 ± 2.99[b]	37.73 ± 3.50[b]	38.22 ± 1.56[b]	38.37 ± 1.73[b]
	Fat (%)	4.33 ± 0.26[b]	6.00 ± 1.00[b]	5.67 ± 0.58[b]	5.17 ± 0.28[b]	5.00 ± 0.50[b]	5.17 ± 0.29[b]
	N (%)	3.70 ± 0.0010[b]	3.64 ± 0.0095[b]	3.60 ± 0.11[b]	3.55 ± 0.0072[b]	3.49 ± 0.0090[b]	3.46 ± 0.11[b]
	WSN (%)	0.84 ± 0.60[b]	0.60 ± 0.28[a]	0.72 ± 0.15[a]	0.81 ± 0.0070[a]	0.82 ± 0.0076[a]	0.92 ± 0.0092[a]
	Salt (%)	2.50 ± 0.75[a]	2.65 ± 0.56[a]	2.50 ± 0.23[a]	2.73 ± 0.79[a]	3.14 ± 0.24[b]	3.29 ± 0.86[b]
	Acidity (SH)	41.2 ± 11.8[b]	54.7 ± 24.4[b]	76.7 ± 16.8[a]	69.0 ± 16.1[b]	73.7 ± 2.4[b]	87.2 ± 1.9[b]
	Acidity (pH)	5.43 ± 0.23[a]	5.29 ± 0.15[b]	5.33 ± 0.15[a]	5.30 ± 0.17[a]	5.37 ± 0.00577[a]	5.33 ± 0.21[b]
	FFA (%)	0.62 ± 0.56[b]	4.13 ± 3.35[b]	2.01 ± 1.79[a]	2.23 ± 2.15[a]	8.43 ± 2.25[b]	3.81 ± 3.88[a]
	FDM	12.10 ± 1.34	16.53 ± 3.23	14.90 ± 2.44	13.72 ± 0.77	13.06 ± 0.78	13.46 ± 0.22
	SDM	7.11 ± 2.56	7.36 ± 2.07	6.55 ± 0.72	7.40 ± 2.82	8.25 ± 0.97	8.60 ± 2.38
Low-fat cheese with Simplesse® D-100 (**S**)	DM (%)	37.56 ± 3.58[b]	38.47 ± 5.59[b]	37.03 ± 1.36[b]	38.33 ± 2.41[b]	39.02 ± 3.83[b]	38.00 ± 3.04[b]
	Fat (%)	4.00 ± 0.50[b]	4.00 ± 0.50[b]	4.50 ± 0.50[b]	4.67 ± 0.76[b]	4.83 ± 0.57[b]	4.67 ± 0.58[b]
	N (%)	3.38 ± 0.39[b]	3.27 ± 0.51[b]	3.27 ± 0.51[b]	3.25 ± 0.49[b]	3.24 ± 0.50[b]	3.18 ± 0.48[b]
	WSN (%)	0.51 ± 0.25[a]	0.57 ± 0.28[a]	0.675 ± 0.16[a]	0.75 ± 0.17[a]	0.87 ± 0.10[a]	0.93 ± 0.11[a]
	Salt (%)	2.70 ± 0.51[a]	2.95 ± 0.39[a]	2.88 ± 0.43[a]	3.52 ± 0.11[b]	3.22 ± 0.47[b]	3.29 ± 0.52[b]
	Acidity (SH)	45.0 ± 13.1[b]	55.7 ± 16.1[b]	76.8 ± 20.6[a]	80.6 ± 17.0[a]	79.7 ± 17.5[a]	94.3 ± 7.0[a]
	Acidity (pH)	5.33 ± 0.21[a]	5.27 ± 0.0025[a]	5.40 ± 0.17[a]	5.30 ± 0.10[a]	5.33 ± 0.21[a]	5.30 ± 0.17[b]
	FFA (%)	1.86 ± 1.65[c]	2.02 ± 3.49[c]	1.53 ± 2.65[a]	3.74 ± 3.38[b]	8.82 ± 2.33[b]	5.49 ± 6.07[b]
	FDM	11.04 ± 1.57	11.31 ± 1.72	12.13 ± 1.00	12.13 ± 1.32	12.37 ± 0.32	12.27 ± 1.19
	SDM	7.39 ± 1.70	7.87 ± 2.00	7.76 ± 1.10	9.22 ± 0.81	8.33 ± 1.75	8.77 ± 1.99
Low-fat cheese with Dairy-Lo™ (**D**)	DM (%)	36.20 ± 2.09[b]	35.80 ± 4.47[b]	35.32 ± 2.25[c]	36.42 ± 1.84[b]	36.68 ± 1.47[a]	37.97 ± 4.03[b]
	Fat (%)	4.00 ± 0.50[b]	4.83 ± 0.29[b]	4.67 ± 0.29[b]	4.50 ± 0.00[b]	4.83 ± 0.29[b]	4.83 ± 0.76[b]
	N (%)	3.25 ± 0.54[b]	3.43 ± 0.45[b]	3.40 ± 0.48[b]	3.39 ± 0.50[b]	3.39 ± 0.46[b]	3.30 ± 0.47[b]
	WSN (%)	0.57 ± 0.27[a]	0.66 ± 0.25[a]	0.70 ± 0.18[a]	0.80 ± 0.0093[a]	0.87 ± 0.0047[a]	0.97 ± 0.0044[a]
	Salt (%)	2.16 ± 0.30[a]	2.50 ± 0.23[a]	2.92 ± 0.0065[a]	3.07 ± 0.86[b]	3.37 ± 0.63[b]	3.22 ± 0.47[b]
	Acidity (SH)	35.3 ± 3.8[c]	59.8 ± 19.6[b]	77.3 ± 10.9[a]	83.5 ± 10.2[a]	66.7 ± 11.2[c]	94.5 ± 8. 3[a]
	Acidity (pH)	5.40 ± 0.10[a]	5.22 ± 0.13[a]	5.33 ± 0.15[a]	5.27 ± 0.12[a]	5.40 ± 0.20[a]	5.30 ± 0.17[b]
	FFA (%)	0.66 ± 0.91[b]	3.08 ± 2.73[b]	5.13 ± 1.26[b]	8.30 ± 1.02[c]	8.29 ± 4. 04[b]	6.10 ± 1.06[b]
	FDM	11.04 ± 1.71	13.59 ± 1.25	13.21 ± 0.11	12.37 ± 0.61	13.16 ± 0.28	12.68 ± 0.80
	SDM	5.91 ± 0.53	7.00 ± 0.57	8.28 ± 0.69	8.37 ± 2.04	9.24 ± 2.07	8.56 ± 1.62
Low-fat cheese white Satiagel ME4 (**St**)	DM (%)	33.08 ± 2.57[b]	35.28 ± 3.86[b]	32.28 ± 0.62[c]	34.52 ± 1.44[c]	33.83 ± 1.58[d]	33.30 ± 1.13[c]
	Fat (%)	3.67 ± 0.29[b]	4.33 ± 1.44[b]	3.50 ± 0.00[b]	4.17 ± 0.58[b]	4.00 ± 0.50[b]	4.16 ± 0.57[b]
	N (%)	3.23 ± 0.38[b]	3.25 ± 0.38[b]	3.24 ± 0.27[b]	3.19 ± 0.25[b]	3.21 ± 0.21[b]	3.19 ± 0.23[b]
	WSN (%)	0.53 ± 0.25[a]	0.61 ± 0.28[b]	0.69 ± 0.13[a]	0.77 ± 0.0074[a]	0.85 ± 0.0029[a]	0.93 ± 0.0029[a]
	Salt (%)	3.37 ± 0.40[b]	3.22 ± 0.65[b]	3.33 ± 0.13[b]	3.60 ± 0.54[b]	3.90 ± 0.66[b]	3.29 ± 0.98[b]
	Acidity (SH)	38.0 ± 16.9[c]	55.0 ± 33.7[b]	80.6 ± 4.0[a]	84.8 ± 11.8[a]	79.0 ± 3.9[b]	89.7 ± 14.9[a]
	Acidity (pH)	5.37 ± 0.25[a]	5.27 ± 0.14[a]	5.33 ± 0.21[a]	5.27 ± 0.15[a]	5.23 ± 0.15[a]	5.17 ± 0.21[a]
	FFA (%)	1.61 ± 1.39[c]	2.84 ± 2.63[c]	4.67 ± 2.14[b]	6.00 ± 1.95[d]	11.38 ± 2.44[c]	14.45 ± 4.62[c]
	FDM	10.77 ± 0.37	12.11 ± 2.74	10.84 ± 0.21	12.03 ± 1.20	11.88 ± 2.02	12.54 ± 1.72
	SDM	9.93 ± 1.64	9.29 ± 2.55	10.32 ± 0.35	10.47 ± 2.03	11.50 ± 1.64	10.03 ± 3.46
Low-fat cheese white Perfectamyl gel MB (**P**)	DM (%)	32.66 ± 2.27[b]	36.13 ± 2.99[b]	35.60 ± 4.80[b]	36.33 ± 3.05[b]	34.93 ± 2.60[d]	37.33 ± 1.25[b]}
	Fat (%)	4.67 ± 0.29[b]	4.33 ± 0.76[b]	4.67 ± 0.58[b]	4.17 ± 0.28[b]	4.17 ± 0.28[b]	4.50 ± 0.50[b]
	N (%)	3.36 ± 0.57[b]	3.59 ± 0.31[b]	3.58 ± 0.31b[b]	3.53 ± 0.39[b]	3.47 ± 0.32[b]	3.44 ± 0.31[b]
	WSN (%)	0.50 ± 0.34[a]	0.55 ± 0.29[a]	0.64 ± 0.22[a]	0.76 ± 0.14[a]	0.85 ± 0.12[a]	0.95 ± 0.0074[a]
	Salt (%)	2.99 ± 0.46[b]	2.80 ± 0.34[a]	2.65 ± 0.0065[a]	3.03 ± 0.39[b]	3.10 ± 0.36[b]	3.25 ± 0.17[b]
	Acidity (SH)	30.5 ± 7.7[c]	37.7 ± 10.9c	55.2 ± 21.5[b]	59.2 ± 12.1[c]	62.5 ± 25.1[c]	96.0 ± 12.9[a]
	Acidity (pH)	6.63 ± 0.11[a]	5.45 ± 0.0083[a]	5.53 ± 0.23[a]	5.40 ± 0.10[a]	5.43 ± 0.15[a]	5.23 ± 0.23[a]
	FFA (%)	0.67 ± 6.61[b]	2.51 ± 3.03[c]	3.30 ± 3.63[b]	5.63 ± 5.06[d]	13.57 ± 12.67[c]	7.3 ± 12.73[b]

Table 2 (*continued*)

Sample no.	Age (days)						
		1	15	30	45	60	90
	FDM	14.90 ± 1.07	11.96 ± 1.77	13.16 ± 0.78	11.48 ± 0.55	11.93 ± 0.51	12.04 ± 1.05
	SDM	9.12 ± 1.09	7.78 ± 1.13	7.53 ± 1.02	8.33 ± 0.86	8.90 ± 1.08	8.73 ± 0.71

[a–d] Means in the same column bearing a common superscript do differ significantly ($p < 0.05$).
[A] Dry matter.
[B] Nitrogen.
[C] Water-soluble nitrogen.
[D] Free fatty acid.
[E] Fat in total solids.
[F] Salt in total solids.

and similar results were reported by Drake et al. (1996); Katsiari and Voutsinas (1994); Katsiari et al. (2002); Koca and Metin (2002); Michaelidou, Katsiari, Voutsinas, Kondyli, and Alichanidis (2003); Romeih et al. (2002); Rudan, Barbano, Yun, and Kindstadt (1999); Sipahioglu et al. (1999); Zalazar et al. (2002).

The mean values of salt and salt in total solids (S/TS) of full and low-fat cheeses at different ripening times are also given in Table 2. Low-fat cheeses had significantly ($p < 0.05$) higher salt contents than full-fat cheese during ripening period. The full-fat cheese (Table 2) also showed lower S/TS values than the respective low-fat variants. This trend was observed throughout cheese ripening and is in close agreement with other reports (Katsiari & Voutsinas, 1994; McGregor & White, 1990; Romeih et al., 2002; Rudan et al., 1999; Sipahioglu et al., 1999). The lower S/TS content in the three low-fat cheeses (**S**, **D** and **P**) may be linked to their higher moisture contents. Also the differences in salt and total solid contents between the full-fat cheese and the low-fat cheeses may have contributed to increased water-binding capacity of the cheese matrix (Romeih et al., 2002).

The effects of reducing the fat content of cheese milk on the mean pH and acidity values of the manufactured white pickled cheese are also shown in Table 2. There were no significant ($p > 0.05$) differences in pH and acidity (SH) between full-fat and low-fat cheeses at any sampling time during ripening and storage. These results agree with those reported by Katsiari and Voutsinas (1994), Katsiari et al. (2002), McGregor and White (1990) and Sipahioglu et al. (1999).

The rate and extent of proteolysis in the cheeses monitored by measuring the levels of water-soluble nitrogen (W-SN) during cheese ripening and storage are shown in Table 2. The W-SN level continuously increased in all cheeses throughout ageing. An increasing trend was observed in the production of W-SN in white pickled cheeses with increasing fat level of cheese milk. However, significant ($p < 0.05$) differences in W-SN levels were observed only between full-fat control cheese and that made from low-fat milk with protein- and carbohydrate-based fat replacers. These results are in conformity with these of other workers (Katsiari & Voutsinas, 1994; Michaelidou et al., 2003; Sipahioglu et al., 1999).

The extents of lipolysis in the cheese, expressed as the acid-degree value (ADV), during ripening are given in Table 2. The ADV values of all samples usually increased during ageing, reflecting a continuous hydrolysis of the lipid fraction. The mean value of ADV of low-fat control cheese was somewhat lower than that of full-fat cheese. However, it should be noted that the difference was significant ($p < 0.05$). Comparing the cheese containing protein- and carbohydrate-based fat replacers with full-fat cheese, the higher lipolysis levels of the cheeses made with the fat replacers might be attributed to their higher moisture contents, which generally flavour enzyme activity and microbial growth. The declining trend observed in the ADV of cheese with decreasing fat content is in line with previous results (Katsiari & Voutsinas, 1994; Romeih et al., 2002).

3.3. Sensory evaluation

The results of the sensory panel's assessment of cheese quality during ripening are given in Table 3. The data show that the appearance, body, texture and flavour of white brined cheeses were affected by the fat replacer type used in cheese making. Regarding appearance, a significant difference was observed, only at 45 days of ageing, between full-fat, low-fat control cheese and that made from milk containing fat replacers. Moreover, the body and texture of cheeses made from full-fat, and containing protein- and carbohydrate-based fat replacers, improved during storage. Significant differences in body and texture among cheeses were observed only at 45 days of ageing. The type of fat replacers added to cheese milk had no significant negative effect ($p > 0.05$) on the flavour score of the resultant white-pickled cheese (Table 3). Significant differences in flavour among cheeses were

Table 3
Sensory characteristics of low-fat and full-fat cheeses during ageing

Sample no.	Age (days)						
		1	15	30	45	60	90
Full-fat cheese (**F**)	Flavour	20.57 ± 1.20^{a}	27.03 ± 1.91^{a}	22.40 ± 1.39^{a}	24.00 ± 6.92^{a}	26.67 ± 5.77^{a}	33.67 ± 2.31^{a}
	Appearance	16.30 ± 1.18^{a}	15.00 ± 2.60^{a}	12.63 ± 2.30^{a}	15.57 ± 0.51^{a}	16.00 ± 3.61^{a}	16.80 ± 1.91^{a}
	B.T.[A]	27.10 ± 1.39^{a}	20.40 ± 7.54^{a}	17.33 ± 4.04^{a}	12.90 ± 6.16^{a}	26.67 ± 7.64^{a}	26.97 ± 13.38^{a}
	Odour	13.70 ± 6.13^{a}	8.19 ± 0.44^{a}	9.03 ± 1.42^{a}	8.17 ± 0.97^{a}	9.33 ± 1.15^{a}	8.83 ± 1.46^{a}
Low-fat cheese (**L**)	Flavour	19.67 ± 1.81^{a}	19.10 ± 4.71^{b}	23.77 ± 7.26^{a}	15.50 ± 7.79^{b}	13.43 ± 14.35^{b}	18.40 ± 13.58^{b}
	Appearance	17.87 ± 2.19^{a}	13.10 ± 1.65^{a}	12.00 ± 1.73^{a}	6.17 ± 1.04^{b}	12.20 ± 2.55^{b}	12.10 ± 6.93^{b}
	B.T.	27.43 ± 1.56^{a}	20.90 ± 2.77^{a}	16.00 ± 1.00^{a}	16.40 ± 7.12^{b}	21.67 ± 12.58^{b}	18.30 ± 13.15^{b}
	Odour	11.33 ± 5.62^{a}	8.40 ± 0.96^{a}	8.00 ± 0.00^{a}	7.53 ± 0.45^{a}	10.00 ± 0.35^{a}	6.90 ± 7.21^{b}
Low-fat cheese with Simplesse® D-100 (**S**)	Flavour	21.37 ± 3.70^{a}	20.20 ± 2.55^{b}	28.23 ± 1.54^{b}	20.00 ± 0.00^{c}	26.67 ± 7.64^{a}	16.53 ± 10.25^{b}
	Appearance	17.07 ± 0.50^{a}	14.17 ± 1.44^{a}	11.77 ± 1.66^{a}	14.23 ± 1.08^{a}	16.00 ± 1.73^{b}	11.57 ± 0.25^{b}
	B.T.	25.37 ± 3.42^{a}	26.77 ± 2.46^{a}	17.57 ± 2.12^{a}	15.67 ± 8.14^{b}	26.67 ± 7.64^{a}	24.77 ± 9.25^{a}
	Odour	12.10 ± 3.75^{a}	7.80 ± 0.69^{a}	8.90 ± 1.30^{a}	6.90 ± 0.44^{a}	9.33 ± 1.15^{a}	8.87 ± 1.03^{a}
Low-fat cheese with Dairy-Lo™ (**D**)	Flavour	20.80 ± 2.40^{a}	20.63 ± 2.54^{b}	17.53 ± 5.71^{c}	15.57 ± 8.45^{b}	29.77 ± 9.06^{c}	17.13 ± 4.87^{b}
	Appearance	16.30 ± 6.15^{a}	12.73 ± 3.18^{a}	13.17 ± 2.57^{a}	8.67 ± 4.37^{b}	12.10 ± 2.59^{a}	16.13 ± 7.68^{a}
	B.T.	23.77 ± 6.37^{b}	19.87 ± 2.54^{a}	13.60 ± 1.97^{b}	12.00 ± 7.21^{a}	21.67 ± 12.58^{b}	17.87 ± 6.74^{b}
	Odour	11.30 ± 5.48^{a}	9.26 ± 1.59^{a}	8.07 ± 1.36^{a}	7.53 ± 0.45^{a}	14.67 ± 8.96^{b}	10.00 ± 2.00^{a}
Low-fat cheese white Satiagel ME4 (**St**)	Flavour	19.17 ± 0.76^{a}	24.67 ± 7.51^{c}	24.67 ± 7.51^{a}	12.70 ± 6.82^{b}	31.67 ± 2.89^{d}	22.43 ± 2.49^{c}
	Appearance	10.83 ± 1.71^{b}	11.40 ± 0.35^{b}	11.40 ± 0.35^{a}	11.90 ± 2.13^{c}	$11.67 \pm 2.\ 89^{b}$	15.07 ± 3.11^{a}
	B.T.	20.30 ± 3.44^{c}	17.43 ± 3.09^{c}	17.43 ± 3.09^{b}	15.90 ± 6.69^{b}	30.00 ± 8.66^{c}	$22.00 \pm 5.\ 57^{a}$
	Odour	8.80 ± 1.04^{b}	8.33 ± 1.14^{a}	8.33 ± 1.14^{a}	7.43 ± 0.49^{a}	9.33 ± 1.15^{a}	10.00 ± 2.00^{a}
Low-fat cheese white Perfectamyl gel MB (**P**)	Flavour	21.07 ± 2.25^{a}	22.70 ± 2.77^{b}	18.63 ± 7.06^{c}	18.57 ± 5.33^{c}	26.43 ± 7.95^{a}	21.93 ± 1.01^{b}
	Appearance	19.17 ± 3.30^{b}	15.60 ± 0.69^{a}	10.77 ± 3.33^{a}	12.67 ± 3.78^{b}	13.33 ± 2.89^{b}	13.53 ± 1.75^{b}
	B.T.	28.00 ± 0.98^{a}	22.30 ± 3.28^{a}	18.67 ± 6.50^{b}	12.53 ± 9.51^{a}	21.67 ± 12.58^{b}	26.13 ± 3.06^{a}
	Odour	12.50 ± 8.01^{a}	8.83 ± 1.04^{a}	7.93 ± 1.53^{a}	7.87 ± 0.71^{a}	14.20 ± 9.43^{b}	9.47 ± 2.84^{a}

[a–d] Means in the same column bearing a common superscript do not differ significantly ($p < 0.05$).
[A] Body and texture.

found only on the 45th day of ripening. Evidently, the full-fat cheese gave a slightly higher overall score than all low-fat products. Nevertheless, all cheeses were judged as acceptable products by the panellists. Finally, it should be noted that no off-flavour or bitterness was detectable, by any member of the panel, in the low-fat cheeses during storage. Several other workers have also reported the successful application of different types of fat replacers in improvement of the sensory characteristics of various reduced and low-fat cheese varieties (Drake et al., 1995; Katsiari & Voutsinas, 1994; Muir et al., 1999; Romeih et al., 2002; Sipahioglu et al., 1999; Zalazar et al., 2002).

3.4. Hardness

The results of objective evaluation of cheese hardness during ripening are given in Table 4. The use of the different types of fat replacers did significantly

Table 4
Measurement of hardness units of full-fat and low-fat cheese during ageing

Sample no.	Age (days)					
	1	15	30	45	60	90
Full-fat cheese (**F**)	25.47 ± 0.93^{a}	23.00 ± 2.26^{a}	22.23 ± 3.19^{a}	18.65 ± 3.55^{a}	15.89 ± 3.74^{a}	12.29 ± 2.32^{a}
Low-fat cheese (**L**)	22.75 ± 1.38^{a}	21.08 ± 0.88^{a}	18.70 ± 2.60^{a}	15.32 ± 2.09^{a}	12.22 ± 1.95^{a}	9.96 ± 0.89^{a}
Low-fat cheese with Simplesse® D-100 (**S**)	41.68 ± 2.26^{b}	32.23 ± 2.16^{b}	31.69 ± 0.51^{b}	29.19 ± 1.48^{b}	26.64 ± 1.17^{b}	23.97 ± 1.18^{b}
Low-fat cheese with Dairy-Lo™ (**D**)	23.38 ± 1.94^{a}	19.75 ± 0.19^{a}	18.97 ± 1.98^{a}	16.36 ± 1.31^{a}	13.80 ± 2.38^{a}	11.29 ± 0.77^{a}
Low-fat cheese white Satiagel ME4 (**St**)	14.14 ± 1.27^{c}	10.84 ± 0.95^{c}	9.73 ± 1.16^{c}	$8.56 \pm 3.215\text{E-}02^{c}$	7.81 ± 0.22^{c}	7.25 ± 0.52^{c}
Low-fat cheese white Perfectamyl gel MB (**P**)	26.93 ± 2.99^{a}	26.28 ± 4.24^{a}	25.80 ± 6.21^{a}	22.79 ± 6.95^{a}	20.65 ± 7.72^{b}	18.86 ± 8.16^{b}

[a–c] Means in the same column bearing a common superscript do not differ significantly ($p < 0.05$).

($p < 0.05$) affect the hardness of the low-fat cheese relative to the full fat and low-fat control cheese. Thus, the experimental cheeses were harder than the full-fat control cheese and gummier and more chewy at 90 days. It is evident, therefore, that the addition of the fat replacers was not sufficient to significantly improve the textural characteristics of low-fat white-pickled cheese. This finding is consistent with previous results (Romeih et al., 2002; Sipahioglu et al., 1999; Ustunol, Kawachi, & Steffe, 1995; Zalazar et al., 2002) on the combined effect of using fat replacers, fat reduction and increased moisture content on some characteristics of Feta cheese, White-brined cheese, low-fat soft cheeses and Cheddar cheese.

4. Conclusion

Fat reduction in white pickled cheese and the use of the protein-based fat replacers, Dairy-Lo™ and Simplesse® D-100 and carbohydrate-based fat replacers Perfectamylgel MB and Satiagel ME4 affected low-fat cheeses in different ways. Fat reduction caused an increase in moisture, total nitrogen and hardness. The use of fat replacers, in low-fat white pickled cheese had an effect on the total solids, salt, salt in total solids, pH and acidity values of cheeses. Also, the water-soluble nitrogen content of cheese extracts showed that the fat replacer had little effect on the ripening characteristics. Overall, quality evaluation showed that it was possible to produce acceptable low-fat cheese (with fat replacer) by the conventional production techniques. No off-flavour or bitterness was noted in the cheese by any member of the taste panel. Differences between cheeses made, especially with Simplesse® D-100, and full-fat cheese or low-fat cheese without fat replacer, as found by the taste panel, were not detectable. Low-fat cheeses, produced by adding Dairy-Lo™, Perfectamylgel MB and Satiagel ME4, were highly acceptable compared to the low-fat cheese without fat replacers. The importance of this finding to the cheese industry is significant, owing to the great demand for a variety of low-fat food items by the consumic public.

Acknowledgements

Author thank Murat Nurlu, instructor of English at the Agean University Department of foreign languages for the revisions of the English version of this paper. The present study has been supported by a grant from the Agean University Scientific Research Fund (Project No: 2001-ZRF-006) and Pınar Dairy Factory Co., İzmir, Turkey.

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