J Food Sci Technol (October 2015) 52(10):6749–6755
DOI 10.1007/s13197-015-1736-0

ORIGINAL ARTICLE

Low-fat Gouda cheese made from bovine milk-olive oil emulsion: physicochemical and sensory attributes

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Revised: 9 January 2015 / Accepted: 12 January 2015 / Published online: 21 January 2015

Abstract The objective of this paper is to study the effect of milk–fat replacement on Gouda cheeses composition, lipolysis and sensory characteristics. A Gouda cheese–like product was prepared from the substitution of milk fat with emulsified olive oil. For comparison, the low–fat variant without fat replacers and the full–fat cheese were also studied. Milk samples are initially pasteurized at 72 °C for 3 s, cooled to 35 °C, and added with 0.016 g L^{-1} of lactic ferments and 0.30 mL L^{-1} of microbial rennet. Total solids content was lower in cheeses containing fat replacers than in full and low–fat control cheeses due to the higher water–binding capacity of fat replacers. Free fatty acids rates were the highest in the case of reduced fat cheese-like product. The full–fat cheese showed a significantly higher overall impression score than all low–fat products.

Keywords Fat replacers · Cheese like products · Emulsified olive oil · Lipolysis · Overall impression

Introduction

During the last decennia, the consumption of reduced – fat food products became more than just a trend. With the aim of the general consensus that the type and the amount of fat consumed is important for the aetiology of several chronic diseases (eg. obesity, cancer cardiovascular disease), it is not surprising that consumers adhere more easily to the nutritional guidelines concerning fat consumption.

In fact, due to the better understanding of the relationship between health and diet, a significant modification is observed in consumer's attitude regarding low fat variants with sensory and physical characteristics that look almost like those of the standard full-fat products. Because of the important role of fat in flavor, appearance and texture of food, it quickly became apparent that the development of low-fat products with correspondence to the quality of their full–fat counterparts is a rather difficult task when replacing fat with alternative ingredients.

Low–fat dairy products such as milk, yoghurt, and some cheeses are available for many years (Rodriguez 1998). In the cheese, the reduction or the removal of milk fat affects negatively both their texture and flavor (Banks et al. 1989; Olson and Johnson 1990), low–fat cheeses are generally identified as soft, firm, rubbery and defective in color (Sipahioglu et al. 1999).

To mimic the different functions of fat in a significantly reduced–fat product, one should consider solids adjustment, particle size impact on mouthfeel, consistency matching, contribution to color and appropriate balance of perceived flavor characteristics of the system. Therefore, different technological strategies and many ingredients have been developed for the characteristic purpose of fat substitution in food products (Lucca and Tepper 1994).

Water-dispersible fat replacers have usually been recommended for use in cheese products, consisting principally of carbohydrate-based materials– or microparticulated protein. These materials work mainly by mechanically entrapping water, giving a sense of creaminess and lubricity (i.e., rheological matching); but, they may not efficiently replace the non polar

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functional properties of fat, like flavor carrying capacity (Romeih et al. 2002).

Replacement of milk fat by emulsified vegetable oils in milk is an option for obtaining cheese with healthier saturated/unsaturated fat balance (Yu and Hammond 2000). However, incorporation of emulsified vegetable oils alters the content, the type and the distribution of the fat droplets into the protein's network, causing changes in cheese microstructure and textural behavior (Lobato-Calleros et al. 2002; Lobato-Calleros et al. 2003).

Fat replacers were used to maintain the sensory characteristics of low-fat cheese, as well as those based on whey proteins (Drake et al. 1996; Lobato-Calleros et al. 2001; McMahon et al. 1996; Tamime et al. 1999).

Previous studies were focused on milk fat substitution by canola oil (Lobato-Calleros et al. 2001, 2003). Few data were available in literature concerning milk fat substitution by olive oil emulsion. The aim of this paper was then to estimate the impact of milk fat reduction and substitution by emulsified olive oil on Gouda cheeses composition, lipolysis and sensory attributes during ripening.

Materials and methods

Materials

Olive oil (OO) (Chaâl Oil, SOCOHUILE, Sfax., Tunisia) was used as the oil phase of the $W_1/O/W_2$ emulsion. The hydrophilic emulsifier (WE) (P4780, SIGMA-ALDRICH, St Louis, USA, esters of monoglycerides and diglycerides of diacetyltartaric acid) and hydrophobic emulsifier (OE) (85548, SIGMA-ALDRICH, Chemie Gmbh, CH-9471 Buchs, Spain, esters of polyglycerol and polyricinoleate fatty acids) were purchased from SIGMA-ALDRICH France. The biopolymers used were gellan gum (GG) (P8169, SIGMA-ALDRICH, St Louis, USA) and carboxymethylcellulose (CMC) (GA 20529, SIGMA-ALDRICH, CH-9471 Buchs, Steinheim, Netherlands). The water used in all of the experiments was double-distilled.

Formulation and preparation of the $W_1/O/W_2$ emulsions

$W_1/O/W_2$ emulsions were prepared at room temperature using a two-stage emulsification procedure (Dickinson and McClements 1996; Felfoul et al. 2012). In the first stage, a W_1/O emulsion was made having a 20 % (*w/w*) dispersed aqueous phase, a GG concentration of 0.1 % (*w/w*) and a total emulsifiers concentration of 8 % (*w/w*) (one part of WE to four parts of OE). In all cases the aqueous inner phase (W_1) (distilled water + WE + GG) was added drop-wise to the oil phase (O) (OO + OE) using an Ultra-Turax homogenizer (Ultra-Turax H 500 SLT, Service Trade Laboratory Equipment, Germany) at 5800 rpm for 5 min. In the second stage the W_1/O primary emulsion was re-emulsified in the biopolymer aqueous solution (0.5 % *w/w* CMC), at 5200 rpm for 10 min using the Ultra-Turax homogenizer, yielding the following $W_1/O/W_2$ emulsion: EC_{CMC}. The $W_1/O/W_2$ emulsion had dispersed phase fraction of 0.2.

Whole milk composition

Total solids and ash contents were determined according to AFNOR methods (1993). The pH of milk was measured using a pH meter (Model pH 315i /SET, WTW Inc., Weilheim, Germany) according to N.F. V 04–281 (1968). Fat, calcium and phosphorous contents of milk were determined according to AOAC (1995).

Cheese making process

A control Gouda cheese (Full–fat cheese) was prepared from milk containing 29±0.58 g of milk-fat L^{-1}. A low–fat Gouda cheese was prepared by blending full fat milk (29±0.58 of milk fat L^{-1}) with skim milk (1±0.1 g of milk fat L^{-1}). A reduced–fat Gouda cheese–like product was elaborated from skim milk added with 29 g of the $W_1/O/W_2$ emulsions L^{-1}. Cheeses were prepared from 200 L batches of formulated milk in a completely randomized design. The formulated milks were vat-pasteurized at 72±0.1 °C for 3 s, cooled to 35± 0.5 °C, and added with 0.016 g L^{-1} of lactic ferments and 0.30 mL L^{-1} of microbial rennet (*M. miehei*, strength 1:10, 000, Laboratoires ARRAZI, PARACHIMIC, Sfax., Tunisia). After coagulation time of approximately 30 min, the curd was cut into 1 cm^3 cubes. About 30 % of the whey was drained, and salting was carried out by adding 6.3 g of table salt L^{-1} of milk. The curds were transferred to 1 kg round polyvinylchloride containers, kept at room temperature (20± 2 °C) for 2 h, and then placed in a cooling chamber (12± 0.5 °C, 80–90 % RH), for 24 h.

Cheeses were stored at 4 °C. After 24 h of preparation, the cheeses were analyzed for protein, fat and moisture by Kjeldahl method, Gerber method and oven drying, respectively (AOAC 1995) and for lipolysis degree (Gallois and Langlois 1990). Composition results were reported in dry basis.

Sensory evaluation

After 45 days of storage (12±0.5 °C, 80–90 % RH), cheese samples were evaluated organoleptically by a 100-member panel recruited among staff and students of the Laboratoire Central d'Analyses et d'Essai (Tunis, State of Tunisia) who stated that they were cheese lovers and users.

Each of the three cheese samples studied in this paper was cut in 1 cm^3 cubes samples, were coded with three-digit random numbers, and randomly presented to the panel. Panel members evaluated cheeses for appearance, texture, and flavor (odor and taste) using a 6 – point scale, with 0 being the worst and 5 the best quality. Importance was given predominantly to the attributes of flavor, and texture over the appearance of the cheeses, as advised by the IDF (1987).

Statistical analysis

Analysis of variance (ANOVA) was carried out by using the software SPSS statistics 19. Significant differences ($p<0.05$) among treatments were detected using Duncan's multiple range tests. Values expressed are means±standard deviation of triplicate measurements.

Results and discussion

Milk composition

The average composition and some physicochemical properties of different milk samples further to milk fat substitution are given in Table 1.

It was observed that the difference between pH of various milk samples was significant ($p<0.05$) (Table 1). This result was in disagreement with those of Romeih et al. (2002) and Kavas et al. (2004). It was concluded that the combined action of fat content reduction and fat replacers addition did not have any significant effect on pH ($p<0.05$).

Table 1 showed that milk fat and total solids contents were the highest in the case of full fat milk (29.33 g/L, 108.69 g/L, respectively) in comparison with low fat milk and milk-olive oil emulsion. The more the raw material was rich in fat, the more total solids content was higher.

Total solids content was significantly more important in the case of low fat milk than for milk-olive oil emulsion ($p<0.05$). This result was due to ash contents for both milk samples. The difference in total nitrogen content between low fat milk and milk-olive oil emulsion samples was not significant ($p<0.05$).

Basing on an equal fat content, total nitrogen content is not different significantly ($p<0.05$) between low fat and milk-olive oil emulsion samples. However, low fat milk showed highest total solids content. This was explained by ash content for both milk samples.

Whey composition

The examination of Table 2 showed that whey resulting from low–fat milk was characterized by the lowest pH compared to full–fat milk and milk-olive oil emulsion.

Whey fat content was more significant in the case of milk-olive oil emulsion than that of full–fat milk. The reduction of fat content and the simultaneous addition of fat replacers had significant effect on whey fat content ($p<0.05$) (Table 2).

However, considering the difference between the initial contents of the two milk samples, fat content loss rate (%) was determined in each whey sample in order to better fit with the inherent phenomena (Fig. 1).

Figure 1 showed that fat content loss rate in the whey was very important in the case of reduced fat Gouda cheese-like product (62.20 %). Fat replacers used did not have a higher Fat Recovery Percentage than that of the original milk fat.

Total solids content was not significantly different for whey samples released from full–fat and milk-olive oil emulsion samples ($p<0.05$). This was attributed to the highest ash and fat contents in the case of reduced fat whey-like product and to the important total nitrogen content for full fat whey.

No significant difference was observed concerning total nitrogen content for all whey samples ($p<0.05$). Moreover, whey expulsed from milk-olive oil emulsion was characterized by a higher mineralization rate than its full and low–fat counterparts. Calcium contents for the three whey samples resulting from full, low-fat milks and milk-olive oil emulsion were not significantly different ($p<0.05$). However phosphorous content was significantly highest in the case of full fat whey (Table 2).

Cheese compositional characteristics

In this section, the evolution of some physicochemical parameters of various cheese samples was followed in order to be able to fit with the phenomena which could intervene during refining after milk fat substitution by emulsified olive oil.

Table 1 Physicochemical characteristics of milk samples

	pH	Fat (g/L)	Total solids (g/L)	Total nitrogen (g/L)	Ash (g/L)	Calcium (g/L)	Phosphorous (g/L)
Full - Fat	$6.49±0.03^{a}$	$29.33±0.58^{b}$	$108.69±0.01^{c}$	$30.83±1.91^{a}$	$6.76±0.04^{ab}$	$1.01±0.04^{a}$	$0.81±0.06^{b}$
Low - Fat	$6.62±0.01^{b}$	$15.00±0.00^{a}$	$99.03±0.89^{b}$	$32.21±0.18^{a}$	$6.96±0.13^{b}$	$1.07±0.03^{a}$	$0.83±0.03^{b}$
Olive oil emulsion	$6.69±0.01^{c}$	$15.00±1.00^{a}$	$92.01±0.72^{a}$	$31.79±0.21^{a}$	$6.54±0.14^{a}$	$1.01±0.04^{a}$	$0.71±0.03^{a}$

Means±standard deviation (SD) of three separate determinations

^{a,b,c} Values sharing same letter within a column are not significantly different by Duncan's multiple-range test ($p<0.05$)

Table 2 Physicochemical characteristics of expulsed whey

	pH	Fat (g/L)	Total solids (g/L)	Total nitrogen (g/L)	Ash (g/L)	Calcium (g/L)	Phosphorous (g/L)
Full – Fat	6.51±0.01[c]	6.67±0.58[b]	68.62±0.25[b]	6.95±0.19[a]	5.59±0.14[a]	0.50±0.09[a]	0.50±0.00[b]
Low – Fat	6.33±0.01[a]	4.00±0.00[a]	65.13±1.48[a]	7.00±0.07[a]	5.83±0.34[a]	0.43±0.02[a]	0.46±0.03[a]
Olive oil emulsion	6.45±0.01[b]	9.33±1.15[c]	68.11±1.16[b]	6.92±0.30[a]	8.02±2.87[a]	0.49±0.05[a]	0.44±0.00[a]

Means±standard deviation (SD) of three separate determinations

[a,b,c] Values sharing same letter within a column are not significantly different by Duncan's multiple-range test ($p<0.05$)

pH

Table 3 showed that pH of full, low–fat and reduced fat cheese-like product samples had the same profile all along maturation. However, the difference between these samples in the beginning and at the end of ripening was not statistically significant ($p<0.05$).

These results were in agreement with those reported by Kavas et al. (2004), Katsiari and Voutsinas (1994), Katsiari et al. (2002), McGregor and White (1990) and Sipahioglu et al. (1999).

Dry matter

Table 3 represented dry matter variation of three cheese samples resulting from full, low–fat milks and milk-olive oil emulsion during maturation.

It was first of all noticed that reduced fat Gouda cheese-like product had lower dry matter content than its full and low–fat counterparts (Table 3).

Milk fat content of cheese affected significantly ($p<0.05$) total solids content which was inversely related to milk fat content of cheese. Full–fat cheese had higher total solids content than cheeses produced from low–fat milk ($p<0.05$). These differences between full and low–fat cheeses were attributed to their total nitrogen contents. Furthermore, fat replacers are known for their water–binding capacity, which may in return explain the lower total solids content found in cheeses containing fat replacers than in full and low–fat control cheeses.

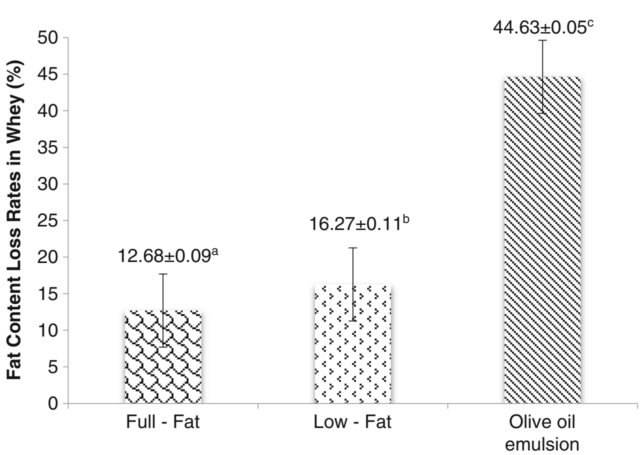

Fig. 1 Fat content loss rates in whey samples (%)

Concerning the evolution of total dry matters content during ripening, it was shown that it was not significant for the three cheese samples during the first 15 days of ripening. However, the difference between the various cheese samples was statistically significant ($p<0.05$) at the end of ripening. This finding was in agreement with those of Lobato-Calleros et al. (2003) who have worked on Mexican Manchego cheese-like products prepared from canola oil and emulsifier blends.

These variations in dry matter content could not be significantly correlated to fat or protein content or HLB. These differences could be attributed to the accuracy of the method used to determine the total solids content in the cheeses or to variations in their preparation.

The reduction of fat content caused increases in protein and decreases in dry matter contents of low fat cheeses. The uses of fat replacers in reduced fat cheeses manufacture increased water binding capacity and improved the total quality of cheeses.

Dry matters content in cheeses was primarily affected by emulsifiers blend and milk fat content. In fact, the water acts like a low viscosity lubricant between casein and fat, and it fills all the space between the casein and the fat (McMahon et al. 1993).

Fat

Table 3 illustrated that fat content evolution for full, low – fat and reduced fat cheese-like product samples was variable during time. This fluctuation was explained by total fat content variability of various samples and by the emulsion addition.

Cheeses resulting from milk-olive oil emulsion showed the highest fat content compared to its full and low–fat counterparts at day 15. The difference between various cheese samples was statistically significant ($p<0.05$).

Total nitrogen

Table 3 represented total nitrogen content variation of three cheese samples resulting from full, low–fat milks and milk-olive oil emulsion during maturation.

Full–fat cheese sample presented the lowest total nitrogen contents all along maturation period. However, at day 60, the

Table 3 Evolution of some physicochemical attributes of cheese samples during maturation

	Samples	Days 0	15	30	45	60
pH	Full – fat	5.03±0.08^{aA*}	4.99±0.03^{aA}	5.20±0.05^{aB}	4.97±0.03^{aA}	5.56±0.13^{aC}
	Low – fat	5.00±0.02^{aA}	5.04±0.03^{abAB}	5.23±0.01^{aC}	5.08±0.01^{bB}	5.53±0.05^{aD}
	Olive oil emulsion	5.08±0.05^{aA}	5.09±0.07^{bA}	5.32±0.05^{bB}	5.12±0.03^{bA}	5.68±0.12^{aC}
Dry Matter (%)	Full – fat	53.71±0.23^{cA}	55.18±0.40^{cB}	54.29±0.08^{cAB}	57.68±1.48^{bC}	61.65±0.34^{cD}
	Low – fat	50.38±0.32^{bA}	51.72±0.53^{bB}	52.86±0.02^{bC}	56.16±0.01^{bD}	51.62±0.27^{bB}
	Olive oil emulsion	48.03±0.04^{aA}	49.69±0.25^{aB}	49.60±0.95^{aB}	48.29±0.11^{aA}	50.38±0.05^{aB}
Fat (%)	Full – fat	38.31±0.23^{cA}	36.26±1.66^{bA}	43.29±2.02^{cB}	36.24±1.38^{cA}	42.67±0.82^{cB}
	Low – fat	28.31±0.72^{aB}	31.26±1.97^{aC}	28.45±0.08^{bB}	25.89±0.21^{aA}	31.57±0.31^{aC}
	Olive oil emulsion	30.45±1.14^{bB}	37.14±1.23^{bD}	23.14±1.42^{aA}	29.74±1.00^{bB}	34.06±0.60^{bC}
Total nitrogen (%)	Full – fat	27.75±1.34^{aC}	25.68±0.14^{aABC}	25.46±0.92^{aAB}	24.76±1.67^{aA}	27.10±0.93^{aBC}
	Low – fat	28.70±1.17^{aA}	32.42±4.40^{abA}	30.16±0.23^{bA}	31.82±1.01^{bA}	30.29±0.61^{aA}
	Olive oil emulsion	33.08±1.29^{bA}	30.02±1.54^{bA}	31.13±1.51^{bA}	29.75±0.39^{bA}	29.44±3.29^{aA}
Lipolysis	Full – fat	1.01±0.05^{aA}	1.26±0.09^{aB}	1.37±0.01^{aBC}	1.50±0.06^{aC}	1.84±0.09^{aD}
	Low – fat	1.42±0.01^{cA}	1.48±0.02^{bA}	1.53±0.01^{bA}	1.55±0.01^{bB}	1.75±0.07^{aC}
	Olive oil emulsion	1.33±0.01^{bA}	1.50±0.01^{bB}	1.75±0.03^{cC}	1.83±0.01^{cD}	2.21±0.01^{bE}

Means±standard deviation (SD) of three separate determinations

^{A,B,C,D,E} Values sharing same capital letter within a row are not significantly different by Duncan's multiple-range test ($p<0.05$)

^{a,b,c} Values sharing same lowercase letter within a column are not significantly different by Duncan's multiple-range test ($p<0.05$)

difference between full–fat and reduced fat cheese-like product samples was not significant ($p<0.05$).

Katsiari et al. (2002) noticed the existence of a significant difference ($p<0.05$) in nitrogen content between full and low–fat cheese samples, which was in agreement with the results found in this paper. Cheeses nitrogen contents were affected by milk fat content. The finding results of this component were conversely related to milk fat rate. Moreover, Rudan et al. (1998) made the same observations for reduced fat Mozzarella cheese. However, this result did not confirm those of Drake et al. (1996), which reported that low-fat Cheddar cheese manufactured by using fat mimetics contained more protein than other reduced fat Cheddar cheeses.

Besides, cheeses total nitrogen content was positively affected by emulsifiers blend and fat content. The contribution of milk fat and emulsifiers blend to nitrogen content has to be indirect, as they are naturally lipids.

In the same context, Lobato-Calleros et al. (2003) did not observe any significant difference in total nitrogen contents between full and low–fat cheeses. Otherwise, Michaelidou et al. (2003) having worked on low-fat Feta-type cheeses showed that the reduction in fat content resulted in increases in total nitrogen rates.

Lipolysis

The lipolysis extent in full, low–fat cheeses and reduced fat Gouda cheese-like product, as assessed by the acid-degree value (ADV), was determined during ripening.

The free fatty acids rates of all cheese samples increased over aging, reflecting a continuous lipid fraction's hydrolysis. The mean free fatty acids rates value of low–fat control cheese was higher than that of full–fat cheese and it was noticed that the difference was significant ($p<0.05$) (Table 3). However, a declining trend in the free fatty acids rates with decreasing milk fat content has been found for Cheddar cheese (Dulley and Grieve 1974) and Feta cheese produced from ewe's milk (Katsiari and Voutsinas 1994).

Lipolysis products convey the characteristic flavor of cheeses. In spite of low–fat content of cheeses with fat replacers addition, their free fatty acids rate was significantly higher ($p<0.05$).

Compared to low–fat cheese without fat replacers' addition, the higher lipolysis degrees of cheeses made with fat replacers was attributed to their lower dry matter contents, which usually promote microbial growth and strong enzyme activity. In addition, changes in the cheese microstructure due to the incorporation of fat replacers in low–fat products with fat replacers could contribute to the enhanced lipolysis in these products.

Sensory evaluation

The panel's scores for the 45 day cheese samples are presented in Table 4. A significant difference ($p<0.05$) was observed

Table 4 Sensory attribute ratings of the 45-day-matured cheeses (scores from 100 naïve panelists)

	Appearance	Odor	Bitterness	Acidity	Saltiness	Hardness	Overall impression
Full - fat	3.40±1.12[b]	2.64±1.44[b]	2.23±1.64[a]	1.89±1.40[a]	2.40±1.40[c]	2.88±1.33[ab]	3.49±1.16[b]
Low - fat	2.79±1.25[a]	2.13±1.54[a]	2.39±1.54[a]	1.72±1.57[a]	1.56±1.23[a]	3.18±1.27[b]	2.46±1.55[a]
Olive oil emulsion	2.94±1.27[a]	2.64±1.60[b]	2.49±1.51[a]	1.88±1.51[a]	1.95±1.23[b]	2.70±1.30[a]	2.08±1.43[a]

Means±standard deviation (SD) of three separate determinations

[a,b,c] Values sharing same lowercase letter within a column are not significantly different by Duncan's multiple-range test ($p<0.05$)

between full and low–fat cheeses, reflecting the generally recognized negative effect of fat reduction on appearance scores of cheeses. However, the low–fat cheese with fat replacers' addition received a higher appearance score than the low–fat cheese without fat replacers. There was a significant negative effect ($p<0.05$) on both flavor and odor scores by fat reduction in cheese milk. Although the characteristic flavor of Gouda cheeses is primarily due to their strong acidity, bitterness and salty taste, all cheeses made in this study were generally criticized as being quite bitter.

Low fat product without fat replacers' addition received higher scores for hardness compared to full–fat cheese. These findings are in agreement with data reported by Drake et al. (1996) for Cheddar and Katsiari and Voutsinas (1994) for Feta cheese. It is also interesting to notice that among all products, cheeses made with fat replacers' addition have received the lowest scores for hardness by the judges. For odor, no significant difference ($p<0.05$) was observed between full and low-fat cheeses with fat replacers' addition.

Full-fat cheese showed a significantly higher overall impression score than all low-fat products. Nevertheless, all cheeses were judged as acceptable products by the panelists. Finally, it should be noticed that some off-flavor notes were detectable by some members of the panel for the low-fat cheeses during storage. This may be linked to the general high bitterness scores received for these products; i.e., the detection of off-flavor notes may be masked by the high levels of bitterness.

Conclusion

The study focused on milk fat substitution by emulsified olive oil in Gouda type cheese. The total dry matters content evolution was similar for all cheese samples studied but the cheese-like product remained rich in total dry matters during maturation. Plus, full–fat cheese presented the lowest total nitrogen contents during the whole refining period.

Concerning lipolysis degree, low–fat cheeses with fat replacers' addition presented higher lipolysis degrees than full and low–fat cheeses without fat replacers' addition. This was attributed to its low dry matter content.

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