Improving the UF low-fat white cheese characteristics using corn oil as a natural fat substitute

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Abstract

This study aimed to improve the quality of UF low-fat soft cheese by using corn oil as a fat replacer. UF low-fat milk retentate (3.50%, w/w) was divided into five portions, with one serving as the control (blended with pasteurized milk cream at 40% fat, w/w). The remaining portions replaced milk fat with corn oil at concentrations of 25, 50, 75, and 100% w/w. Increasing corn oil replacement led to a decline in total solids, protein, and soluble nitrogen contents, while storage time increased these factors. Differences in soluble nitrogen contents were mostly insignificant ($P > 0.05$), except for T100, which recorded 1.64 by the 28th day. pH values and fat content increased with corn oil ratios, while titratable acidity declined (0.32–0.56 TA for T100). Rheological properties like hardness, gumminess, and cohesiveness rose in most samples, except for springiness and chewiness. Cheese with 75% corn oil showed the highest springiness (6.60–6.80) and chewiness (12.00–15.60). The best flavor score (≥ 46) was found in cheese with 25% corn oil after 1 week. Cheese with 50% corn oil had superior body and texture scores ($P < 0.05$) compared to most samples. Control cheese and that with 25% corn oil had the highest color and appearance scores. Ultimately, using corn oil as a fat replacer in UF low-fat soft cheese increased yield and improved rheological and sensory properties.

Keywords: Low-fat soft cheese, corn oil, ultrafiltration, retentate

Introduction

The growing consumer demand for nutritious foods has caused great interest in lowering the fat level of various dairy products while maintaining their chemical and sensory properties. Soft white cheese is considered one of the common appealing cheeses consumed in Egypt that is often associated with high-fat content and raises concerns for health-conscious consumers. Thus, the optimization of fat replacers in cheese formulations has become a main argument of research. Literally, there are several factors that affect the quality of cheese, including milk composition, curd manipulation, conditions of ripening, acid development, moisture content, and starter cultures (Walstra et al. 2006; Sameen et al. 2010). Milk fat acts as a carrier for aroma components, contributing to the smooth and creamy textures of full-fat dairy products (Yuan et al., 2015). The main concern in this study is to optimize the corn oil replacers while retaining an acceptable sensory characteristic, as excessive substitution may result in unpleasant textures or off-flavors. Corn oil stands out as a plant-based fat and is rich in unsaturated fatty acids (e.g., linoleic acid) that probably improve the texture profile, smoothness, creaminess, and flavor of cheese by imparting acceptable flavor and enhancing mouthfeel (Anema et al., 2016; Friedrich et al., 2017; López et al., 2019; Dionísio et al., 2021). Such oils, rich in unsaturated fatty acids, may also enhance oxidative stability, thus improving the dairy product's quality (Friedrich et al., 2017). Several studies referred to the role of corn oil as a fat replacer in improving the texture properties of low-fat cheese by influencing its gel formation and moisture retention over time (Choi et al., 2020; Dionísio et al., 2021). Probable interactions between milk components and corn oil affect cheese quality alongside storage conditions. Corn oil may also prevent the negative rheological changes, such as brittleness, crumbliness, dryness, and brittleness (Dionísio et al., 2021). The current study aims to optimize the amount of corn oil as a fat replacer incorporated into low-fat

white cheese and evaluate its effects on quality attributes during storage, including physiochemical and microbiological properties, texture profile, and sensory characteristics, besides phytochemicals of corn oil. This study will contribute to the cutting edge of appetizing and healthier dairy alternatives and an understanding of their effects on product quality over time.

Materials and Methods

Fresh buffalo's whole milk was obtained from the farm of the Agriculture Faculty, Cairo University. Low-fat skim milk and UF buffalo's milk retentate were prepared at the Unit of Dairy Technology Department, Animal Production Research Institute, Ministry of Agriculture, Giza, Egypt. Microbial rennet powder (Formase TL2200) was obtained from Chr. Hansen's Laboratories, Copenhagen, Denmark. Commercial fine-grade salt (sodium chloride, 98% NaCl) was obtained from El-Nasser Saline Company, Alexandria, Egypt. Raw corn oil was purchased from the local market in New Damietta City, Egypt. LAB starter cultures were obtained from Mifad Company (The Chr. Hansen's Laboratory Denmark, agent in Egypt). Elliker's agar medium was used to enumerate total available bacteria (Matalon & Sandine, 1986). while DeMan, Rogosa, Sharpe (MRS agar) was used to enumerate lactobacilli bacteria (Azhari, 2011). All chemicals were used as analytical and laboratory grade.

Manufacturing UF low-fat cheese

Fresh buffalo's whole milk obtained from the farm of the Agriculture Faculty, Cairo University, was centrifuged to obtain low-fat milk (11.07% total solids, 4.91% protein, 1.0% fat, 4.60% lactose, 0.85% ash (*w/w*), and 0.16% titratable acidity). The resultant fresh cream (2.3% protein, 40 % fat, *w/w*) was kept at 5±1°C till use. UF buffalo's milk retentate was produced through ultrafiltration of low-fat milk at a concentration factor of 4 using a DDS Lab 20 ultrafiltration unit at 45°C with inlet and outlet pressures of 3.6 and 0.6 bar, respectively. Compositions of UF buffalo's milk

retentate were adjusted as follows: 27.55% total solids, 16.81% protein, 3.50% fat, 4.76% lactose, 2.50% ash (*w/w*), and 0.32% titratable acidity. Low-fat soft cheese was manufactured with few modifications as described in a previous study (Wu et al., 2024) to obtain a final pre-cheese of 40% fat, *w/w*, as dry matter. UF retentate was initially divided into five portions as follows: $T1_{Control}$, UF retentate was blended with pasteurized milk cream at a fat concentration of 40%, *w/w*; $T2_{Corn}$, replacing 25% of milk fat with corn oil; $T3_{Corn}$, replacing 50% of milk fat with corn oil; $T4_{Corn}$, replacing 75% of milk fat with corn oil; $T5_{Corn}$, replacing 100% of milk fat with corn oil. Each portion of pre-cheese milk was next homogenized separately under pressure of 250 kg/cm at 58°C using a single-stage homogenizer (Rannie, Copenhagen, Denmark). The homogenized mixtures were then filled in polypropylene molds at 38 °C and pasteurized at 72 °C for 15 s and cooled to 38 °C. Lactic acid starter culture (YF-L811), containing *Streptococcus thermophiles* and *Lactobacillus delbrueckii* subsp. *bulgaricus* in combination with an adjunct culture of *Lactobacillus helveticus* (White Daily 82), was inoculated into each portion at a concentration of 2g per 100 kg of retentate mixture. The mixture was incubated for 30 min at 37°C after gentle stirring for 20 min. Fermentation ceased when the acidity of the gel reached 0.35% v/v to prevent an excessively firm gel (Ong et al., 2013). Following fermentation, 2.5% sodium chloride (NaCl, *w/w*) was added to the pre-cheese curds at 38°C while stirring until completely dissolved to improve the flavor and as a stabilizer to bind the water in the cheese. Microbial rennet powder (Formase TL2200) was then added at a concentration of 5 g/100 kg milk retentate with stirring for 1 min. The pre-cheese curd was finally dispensed into plastic containers and incubated at 38 ± 1°C till the proper curdling formed in about 2 h. All samples were kept at 5±1°C and analyzed at several intervals: zero time, 7, 14, 21, and 28 days.

Phytochemical analyses

Corn oil was applied for phytochemical determination before using it in the manufacturing of cheese (Table 1). Tannins were determined through the preparation of about 1 mL of KOH (10 %) and added to 1 mL of each of the extracts and observed for dirty white precipitate. 2 drops of $FeCl_3$ (5 %) were then added to 1 mL of the extracts, and the green precipitate was observed. The test for saponins (frothing test) was applied by shaking 2 mL of each extract in a test tube vigorously for two min and the persistent foaming was observed. Flavonoids were tested by adding 1 mL of NaOH to 3 mL of each extract, and the yellow coloration was observed. Salkowski's test was performed for steroid determination by adding 5 drops of concentrated H_2SO_4 to 1 mL of each extract, and the red coloration was observed. Fehling's test was applied for glycosides by adding 10 mL of 50 % H_2SO_4 to 1 mL of the extract in a test tube and heating in a boiling water bath for 15 min. 10 mL of Fehling's solution was then added to the mixture, boiled, and the brick-red precipitate observed.

Table 1 Phytochemical analysis of corn oil

Phytoconstituents	Test	Corn oil
Tannins	$FeCl_3$	+
Saponins	Frothing	+
Flavonoids	NaOH	++
Glycosides	Fehling	+
Steroids	Salkowski	++

Note: +: Present in small concentration; ++: Present in moderately high concentration; +++: Present in a very high concentration; -- : Absent.

Physiochemical analyses

The pH of UF soft cheese samples was measured using a digital pH meter (Jenway spear electrode No: 29010, Jenway Limited, Gransmore Green, Felsted, Dunmow, England) (Ling, 1963). Titratable acidity (TA) as % lactic acid was analyzed according to the method of AOAC (AOAC, 2007). Total solids (TSs) were measured according to AOAC (AOAC 2007, methods, 926.08). Moisture content was expressed by analysis of the weight of the residue's total solid content as percentage moisture using this formula: moisture percentage = TS percentage - 100. Fat content

was determined by Gerber's according to the method described in AOAC (AOAC 2023, methods, 2000.18). The semi-micro Kjeldahl method of AOAC (AOAC 2007, methods, 2001.14) was applied to evaluate the total nitrogen (T.N.) contents, and the 6.38 N factor was used to change nitrogen into total protein (T.P.). The protein content was obtained by multiplying the percentage of TN by 6.38. The water-soluble nitrogen (WSN/TN) was measured as described by Innocente (Innocente 1997). Extraction of the water-soluble compounds in cheese was carried out according to a previous method (El-Fattah et al. 2016).

Microbiological analyses

Serial dilutions of each sample were performed to enumerate total viable bacteria (Kaminarides et al. 2007) and poured on the Elliker's agar medium. Meanwhile, MRS agar medium was used to enumerate lactobacilli bacteria (Azhari, 2011; Fayed et al., 2018). All plates were incubated for 48 h at 37 °C under aerobic conditions, and the plates containing from 25 to 250 colonies were counted as CFU g^{-1}.

Texture profile analysis

The texture profile analysis (TPA) of UF cheese samples was performed in triplicate at 20ºC using a Stable Micro Systems texture analyzer (Multi test 1d Memes in, Food Technology Corporation, Slinfold, W. Sussex, UK) (Kaminarides & Stachtiaris, 2000). The cylindrical body with a diameter of 35 mm was inserted about 15 mm into the cheese sample (50 mL, mm height). Two cycles were performed at a constant crosshead velocity of 1.0 mm/s, with a sample depth of 20 mm. Parameters of TPA were evaluated, including stringiness, cohesiveness, adhesiveness, chewiness, hardness, springiness, and gumminess.

Sensory properties evaluation

Cheeses were assessed by 11 experienced panelists from the staff of the Animal Production Research Institute, Ministry of Agriculture, Giza, Egypt, as (40) points for body and texture, (10) points for color and appearance, and (50) points for flavor (sum of scores for different attributes), as described by Clark et al. (2009). Cheese samples were presented in three-digit-coded white plastic containers to prevent any bias and tasted within 15 min after leaving the refrigerator for different periods.

Statistical analysis

All results in this study were expressed as means ± and standard deviation of three duplicate analyses by using the SPSS 25.0 statistical software (Salovuo *et al*., 2005). One-way analysis of variance (ANOVA) and Duncan's multiple range tests were performed for any significant ($P < 0.05$) differences (El-Aziz et al., 2012).

Results and Discussion

Physiochemical properties

As given in Table 2, moisture contents of T_{25} and T_{50} differed non-significantly ($P > 0.05$) during the storage periods, the same as the case of T_{75} and T_{100}. The lowest moisture content was presented by T_{100} from the 7th day up to the end of the storage period and differed non-significantly ($P > 0.05$) in comparison with $T_{25.}$ Meanwhile, T_{100} differed significantly ($P < 0.05$) on the 21st day compared with other treatments and only T_{50} and T_{75} at the end of the storage period. Total solids (TS), protein, and soluble nitrogen contents exhibited a gradual increase up to the end of the storage period due to the water evaporation from cheese samples. Another study referred to the role of the ultrafiltration process used during retentate production in reducing the loss of valuable solids during cheese making that led to an increase in the final cheese yield (Wu et al. 2024). Moreover, the increase of soluble nitrogen during storage might be attributed to the proteases in starter culture

bacteria and the proteolysis activity of the residual rennet (Farkye, 1995). Notably, the TS, protein, and soluble nitrogen contents declined alongside increases in the ratios of corn oil replacement. Regardless of the corn oil replacement, the increase in protein and soluble nitrogen contents during storage might be in correlation with concentration factor (4) of the UF retentate used herein in this study (Wu et al. 2024). On the contrary, fat content increased alongside increases in the ratios of corn oil replacement. The significant difference ($P < 0.05$) revealed from the 7th day up to the end of storage periods by the lower TS contents (36.85-37.14) of T_{100} in comparison with other treatments. In the meantime, all treatments differed significantly ($P < 0.05$) during the storage periods except T_{100} and T_{75}, which differed non-significantly ($P > 0.05$) in TS contents prior to storage and on the 21st day. Remarkably, all treatments differed non-significantly ($P > 0.05$) by soluble nitrogen contents during storage periods except T_{100}, which exhibited a lower content of 1.64 and differed significantly ($P < 0.05$) in comparison with the control treatment. As given in Table 2, there are no significant differences ($P > 0.05$) in fat content between the control and T_{25} treatments on the 7th day, the same as noticed in the case of $T_{25\ and}$ T_{50} by the 21st day. And so, soft cheese manufactured from the UF retentate contains more protein and fat, which could result in the formation of a denser structure after fermentation, representing low chewiness and gumminess values (see also table 5, TPA). Titratable acidity exhibited a gradual increase in all treatments during storage that was attributed to the metabolism of starter lactic acid bacteria fermenting milk lactose. Meanwhile, pH values declined in inverse relationship with acidity during storage. Markedly, acidity declined alongside the increase in the corn oil concentration as a fat replacer, observed for T_{100} in the range of 0.32-0.56 by the end of the storage period. On the contrary, pH values increased alongside increasing the corn oil concentration. At the beginning of storage, all treatments differed non-significantly ($P > 0.05$) in acidity values except T_{100} and control.

Moreover, T_{100} and control differed significantly ($P < 0.05$) during the storage periods, recording 0.56 and 0.69 as TA, respectively. Other treatments exhibited, to some extent, similar values of acidity that were revealed by 0.59 for T_{75} at the end of the storage period. $T_{100,}$ furthermore, showed acidity values lower than T_{75} marginally, except on the 21st day, when it recorded 0.47 and 0.55, respectively. Such changes in acidity might be affected by the UF process that might contribute to differences in physiochemical cheese properties. On the other hand, the presence of *Lb. helveticus* as a thermophilic culture could contribute to acid production more than *Streptococcus thermophilus* in the cheese curd due to the rod culture provided herein being greater than cocci. The substantial drop in pH values noticed on the 7th day for all treatments differed significantly ($P < 0.05$) except for values of T_{25} and control. On the other hand, T_{50} and T_{75} exhibited close pH values that differed non-significantly ($P > 0.05$) by the 7th and 21st days. In spite of the lowest pH values revealed at control 5.39 by the 28th day, T_{50} showed the lower pH values 5.45 differed significantly ($P < 0.05$) in comparison to T_{75} and T_{100} and non-significantly ($P > 0.05$) compared with T_{25}. Such drops in pH values might be due to *Lb. bulgaricus* activity during storage. The contribution of *Lactobacillus helveticus* as an adjunct culture, however, in lactose fermentation was marginal to some extent.

Table 2 Changes in physiochemical properties of low-fat white cheese substituted with corn oil during a storage period of 28 days at 4±2°C

Parameters	Storage period (days)	Treatments				
		Control	T_{25}	T_{50}	T_{75}	$T1_{00}$
Moisture %, *w/w*	0	62.82±0.17^{c}	62.95±0.04^{bc}	63.10±0.11^{b}	63.50±0.05^{a}	63.52±0.12^{a}
	7	62.53±0.08^{a}	62.25±0.07^{bc}	62.41±0.10^{ab}	62.54±0.12^{a}	62.15±0.09^{c}
	14	61.84±0.10^{a}	61.95±0.09^{a}	61.98±0.17^{a}	61.05±0.29^{b}	61.14±0.12^{b}
	21	61.62±0.07^{a}	61.80±0.26^{a}	61.90±0.12^{a}	61.87±0.17^{a}	60.93±0.26^{b}
	28	61.18±0.17^{bc}	61.24±0.14^{bc}	61.41±0.14^{ab}	61.75±0.36^{a}	60.86±0.13^{c}
Total solids %, *w/w*	0	37.18±0.23^{a}	37.05±0.15^{a}	36.90±0.13^{a}	36.50±0.22^{b}	36.48±0.19^{b}
	7	37.87±0.16^{a}	37.75±0.06^{a}	37.59±0.19^{ab}	37.46±0.08^{b}	36.85±0.20^{c}
	14	38.16±0.10^{a}	38.05±0.11^{a}	38.02±0.16^{a}	37.95±0.07^{a}	36.86±0.11^{b}
	21	38.38±0.07^{a}	38.20±0.06^{ab}	38.10±0.14^{b}	38.13±0.14^{b}	37.07±0.15^{c}
	28	38.82±0.10^{a}	38.20±0.11^{c}	38.59±0.11^{b}	38.25±0.09^{c}	37.14±0.09^{d}
Protein %, *w/w*	0	16.50±0.05^{a}	14.60±0.06^{b}	14.07±0.06^{c}	13.58±0.09^{d}	13.50±0.05^{d}
	7	16.60±0.04^{a}	14.77±0.05^{b}	14.23±0.05^{c}	13.73±0.03^{d}	13.10±0.05^{e}
	14	16.88±0.03^{a}	15.07±0.08^{b}	14.52±0.10^{c}	14.01±0.08^{d}	12.50±0.06^{e}
	21	17.40±0.03^{a}	15.67±0.04^{b}	15.10±0.06^{c}	14.58±0.05^{d}	14.50±0.07^{d}
	28	18.00±0.05^{a}	17.50±0.02^{b}	16.00±0.05^{c}	15.20±0.05^{d}	14.50±0.04^{e}
Soluble nitrogen %, *w/w*	0	1.55±0.02^{a}	1.51±0.07^{a}	1.50±0.02^{a}	1.48±0.07^{a}	1.45±0.03^{a}
	7	1.63±0.06^{a}	1.61±0.04^{a}	1.58±0.06^{a}	1.55±0.06^{a}	1.55±0.02^{a}
	14	1.67±0.05^{a}	1.66±0.09^{a}	1.64±0.01^{a}	1.61±0.02^{a}	1.58±0.03^{a}
	21	1.76±0.04^{a}	1.72±0.05^{ab}	1.72±0.02^{ab}	1.70±0.10^{ab}	1.64±0.05^{b}
	28	1.79±0.07^{a}	1.76±0.07^{a}	1.74±0.02^{a}	1.73±0.04^{a}	1.70±0.07^{a}
Fat %, *w/w*	0	10.80±0.04^{e}	10.90±0.02^{d}	11.20±0.05^{c}	11.30±0.04^{b}	11.60±0.03^{a}
	7	11.49±0.04^{d}	11.50±0.08^{d}	12.39±0.02^{c}	12.80±0.05^{b}	13.35±0.06^{a}
	14	12.00±0.08^{e}	12.20±0.05^{d}	12.50±0.06^{c}	12.80±0.05^{b}	13.30±0.07^{a}
	21	12.30±0.02^{d}	12.50±0.09^{c}	12.50±0.06^{c}	12.80±0.04^{b}	13.30±0.06^{a}
	28	12.00±0.04^{d}	12.20±0.05^{c}	12.70±0.06^{b}	12.90±0.07^{a}	12.70±0.05^{b}
pH values	0	6.00±0.03^{c}	6.02±0.02^{c}	6.11±0.04^{b}	6.14±0.05^{b}	6.23±0.04^{a}
	7	5.78±0.03^{d}	5.82±0.02^{d}	5.94±0.05^{c}	6.05±0.03^{b}	6.14±0.05^{a}
	14	5.72±0.03^{d}	5.77±0.04^{cd}	5.83±0.06^{bc}	5.88±0.04^{ab}	5.91±0.02^{a}
	21	5.42±0.04^{c}	5.67±0.05^{b}	5.71±0.02^{b}	5.74±0.05^{b}	5.88±0.04^{a}
	28	5.39±0.08^{d}	5.51±0.05^{c}	5.45±0.03^{cd}	5.63±0.05^{b}	5.72±0.02^{a}
Titratable acidity %, lactic acid	0	0.40±0.05^{a}	0.38±0.02^{ab}	0.37±0.05^{ab}	0.35±0.04^{ab}	0.32±0.03^{b}
	7	0.51±0.04^{a}	0.48±0.03^{ab}	0.46±0.05^{abc}	0.44±0.02^{bc}	0.39±0.03^{c}
	14	0.58±0.04^{a}	0.55±0.06^{ab}	0.52±0.05^{ab}	0.49±0.03^{bc}	0.43±0.02^{c}
	21	0.64±0.03^{a}	0.58±0.04^{ab}	0.56±0.07^{b}	0.55±0.02^{b}	0.47±0.03^{c}
	28	0.69±0.05^{a}	0.65±0.03^{ab}	0.62±0.06^{ab}	0.59±0.04^{b}	0.56±0.05^{b}

*Control, milk-fat cheese contains 40% milk fat/dry matter; T_{25}, replacing 25% of milk fat with corn oil; T_{50}, replacing 50% of milk fat with corn oil; T_{75}, replacing 75% of milk fat with corn oil; T_{100}, replacing 100% of milk fat with corn oil. Each treatment was adjusted to contain 40% fat/dry matter.
Values are means ± standard deviation.
[a-c] Mean values with different lowercase superscripts in the same row are significantly ($P < 0.05$) different.

Microbiological assay

Using *Lactobacillus helveticus* here was stated in the literature as the preferred thermophilic *lactobacillus* starter paired with starter cultures *Streptococcus thermophilus* and *Lactobacillus bulgaricus* in various cheeses. As shown in Table 3, the presence of *Streptococcus thermophilus*

and *Lactobacillus bulgaricus* substantially increased the total viable count in all treatments. It seems that the growth of lactobacilli cells and total viable count generally might be affected by the increase of corn oil concentration (Table 4). The counts of total viable cells or even lactobacilli (CFU g^{-1}) of low-fat white cheese substituted with corn oil changed dramatically, starting from the 3rd day of storage. Remarkably, the lactobacilli cell propagation increased ($6.18\times10^6 \sim 1.15\times10^7$) only till the 3rd day for all treatments except the control, then dropped. As a result, the starter culture increased significantly ($P < 0.05$) the total viable count ($1.11 \text{ X } 10^{10}$) of T_{25} by the 3rd day. Control, however, introduced a gradual increase ($P < 0.05$) in lactobacilli ($1.37 \text{ X } 10^7$) and total viable counts ($1.42 \text{ X } 10^{10}$) up to the 7th day of storage. Despite T_{25} and T_{50} differing non-significantly ($P > 0.05$) in lactobacilli compared with the control by the 3rd and 14th days, the significant ($P < 0.05$) difference occurred by the 21st day. A nonsignificant ($P > 0.05$) difference between T_{75} and T_{100} was noticed in lactobacilli count prior to storage till the 21st day. All the treatments, in general, differed significantly ($P < 0.05$) in lactobacilli count by the 28th day. By the 28th day, however, the total viable count was still somewhat similar for both treatments, T_{75} and T_{100}. The viable lactobacilli cells decreased substantially by the end of storage; that might be attributed to the metabolites released by cultures in cheese curd that influence the growth and activity.

Table 3. Changes in total viable counts (CFU g^{-1}) of low-fat white cheese substituted with corn oil during a storage period of 28 days at 4±2°C

Treatments*	Storage period (days)					
	0	3	7	14	21	28
Control	$1.04\times10^9\pm0.02^a$	$1.25\times10^{10}\pm0.04^a$	$1.42\times10^{10}\pm0.01^a$	$8.80\times10^8\pm0.02^a$	$1.01\times10^8\pm0.03^a$	$1.16\times10^7\pm0.06^a$
T_{25}	$1.13\times10^9\pm0.04^a$	$1.11\times10^{10}\pm0.04^a$	$8.30\times10^9\pm0.03^b$	$1.00\times10^9\pm0.06^a$	$8.40\times10^7\pm0.07^b$	$8.90\times10^6\pm0.03^b$
T_{50}	$8.00\times10^8\pm0.04^b$	$8.60\times10^9\pm0.02^b$	$7.10\times10^9\pm0.06^c$	$5.40\times10^8\pm0.06^b$	$6.10\times10^7\pm0.03^c$	$7.00\times10^6\pm0.02^c$
T_{75}	$6.30\times10^8\pm0.07^c$	$5.40\times10^9\pm0.05^c$	$1.00\times10^9\pm0.03^d$	$1.19\times10^8\pm0.04^c$	$9.00\times10^6\pm0.04^d$	$1.10\times10^6\pm0.02^d$
T_{100}	$5.80\times10^8\pm0.04^c$	$1.05\times10^9\pm0.03^d$	$1.02\times10^8\pm0.06^d$	$7.40\times10^7\pm0.03^c$	$6.60\times10^6\pm0.04^d$	$9.80\times10^5\pm0.06^d$

*Treatments abbreviation, see Table 2.

Values are means ± standard deviation.

[a-d] Mean values with different lowercase superscripts in the same column are significantly ($P < 0.05$) different.

Table 4 Changes in lactobacilli counts (CFU g^{-1}) of low-fat white cheese substituted with corn oil during storage period of 28 days at 4±2°C

Treatments*	Storage period (days)					
	0	3	7	14	21	28
Control	$8.10\times10^{6}\pm0.05^{a}$	$1.02\times10^{7}\pm0.04^{ab}$	$1.37\times10^{7}\pm0.02^{a}$	$5.21\times10^{6}\pm0.05^{a}$	$1.01\times10^{6}\pm0.03^{a}$	$9.13\times10^{5}\pm0.04^{a}$
T_{25}	$7.85\times10^{6}\pm0.03^{a}$	$1.15\times10^{7}\pm0.03^{a}$	$1.02\times10^{7}\pm0.06^{b}$	$4.64\times10^{6}\pm0.06^{a}$	$8.35\times10^{5}\pm0.07^{b}$	$7.10\times10^{5}\pm0.05^{b}$
T_{50}	$5.96\times10^{6}\pm0.03^{b}$	$8.94\times10^{6}\pm0.04^{b}$	$8.22\times10^{6}\pm0.07^{b}$	$4.60\times10^{6}\pm0.05^{a}$	$7.60\times10^{5}\pm0.06^{b}$	$4.51\times10^{5}\pm0.05^{c}$
T_{75}	$5.48\times10^{6}\pm0.01^{b}$	$6.30\times10^{6}\pm0.07^{c}$	$6.0\times10^{6}\pm0.05^{c}$	$3.41\times10^{6}\pm0.01^{b}$	$5.8\times10^{5}\pm0.03^{c}$	$2.19\times10^{5}\pm0.03^{d}$
T_{100}	$5.10\times10^{6}\pm0.07^{b}$	$6.18\times10^{6}\pm0.06^{c}$	$5.77\times10^{6}\pm0.09^{c}$	$2.70\times10^{6}\pm0.10^{b}$	$5.32\times10^{5}\pm0.03^{c}$	$5.50\times10^{4}\pm0.07^{e}$

*Treatments abbreviation, see Table 2.

Values are means ± standard deviation.

[a-e] Mean values with different lowercase superscripts in the same column are significantly ($P < 0.05$) different.

Texture profile analysis

Table 5 presents the results of the TPA for the different cheese treatments. These findings show that production of soft cheese using corn oil as a fat replacer significantly ($P < 0.05$) influenced all the TPA parameters. Control and T_{25} showed higher hardness (4.10-19.25) and gumminess (2.58-14.25) during storage compared with other treatments. In spite of a significant ($P < 0.05$) difference in hardness values revealed among all treatments during storage, T_{75} and T_{100} presented a non-significant ($P > 0.05$) difference in hardness (3.10-3.17) prior to storage. In addition, there is a significant ($P < 0.05$) difference observed in gumminess values among all treatments during storage. Decreased hardness herein in UF low-fat soft cheese has also been observed in UF reduced-fat Cheddar cheese in previous studies, possibly due to increased moisture content (Agrawal & Hassan, 2008). Previous reports in the literature stated the role of UF in decreasing hardness values of low-fat soft cheese, indicating increased moisture content (Agrawal & Hassan, 2008; Spangler et al., 19900), which is in acceptance with our findings. Another study (Covacevich and Kosikowski 1977), however, reported in contradictory interpretation that UF cheese was 26–80% harder than a commercial cheese. On the other hand, the cohesiveness values decreased in conjunction with increasing the corn oil concentration. T_{75}, however, presented cohesiveness

values (0.60-0.67) higher than T_{100} and T_{50}. Control introduced the highest cohesiveness value (0.74) by the end of the storage period. Our findings herein differ from another study (Khanal *et al*., 2017*) that* stated that fat replacers could increase cohesiveness values, interpreted by the proteolytic activity in decreasing the structural integrity of the protein matrix. Noticeably, T_{75} showed higher springiness (6.60-6.80) and chewiness (12.00-15.60) values compared significantly ($P < 0.05$) with other treatments till the 14th day and non-significantly ($P > 0.05$) in comparison with T_{100} by the 21st day. In addition, the control showed the highest springiness values (5.80) by the 21st and 28th days. This implies that the impact of UF retentate at a high concentration factor, ≥4, on the springiness of soft cheese may be beneficial to retain the structure and rheological properties of cheese. In detail, the ultrafiltration technique followed by the homogenization process could produce fewer fat globules that in turn facilitated casein deformation per unit volume (Koca and Metin 2004; and Rashidi et al. 2015). Also, optimizing the UF retentate here to low-fat concentration (3.5%, *w/w*) caused a less firm texture compared with full-fat cheese (Broome et al., 1998; Ong et al., 2013). In addition, standardization, fat-to-protein (3.50-16.81% *w/w*), and acid gel type here (0.32%) contribute to increasing springiness and decreasing hardness and gumminess of the final cheese product (particularly, T_{75} and T_{100}). Our findings on the increased springiness of low-fat soft cheese were also observed in earlier reports that indicated the role of higher fat content in producing cheese with a firmer texture and less spreadability (Brighenti et al., 2008). Using *Lb. helveticus*, also, as an adjunct starter for cheese production might influence the texture properties. Homogenization of pre-cheese milk here under low pressure of 250 kg/cm at 58°C affected, moreover, the final product. This occurred through decreasing the cheese gumminess and texture firmness, in acceptance with other reports regarding the role of milk homogenized at a higher pressure in producing firmer texture of cheese (Ningtyas et al., 2018). These different

factors may also refer to further manipulation of cheese texture using these process variables. Chewiness values decreased in all treatments after 7 days of storage; however, a gradual increase was observed after 21 days of storage. Again, concentration of milk through the ultrafiltration process to CF4 resulted in cheese being distinguished by being less firm than cheeses with a CF of 2.5, such as for biting and chewing. And so, the UF-produced acid gels formed a heterogeneous microstructure in the pre-cheese that led to strong curd compared with the traditional soft cheese. In general, the literature (Romeih et al., 2002; Fathollahi et al., 2010) and current findings of rheological properties suggest that the rheological characteristics are enhanced in cheeses throughout ripening due to ongoing proteolysis. Another study, however, reported that development in rheological characteristics of soft cheese was more greatly associated with the insoluble Ca levels than the extent of primary proteolysis during ripening of cheese (Lucey et al. 2003). The pH development also affected the curd texture, which influenced in turn the solubility of the casein, stating low-pH cheeses are firmer than low-acid cheeses (Fathollahi et al., 2010).

Table 5 Changes in texture profile analysis of low-fat white cheese substituted with corn oil during a storage period of 28 days at 4±2°C

Treatments	Storage period (days)	Hardness (N)	Cohesiveness (%)	Gumminess (N)	Springiness (mm)	Chewiness (N.mm)
Control	0	4.47±0.06^{a}	0.64±0.04^{a}	2.86±0.06^{a}	5.60±0.04^{c}	8.10±0.07^{c}
T_{25}		4.10±0.05^{b}	0.63±0.06^{a}	2.58±0.04^{b}	5.50±0.09^{c}	6.70±0.08^{e}
T_{50}		3.63±0.04^{c}	0.59±0.02^{a}	2.14±0.03^{c}	5.60±0.05^{c}	7.40±0.09^{d}
T_{75}		3.17±0.05^{d}	0.60±0.02^{a}	1.90±0.03^{d}	6.60±0.05^{a}	15.60±0.08^{a}
T_{100}		3.10±0.04^{d}	0.59±0.07^{a}	1.70±0.06^{e}	6.10±0.07^{b}	12.40±0.08^{b}
Control	7	6.57±0.06^{a}	0.66±0.04^{a}	4.31±0.05^{a}	5.60±0.08^{c}	3.90±0.07^{d}
T_{25}		6.02±0.03^{b}	0.65±0.03^{a}	3.91±0.07^{b}	5.30±0.07^{d}	5.60±0.06^{c}
T_{50}		5.63±0.03^{c}	0.60±0.07^{a}	3.38±0.07^{c}	5.20±0.09^{d}	3.40±0.06^{e}
T_{75}		4.73±0.02^{d}	0.61±0.08^{a}	2.89±0.04^{d}	6.70±0.09^{a}	12.00±0.08^{a}
T_{100}		4.00±0.05^{e}	0.59±0.03^{a}	2.50±0.08^{e}	5.80±0.04^{b}	5.80±0.02^{b}
Control	14	10.53±0.04^{a}	0.68±0.06^{a}	7.18±0.05^{a}	5.60±0.07^{b}	6.90±0.08^{a}
T_{25}		9.87±0.03^{b}	0.67±0.07^{a}	6.59±0.06^{b}	5.40±0.09^{c}	4.60±0.05^{b}
T_{50}		8.83±0.06^{c}	0.61±0.03^{a}	5.39±0.03^{c}	5.40±0.06^{c}	2.60±0.09^{e}
T_{75}		7.56±0.05^{d}	0.63±0.05^{a}	4.76±0.06^{d}	6.80±0.05^{a}	6.00±0.04^{c}
T_{100}		7.10±0.06^{e}	0.62±0.02^{a}	6.60±0.03^{b}	5.60±0.06^{b}	5.00±0.09^{d}
Control	21	16.15±0.03^{a}	0.71±0.03^{a}	11.47±0.02^{a}	5.80±0.02^{a}	7.10±0.05^{c}
T_{25}		15.03±0.03^{b}	0.69±0.03^{a}	10.37±0.06^{b}	5.40±0.05^{d}	5.80±0.06^{e}
T_{50}		12.61±0.05^{c}	0.64±0.06^{a}	8.07±0.05^{c}	5.60±0.04^{b}	6.20±0.02^{d}
T_{75}		10.83±0.06^{d}	0.65±0.08^{a}	7.04±0.02^{d}	5.50±0.07^{c}	11.60±0.04^{a}
T_{100}		9.90±0.07^{e}	0.64±0.05^{a}	6.90±0.02^{e}	5.50±0.02^{c}	8.70±0.05^{b}
Control		19.25±0.04^{a}	0.74±0.04^{a}	14.25±0.04^{a}	5.80±0.04^{a}	7.00±0.05^{b}
T_{25}		17.33±0.05^{b}	0.72±0.03^{ab}	12.48±0.06^{b}	5.30±0.04^{d}	5.50±0.07^{d}
T_{50}	28	16.76±0.07^{c}	0.66±0.02^{c}	11.06±0.07^{c}	5.50±0.05^{b}	6.00±0.11^{c}
T_{75}		15.83±0.05^{d}	0.67±0.03^{bc}	10.51±0.05^{d}	5.50±0.06^{b}	15.50±0.06^{a}
T_{100}		15.00±0.03^{e}	0.66±0.03^{bc}	9.90±0.04^{e}	5.40±0.06^{c}	5.00±0.08^{e}

*Treatments abbreviation, see Table 2.
Values are means ± standard deviation.
$^{a\text{-}e}$ Mean values with different lowercase superscripts in the same column are significantly ($P < 0.05$) different.

Sensory evaluation

The sensory evaluation scores of yogurt treatments are presented in Table 6. The results show that there were dramatic differences among the different cheese treatments because of corn oil presence and during 4 weeks of storage. The highest scores were recorded at the beginning of storage for all parameters of different cheese treatments. Control and T_{75} exhibited higher flavor scores when fresh, representing 48 compared non-significantly ($P > 0.05$) with T_{25}. However, T_{25} could introduce the highest score of flavors (≥ 46) after 1 week of storage. These findings might be

attributed to the contribution of *Lactobacillus helveticus* in developing flavor alongside *Lactobacillus bulgaricus* through its proteolytic system controlling (debittering) proteolysis. Another study, in addition, reported that free fatty acids produced through lipolysis contributed to enhancing the flavor of Feta cheese (Vafopoulou *et al.* 1989). T_{50} displayed higher body & texture scores ($P < 0.05$) after 1 week of storage than other treatments except T_{100}. By the end of storage, T_{50} introduced a non-significant ($P > 0.05$) difference in body and texture scores compared with the control and T_{25}. Again, *Lactobacillus helveticus*, when employed as an adjunct starter, will not only accelerate acid generation but also enhance texture and flavor during the ripening of cheese due to the release of peptidase enzymes. The higher color and appearance scores could be achieved in control and T_{25}, differing significantly ($P < 0.05$) after 3 weeks of storage compared with other treatments.

Table 6 Sensory evaluation of low-fat white cheese substituted with corn oil during a storage period of 4 weeks at 4±2°C

	Treatments*					
Parameters	Periods (week)	Control	T_{25}	T_{50}	T_{75}	T_{100}
Flavor (50)	Fresh	48±0.77^{ab}	47±0.62^{abc}	47±0.14^{bc}	48±0.43^{a}	46±0.57^{c}
	1	47±0.71^{b}	48±0.58^{a}	46±0.44^{b}	45±0.20^{c}	45±0.56^{c}
	2	46±0.23^{a}	46±0.36^{a}	45±0.19^{b}	45±0.20^{b}	45±0.19^{b}
	3	46±0.21^{a}	46±0.62^{a}	44±0.11^{c}	44±0.39^{c}	45±0.29^{b}
	4	47±0.27^{a}	46±0.30^{b}	45±0.20^{c}	45±0.38^{c}	45±0.36^{c}
Body and texture (40)	Fresh	38±0.26^{b}	38±0.33^{b}	39±0.40^{a}	38±0.17^{b}	39±0.13^{a}
	1	38±0.10^{b}	38±0.23^{b}	39±0.14^{a}	38±0.20^{b}	39±0.16^{a}
	2	38±0.31^{b}	38±0.19^{b}	39±0.36^{a}	38±0.15^{b}	39±0.13^{a}
	3	37±0.18^{a}	37±0.35^{a}	37±0.28^{a}	36±0.42^{b}	36±0.18^{b}
	4	37±0.28^{a}	37±0.20^{a}	37±0.26^{a}	36±0.28^{b}	36±0.25^{b}
Color and appearance (10)	Fresh	10±0.06^{a}	10±0.03^{b}	10±0.05^{b}	10±0.04^{b}	10±0.03^{ab}
	1	10±0.06^{a}	10±0.05^{a}	10±0.02^{a}	10±0.09^{a}	10±0.04^{a}
	2	9±0.03^{a}	9±0.06^{a}	9±0.08^{a}	8±0.07^{b}	8±0.02^{b}
	3	9±0.05^{a}	9±0.07^{a}	8±0.06^{b}	7±0.04^{c}	7±0.03^{c}
	4	9±0.05^{a}	9±0.06^{a}	8±0.02^{b}	7±0.05^{c}	7±0.03^{c}

*Treatments abbreviation, see Table 2.
Values are means ± standard deviation.
[a-c] Mean values with different lowercase superscripts in the same row are significantly ($P < 0.05$) different.

Conclusion

This study highlights the impacts of using UF milk retentate and corn oil as fat replacers on the properties of low-fat soft cheese when UF is performed at CF 4. The optimized fat content in UF cheese milk increased acid gel flexibility and enhanced the sensory of the cheese product. The sensorial attributes and consumer acceptability of UF low-fat cheese promoted the hypothesis of corn oil as a considerable fat replacer; however, further work is needed to determine further process optimization. Our results confirmed our hypothesis that the properties of UF low-fat soft cheese are highly dependent on the UF concentration factor of milk and the type of fat replacer that can further increase or reverse some of the impacts introduced by UF concentration.

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