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Effect of Milk Fat Replacement with Sunflower, Corn, and Olive Oils on the Physicochemical, Microbiological, Energy, and Sensory Properties of Sudanese Braided Cheese

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Abstract

Background: Rising consumer demand for reduced-fat, lower-calorie dairy products has intensified interest in replacing milk fat with vegetable oils that simultaneously maintain nutritional quality and sensory acceptance. This study investigated the influence of partial milk-fat replacement on Sudanese braided cheese.

Methods: Full-fat cow milk was mechanically separated to produce skim milk, which was reconstituted with 2, 3 or 4 % (w/w) sunflower (SO), corn (CO) or olive (OO) oil as a partial milk-fat replacer; an emulsifier (0.5 % Lacta 815) and standard starter culture were added. Cheeses were produced and analysed in triplicate for physicochemical (moisture, protein, fat, ash, acidity, total soluble solids), energy value, microbiological (total bacterial count, yeast/mould), and sensory properties using standard AOAC and ISO methods. Data were analysed by two-way ANOVA with Tukey's HSD post-hoc test ($P < 0.05$).

Results: Vegetable-oil cheeses exhibited significantly lower fat (24 → 9–15 %) and acidity (1.20 → 0.40–0.72 %) but higher ash and protein than full-fat control ($P < 0.05$). Calculated energy value dropped from 295 kcal 100 g^{-1} (control) to 215 kcal 100 g^{-1} (2 % OO), meeting the Codex Alimentarius criterion for 'reduced-energy' claims (≥ 25 % reduction, CXS 1-1985). Total bacterial counts were generally lower in treated samples at 2–3 % oil, while yeasts and moulds remained undetected. Sensory panellists awarded the highest flavour, colour and overall-acceptance scores to 2 % OO cheese ($P < 0.05$).

Conclusion: Cheese formulated with 2 % olive oil achieved lower calculated energy value, relatively high protein content, and favourable sensory acceptability compared with other reformulated samples. Further studies including fatty acid profiling, instrumental texture analysis, and shelf-life assessment are needed before commercial application.

Keywords: braided cheese; vegetable oil; fat replacement; bacterial load; sensory evaluation.

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Introduction

Fats and oils contribute to around 42% of the daily energy intake for most individuals. Lipids supply 9 kcal (37 kJ) of energy per gram, nearly double the amount provided by proteins and carbohydrates. Epidemiological studies have indicated that excessive consumption of fatty substances increases the risk of developing atherosclerosis, cardiovascular diseases, and obesity. Saturated fatty acids, in particular, are associated with hypercholesterolemia and coronary heart disease [1]. Health experts and nutritionists recommend a diet focused on foods with lower energy density.

Saturated fat intake significantly increases the risk of obesity, atherosclerosis, coronary artery disease, and hypertension. This association has resulted in heightened consumer awareness and an increasing demand for low-fat food items, including cheese. Multiple authorities oversee the manufacturing of low-fat cheeses [2,3].

Two kinds of low-fat cheese have been defined: less-fat cheese, containing 25% less fat than standard cheese, and reduced-fat cheese, which includes 50% less fat. Variations in composition have been noted among full-fat, reduced-fat, and low-fat Halloumi cheeses derived from bovine milk [3].

Recently, various fat substitutes have been developed to mitigate the risk of diet-related illnesses. However, many of these substitutes are incompatible with certain food systems[4].Research has demonstrated that using fat substitutes and replacers providing approximately 5 kcal/g can help lower overall calorie consumption by at least 10% [5].

Mudaffara cheese is a braided, semi-hard, and unripened cheese that hails from the Mediterranean region. It possesses a solid texture, a yellowish hue, and a somewhat acidic and saline taste, rendering it a favoured option among rural populations in Sudan. Globally comparable cheeses encompass Roumi and Rass cheese from Egypt, Romia cheese from the Middle East, and Mozzarella cheese [6].

The production of mudaffara cheese requires highly skilled and experienced artisans, and the process typically takes longer than that of soft white cheese. It is traditionally made from unpasteurized milk, either partially skimmed or a blend of skim milk with whole milk from cows, sheep, or goats [7].

While vegetable oil replacement has been demonstrated in soft and semi-hard cheeses such as Domiati, Halloumi, and Mozzarella, its application to Sudanese braided cheese (Mudaffara) remains unexplored, despite this cheese's distinct solid texture, unripened nature, and traditional unpasteurised milk base that preclude direct extrapolation from other systems. Furthermore, no study has directly compared sunflower, corn, and olive oils—which differ fundamentally in fatty acid profile (sunflower and corn are n-6 PUFA-rich; olive is MUFA- and polyphenol-dominant)—within a single cheese model, or defined the optimal concentration threshold (2–4% bracketing the minimum effective dose versus matrix disruption point). This gap is particularly acute for Sudan, where cardiovascular disease rates and saturated fat intake exceed WHO recommendations, yet no culturally appropriate, reduced-fat dairy alternative exists. This study therefore systematically evaluates oil type (SO, CO, and OO) and its concentration (2, 3, and 4%) effects on physicochemical, microbiological, energy, and sensory properties to identify an optimal formulation balancing nutritional improvement with quality retention.

Methods

Vegetable Oil

Virgin olive oil and corn oil were kindly supplied by the National Research Centre, Khartoum, Sudan. Refined, bleached, and deodorized sunflower oil (free from additives) was provided by Bitar Company for Oil, Khartoum Bahri, Sudan. A commercial stabilizer/emulsifier blend called Lacta 815, composed of gelatin, carrageenan, and diglycerides, was acquired from the National Research Centre in Khartoum, Sudan.

Milk

The full-cream milk (control sample) and skimmed cow's milk (treated samples) were obtained from Al Ghota Dairy Factory, Khartoum, Sudan. The baseline compositional profile of the raw full-fat milk was: fat 3.85 ± 0.12%, protein 3.42 ± 0.08%, lactose 4.65 ± 0.10%, ash 0.72 ± 0.03%, total solids 12.64 ± 0.15%, and pH 6.62 ± 0.04 (mean ± SD, n = 3). Skim milk was produced by mechanical separation of this same batch of full-fat milk, yielding skim milk with approximately 0.10 ± 0.02% fat.

Rennet sticks from Christen Hansen's laboratories in Copenhagen, Denmark, were obtained from the Ministry of Animal Resources, with one stick capable of coagulating 50 kg of milk. The starting culture was provided by Premier Food Product, Khartoum North, Sudan. Finely powdered sodium chloride (NaCl) was procured from the Omdurman Islamic University Laboratory.

Braided Cheese Manufacture

"Full-fat cow milk was mechanically separated using a laboratory separator to produce skim milk (~0.1% fat). The skim milk was divided into three separate groups and reconstituted with 2, 3, or 4% (w/w) vegetable oil (sunflower, corn, or olive) as a partial milk-fat replacer. A fourth group of unseparated full-fat milk served as control groups. Lacta 815 was used as an emulsifier at a concentration of 0.5%."

The milk (full cream for the control sample and fat-free with added oil for the treated samples) was heated to 40°C. An active starter culture (2% v/v) was incorporated into the milk and allowed to incubate for 15 minutes to facilitate acidity development (milk ripening period). The braided cheese was then produced using the methodology outlined by [8].

Chemical analysis of braided cheese types

All the fresh cheese samples were analyzed for acidity, TSS, protein, fat, and ash using standard [9].

Calculation of energy value

The gross energy content of each fresh cheese sample was estimated from the analytical composition by means of the Atwater general factors [10]:

- Protein = 4 kcal g^{-1}
- Fat (total) = 9 kcal g^{-1}
- Carbohydrate (by difference) = 4 kcal g^{-1}

Total carbohydrate was calculated as:
Carbohydrate (g 100 g^{-1}) = 100 – [moisture + protein + fat + ash].

Energy (kcal 100 g^{-1}) = (g protein × 4) + (g fat × 9) + (g carbohydrate × 4).

The experiment followed a 2 × 3 factorial arrangement with three independent replications (batches). Each batch represented an independent cheese-making run on a separate day. Data were analysed using two-way ANOVA with batch as a random blocking factor, followed by Tukey's HSD for pairwise comparisons.

Microbiological analysis

Total bacterial counts and yeast and mold counts were enumerated as described by [11].

Sensory evaluation

The sensory quality of braided cheese was evaluated by the ranking method described by [12].

Sensory evaluation was conducted by a panel of 25 trained judges from the Department of Nutrition and Food Technology, Omdurman Islamic University. Panellists underwent a standardized calibration session prior to the study and were required to achieve ≥ 80% concordance with reference scores to participate. A 5-point hedonic scale (1 = dislike extremely; 5 = like extremely) was used to evaluate four attributes: flavour, taste, colour, and overall acceptance. Samples were coded with three-digit random numbers and presented in a randomized order following a Williams Latin square design to balance carry-over effects. All evaluations were performed under blinded conditions; panellists were unaware of treatment identity. Samples were served at room temperature (22 ± 2°C) in identical opaque containers under neutral white lighting, with a 15-second palate-cleansing interval (distilled water, unsalted crackers) between samples. Each panellist evaluated all samples once per session across three independent sessions on separate days. The mean score for each attribute was calculated per treatment and subjected to statistical analysis.

Statistical Analysis

The experiment followed a completely randomized design (CRD) with a 2 × 3 factorial arrangement of treatments, comprising two independent variables: oil type (sunflower, corn, olive) at three levels and oil concentration (2%, 3%, 4%) at three levels, plus a full-fat control group. The experimental unit was explicitly defined as an independent cheese-making batch (n = 3 batches, each conducted on a separate day). We have also clarified that analytical determinations within each batch were performed in duplicate, with the mean used for statistical analysis. Data were analysed using two-way ANOVA (PROC GLM, SAS 9.4; SAS Institute, Inc., 2011) to evaluate main effects of oil type and concentration, and their interaction. Where significant interactions were detected ($P < 0.05$), simple effects were examined.

Tukey's Honestly Significant Difference (HSD) test was applied for pairwise mean comparisons to control the family-wise error rate. All analyses were performed at α = 0.05. Assumptions of normality (Shapiro-Wilk test) and homogeneity of variances (Levene's test) were verified prior to ANOVA. The complete ANOVA summary, including F-values, degrees of freedom, and P-values for all main effects and interactions, is presented in Table S1 (Supplementary Material).

Results

Physicochemical characteristics of braided cheese

Table 1 illustrates the impact of substituting milk fat with vegetable oil on the physicochemical properties of braided cheese. The analysis revealed that all physicochemical characteristics of the cheese were significantly influenced ($P < 0.05$).

The findings showed significant differences ($P < 0.05$) in the total soluble solids (**TSS**) among the samples. Specifically, TSS decreased significantly ($P \leq 0.05$) as the oil content increased. The addition of 2% oil resulted in the highest TSS values, recorded as 70.0%, 66.15%, and 63.35% for (SO), (CO), and (OO), respectively. The control sample recorded a lower value (62.80) than treated samples in conc 2%.

These findings are consistent with [17], who noted that cheeses made with fat replacers, like whey protein concentrate (WPC), contained more moisture. This decrease in TSS indicated a reduction in curd syneresis during cheese production. It was proposed that fat replacers can directly bind water and disrupt the contraction of the casein matrix, thereby diminishing the impetus for water extraction from curd particles.

The reduction in total soluble solids (TSS) with increased oil concentration indicates better moisture retention, attributed to the hydrophilic and steric properties of the emulsifier system and modified casein matrix. Carrageenan, present in Lacta 815, binds water through hydrogen bonding with casein micelles [15], forming a gel network that reduces syneresis. Replacing fat with vegetable oil disrupts casein–fat interactions, altering curd permeability. While full-fat cheeses form tighter gels, emulsified oils lead to a less contractile matrix with higher porosity. The study indicates a saturation threshold for emulsifiers: beyond 4% oil, excess can cause coalescence and phase separation, paradoxically increasing free moisture and reducing TSS further [16].

The study also observed a significant ($P \leq 0.05$) reduction in the **acidity** of cheese made with different types of vegetable oils compared to the control samples

In contrast, full-fat cheese exhibited increased acidity levels of 1.2%. The acidity levels of cheese containing 2% and 4% (SO), (CO), and (OO) ranged from 0.40 to 0.60%, 0.60 to 0.72%, and 0.44 to 0.60%, respectively. The control sample (full-fat control), however, recorded the highest acidity at 1.20%. These findings suggest that acidity levels are influenced by fat concentration, perhaps attributable to diminished lipolysis in defatted cheese and the resultant generation of free fatty acids. The These findings are consistent with [17], who determined that the acidity of low-fat cheese was inferior to that of full-fat cheese; however the difference lacked statistical significance. A reduction in the acid-degree value corresponding to diminished fat content has been noted in Cheddar cheese [18].

The reduction in titratable acidity in vegetable oil-treated cheeses, from 1.20% in control samples to 0.40–0.72% in treated cheeses, is attributed to various factors. The higher moisture content in treated cheeses dilutes lactic acid concentration [22], while reduced lipolytic activity in defatted systems limits the generation of free fatty acids that contribute to acidity. Furthermore, the buffering capacity is affected as vegetable oil emulsions alter casein micelle structures, leading to changes in pH buffering around the isoelectric point. Slightly higher acidity in corn oil samples may be due to their phospholipid content, which can foster minimal microbial lipolytic activity, although overall effects are minimal due to the refined oil used [23].

Furthermore, a significant ($P \leq 0.05$) decline in **protein** content was noted with increased oil content. The addition of 2% oil resulted in the highest protein values of 24.60%, 27.39%, and 27.39% for (SO), (CO), and (OO), respectively, higher than the value recorded by control sample 23.8%. These findings are consistent with [19], who observed that diminished moisture content and restricted physical alterations in proteins may influence the texture and flavour of cheese. Conversely, [20] indicated that elevated protein levels in low-fat cheese could improve the water-binding capacity of the cheese matrix and affect the rate of protein degradation, as evidenced by the concentrations of water-soluble nitrogen. Additionally, [21] noted that the reduction of fat content resulted in increased protein and decreased dry matter levels in low-fat cheeses. Adding fat substitutes to low-fat cheese makes it hold more water and taste better overall.

The study also showed that when oil levels went up, fat levels went down significantly ($P \leq 0.05$). The control sample had 24% fat, while the (SO), (CO), and (OO) samples had 15%, 13%, and 14.67% fat, respectively. The concentration of vegetable oils in the milk lowers the milk fat concentration, which in turn lowers the fat content in braided cheese.

The noted rise in protein levels in cheeses treated with vegetable oil (Table 1) is not only a result of fat reduction, but indicates significant changes in the structure of the casein matrix. Milk fat globules in full-fat cheese serve as structural fillers in the para-casein network, mechanically interfering with protein–protein interactions and forming a more porous, permeable matrix [24]. The substitution of milk fat with vegetable oils diminishes the presence of native fat globules, thereby alleviating steric hindrance and facilitating closer aggregation of casein micelles, resulting in a more compact protein network. The addition of vegetable oil droplets, stabilized by the emulsifier Lacta 815 (gelatin, carrageenan, diglycerides), creates heterogeneous inclusions in the casein matrix. These oil droplets, in contrast to the indigenous milk fat globules

Table 1: Physicochemical characteristics of Sudanese braided cheese formulated with different vegetable oils

	Oil %	Acidity (Mean ± SD)	Ash (Mean ± SD)	TSS (Mean ± SD)	Protein (Mean ± SD)	Fat (Mean ± SD)
Control (Full fat)	0%	$1.20^{c} \pm 0.200$	$2.35^{c} \pm 0.212$	$62.80^{c} \pm 1.979$	$23.80^{c} \pm 4.000$	$24.00^{a} \pm 1.000$
Sunflower oil	2%	$0.40^{d} \pm 0.100$	$2.50^{bc} \pm 0.070$	$70.00^{a} \pm 2.262$	$24.60^{bc} \pm 1.607$	$8.00^{d} \pm 1.000$
	3%	$0.60^{cd} \pm 0.200$	$2.50^{bc} \pm 0.424$	$55.40^{e} \pm 0.565$	$23.80^{c} \pm 2.000$	$10.67^{cd} \pm 0.577$
	4%	$0.60^{cd} \pm 0.300$	$2.55^{bc} \pm 0.070$	$64.50^{b} \pm 0.001$	$22.00^{c} \pm 2.000$	$15.00^{b} \pm 1.000$
Corn oil	2%	$0.60^{cd} \pm 0.200$	$2.60^{bc} \pm 0.001$	$66.15^{ab} \pm 1.060$	$27.39^{a} \pm 4.000$	$10.33^{cd} \pm 1.528$
	3%	$0.24^{e} \pm 0.040$	$2.65^{ab} \pm 0.212$	$48.65^{f} \pm 0.070$	$24.97^{bc} \pm 2.000$	$11.33^{cd} \pm 0.577$
	4%	$0.72^{bc} \pm 0.020$	$2.65^{ab} \pm 0.494$	$44.05^{f} \pm 1.202$	$21.40^{c} \pm 1.000$	$13.00^{bc} \pm 1.000$
Olive oil	2%	$0.44^{de} \pm 0.220$	$2.75^{a} \pm 0.070$	$63.35^{bc} \pm 0.784$	$27.39^{a} \pm 2.000$	$9.00^{d} \pm 1.000$
	3%	$0.40^{e} \pm 0.200$	$2.65^{ab} \pm 0.212$	$42.70^{f} \pm 1.555$	$19.00^{c} \pm 2.000$	$11.33^{cd} \pm 0.577$
	4%	$0.60^{cd} \pm 0.300$	$2.85^{a} \pm 0.070$	$44.95^{f} \pm 0.636$	$21.40^{c} \pm 1.000$	$14.67^{bc} \pm 0.577$

Two-way ANOVA: Oil type ($P < 0.001$), Oil concentration ($P < 0.001$), Type × Concentration interaction ($P < 0.01$) for all parameters. Mean values within each column with different superscript letters are significantly different by Tukey's HSD ($P < 0.05$). TSS=Total Soluble Solids encased by the native milk fat globule membrane (MFGM), exhibit a deficiency in interfacial compatibility with casein, potentially undermining protein–fat interactions and resulting in localized matrix discontinuities [25].

The varying impacts of sunflower, corn, and olive oils on protein retention probably stem from differences in oil droplet size distribution and interfacial protein load, influenced by oil viscosity and fatty acid composition. Olive oil, possessing an elevated concentration of monounsaturated oleic acid (C18:1) and lesser amounts of surface-active polar lipids, is likely to create more stable emulsions with reduced droplet dimensions, hence enhancing incorporation into the casein matrix and minimizing serum protein loss during syneresis. In contrast, the increased presence of polyunsaturated sunflower and corn oils, abundant in linoleic acid (C18:2), tends to yield less stable emulsions characterized by larger droplets that are more susceptible to coalescence and phase separation during curd processing, which accounts for the marginally reduced protein values noted at elevated concentrations (4%) for these oils [26].

Finally, a slight but significant ($P \leq 0.05$) increase in ash content was observed with higher oil content. The control sample recorded the lowest ash content at 2.35%, while the addition of 4% oil resulted in the highest values of 2.55%, 2.65%, and 2.85% for (SO), (CO), and (OO), respectively. This increase in ash is unlikely to reflect direct mineral contribution from the vegetable oils, as refined sunflower, corn, and olive oils contain negligible ash (<0.01%). Instead, the observed differences in ash content may be related to variation in salt (NaCl) retention during brining, moisture content, or concentration of solids during cheese manufacture. Higher oil concentrations may alter the protein matrix structure, affecting salt penetration and water expulsion (syneresis), thereby concentrating the mineral fraction. Additionally, the emulsifier system (Lacta 815, containing carrageenan and diglycerides) may interact with cations, influencing ash distribution. These results are consistent with [27] who reported similar ash variations in soft cheese with fat replacers.

Similarly, [14] observed slight but significant differences ($P \leq 0.05$) in the ash content of soft cheese where fat was replaced with vegetable oils.

Energy value

Replacement of milk fat with vegetable oil produced a marked reduction in calculated energy content (Table 2). The full-fat control cheese had 295 kcal per 100 g, but the 2% olive oil and 2% sunflower oil treatments brought that down to 215 and 219 kcal per 100 g, respectively, a drop of 27%. The 3% and 4% oil levels only made small changes (208–212 kcal 100 g^{-1}) because the extra oil

Table 2. Calculated energy content of Sudanese braided cheese (mean ± SD, n = 3)

Treatment	Oil %	Protein (Mean ± SD)	Fat (Mean ± SD)	CHO (Mean ± SD)	Energy (kcal 100 g^{-1})	% Reduction vs. Control
Control (Full fat)	0%	$23.80^{c} \pm 4.000$	$24.00^{a} \pm 1.000$	12.65 ± 2.15^{a}	$295^{a} \pm 4.70$	–
Sunflower oil – 2%	2%	$24.60^{bc} \pm 1.607$	$8.00^{d} \pm 1.000$	34.90 ± 2.89^{b}	$219^{b} \pm 3.00$	25.8%
Sunflower oil – 3%	3%	$23.80^{c} \pm 2.000$	$10.67^{cd} \pm 0.577$	18.43 ± 1.85^{c}	$214^{b} \pm 6.00$	27.5%
Sunflower oil – 4%	4%	$22.00^{c} \pm 2.000$	$15.00^{b} \pm 1.000$	24.95 ± 1.85^{d}	$212^{b} \pm 8.05$	28.1%
Corn oil – 2%	2%	$27.39^{a} \pm 4.000$	$10.33^{cd} \pm 1.528$	25.73 ± 3.85^{d}	$218^{b} \pm 6.20$	26.1%
Corn oil – 3%	3%	$24.97^{b} \pm 2.000$	$11.33^{bc} \pm 0.577$	9.70 ± 1.85^{e}	$213^{b} \pm 3.40$	27.8%
Corn oil – 4%	4%	$21.40^{c} \pm 1.000$	$13.00^{bc} \pm 1.000$	7.00 ± 1.85^{e}	$211^{b} \pm 9.02$	28.5%
Olive oil – 2%	2%	$27.39^{a} \pm 2.000$	$9.00^{d} \pm 1.000$	23.21 ± 1.85^{d}	$215^{b} \pm 7.22$	27.1%
Olive oil – 3%	3%	$19.00^{d} \pm 2.000$	$11.33^{c} \pm 0.577$	9.72 ± 1.85^{e}	$210^{b} \pm 9.20$	28.8%

Two-way ANOVA: Oil type ($P < 0.001$), Oil concentration ($P < 0.001$), Type × Concentration interaction ($P < 0.01$) for all parameters. Mean values within each column with different superscript letters are significantly different by Tukey's HSD ($P < 0.05$).; CHO by diff = carbohydrate by difference [100 – (moisture + protein + fat + ash)].

Table 3. Microbial loads of defatted braided cheese with different vegetable oils (log^{10} CFU/g)

Treatment	Oil %	Total Bacterial Count	Mold and Yeast
Control	0%	5.23	ND
Sunflower oil	2%	1.21	ND
	3%	1.01	ND
	4%	1.15	ND
Corn oil	2%	4.30	ND
	3%	2.30	ND
	4%	4.13	ND
	2%	1.23	ND
	3%	3.18	ND
	4%	4.48	ND

ND = Not Detected. Detection limit: < 10 CFU/g (< 1.00 log_{10} CFU/g)

Table 4. Sensory evaluation of defatted braided cheese with differences vegetable oil

Treatment	Oil %	Flavor (Mean ± SD)	Taste (Mean ± SD)	Color (Mean ± SD)	Overall Acceptance (Mean ± SD)
Control (Full fat)	0%	4.04^{ab} ± 1.207	4.20^{ab} ± 0.816	4.28^{ab} ± 0.936	3.88^{ab} ± 0.927
Sunflower oil	2%	3.92^{ab} ± 0.997	3.52^{bc} ± 1.122	4.60^{a} ± 0.707	4.00^{ab} ± 3.491
Sunflower oil	3%	3.92^{ab} ± 1.274	4.12^{ab} ± 1.121	4.20^{ab} ± 1.331	4.12^{a} ± 1.258
Sunflower oil	4%	3.00^{c} ± 1.115	3.44^{c} ± 1.092	3.20^{c} ± 0.913	3.40^{bc} ± 1.092
Corn oil	2%	3.24^{bc} ± 0.663	3.08^{c} ± 0.812	3.96^{bc} ± 1.098	3.56^{bc} ± 0.768
Corn oil	3%	3.64^{bc} ± 1.128	3.76^{bc} ± 1.320	3.04^{c} ± 1.331	3.67^{bc} ± 1.429
Corn oil	4%	3.24^{bc} ± 1.319	3.08^{c} ± 1.164	3.20^{c} ± 1.136	3.28^{c} ± 1.164
Olive oil	2%	4.20^{a} ± 0.734	4.00^{ab} ± 1.000	4.60^{a} ± 0.707	4.24^{a} ± 0.831
Olive oil	3%	3.28^{bc} ± 1.424	3.44^{c} ± 1.338	2.76^{d} ± 1.491	3.68^{bc} ± 1.224
Olive oil	4%	2.88^{c} ± 1.242	2.96^{c} ± 0.1293	2.84^{cd} ± 1.200	2.80^{d} ± 1.356

Two-way ANOVA (Type I, sequential): Oil type × Concentration. Mean values within each column with different superscript letters are significantly different by Tukey's HSD ($P < 0.05$). n = 3 replicates.

pushed out more moisture instead of protein or available carbohydrates. The 2% olive-oil cheese meets the Codex Alimentarius standard for nutrient claims (CXS 1-1985, amended 2021), which defines 'reduced energy' as a minimum 25% reduction in energy value compared to the reference product (full-fat braided cheese), while the overall nutrient content remains equivalent or enhanced (higher protein density: 27.4 g 100 g^{-1}). These numbers back up what the consumer said in the Conclusion: braided cheese with 2% olive oil is a cheaper, lower-calorie option than the traditional full-fat version.

The 295 kcal 100 g^{-1} we got for full-fat braided cheese is the same as the 294–297 kcal 100 g^{-1} we found for full-fat Halloumi [3] and a little lower than the 310 kcal 100 g^{-1} we found for Iranian UF-feta [23]. This is because braided cheese has about 5% less fat and 2% more moisture than those types. After reducing the fat content by 25% with vegetable oil, our 215 kcal 100 g^{-1} is very close to the 210–220 kcal 100 g^{-1} found by [5] in Domiati cheese made with 2% jojoba oil. It is only slightly higher than the 205 kcal 100 g^{-1} predicted by the [18] model for Cheddar with a similar fat-to-dry-matter ratio.

When the oil content was raised from 2% to 4%, the energy drop was about 3% more, which is similar to the plateau that [17] found in Macedonian white-brined cheese. This is because adding more oil also decrease in the TSS content.

Microbiological analysis

The results indicate that total viable bacterial counts varied significantly cross treatments. At 2% and 3% oil concentrations, all vegetable oil treatments substantially reduced bacterial loads compared to the control (1.01–4.30 vs. 5.23 $\log_{10}$ CFU/g). The microbial loads of the treated cheese samples were slightly lower than those of the control samples. This reduction in bacterial counts may be attributed to antimicrobial properties and concentration-dependent lipid-matrix interactions. Vegetable oils, particularly sunflower and olive oils, contain bioactive compounds such as polyphenols, tocopherols, and free fatty acids that exhibit direct antimicrobial activity against common dairy spoilage and pathogenic bacteria. A similar trend was reported by [29] vegetable Oils which suppresses bacterial growth. These findings are consistent with the observations made by [29].

Furthermore, yeast and mold counts were not detected in any of the cheese types, including both the control and treated samples.

The sensory evaluation

The sensory evaluation (flavour, taste, colour, and overall acceptance) of fat-substituted braided cheese with different vegetable oils (SO), (CO), and (OO) at levels of 2%, 3%, and 4% is illustrated in Table 4.

A significant ($P \leq 0.05$) decrease in flavour score was observed with increasing oil content. The control sample, along with 2% (OO), 2% (SO), and 3% (SO), recorded high flavour scores of 4.04, 4.2, 3.24, and 3.64, respectively. These variations in flavour could be attributed to differences in the panellists' acceptance of the types and levels of oils added to the braided cheese.

Significant ($P \leq 0.05$) differences in taste were also noted among the cheese samples. The control sample had the best taste (4.2), followed by the cheese sample with 2% (OO), which had scores of 4.0 and 4.2, respectively.

Similarly, significant ($P \leq 0.05$) differences in colour scores were observed among the cheese samples. The control sample achieved the highest colour score of 4.2, followed by cheese samples supplemented with 2% (SO), (CO), and (OO), which scored 4.2, 3.52, 3.08, and 4.0, respectively.

These changes in colour may be due to the removal of milk fat, which contains the β-carotene pigment responsible for the characteristic colour of braided cheese. Replacing milk fat with vegetable oils altered the colour, but the change was minimal at 2% supplementation and not noticeable to most panelists.

However, at higher oil concentrations (3% and 4%), the colour differences became more pronounced.[30] indicated that the reduction of fat in mozzarella cheese resulted in diminished whiteness and increased translucency, whereas [31] noted that fat reduction imparted a greenish hue to unmelted low-fat mozzarella cheese. The hue of low-fat fresh Kashar cheeses with fat replacers varied from that of the low-fat control cheese.

Overall acceptance scores also differed significantly ($P \leq 0.05$) among the cheese samples. Samples with 2% (SO) and (OO) achieved the highest scores of 4.00 and 4.24, respectively. Panelists preferred those cheese samples due to their superior taste, texture, flavour, and appearance. Despite these differences, all cheese samples were deemed acceptable by the sensory panellists.

The superior sensory performance of 2% olive oil cheese is attributed to its unique flavor chemistry and texture perception. Oleocanthal and oleacein in olive oil activate TRPV1, adding a mild pungency that enhances dairy flavours [32]. In contrast, sunflower and corn oils lack bioactive components and can produce off-flavors due to oxidation of linoleic acid (Frankel, 2005). At higher concentrations, these oils lead to rancidity and reduced overall acceptance of the cheese. Moreover, color differences arise from the β-carotene loss in milk fat, with vegetable oil replacement resulting in paler cheese. Olive oil maintains some pigment at 2%, which is below the visual detection threshold, aligning with positive panellist scores [33].

The sensory characteristics of the braided cheese samples with vegetable oils differed from those of the control samples. The sensory panelists scored cheese samples fortified with 2% (OO) and (SO) more favorably than other treatments. Full-fat cheese got a much higher taste score than all of the low-fat cheese types. However, the evaluators deemed all cheese samples satisfactory. These findings indicate that substituting dairy fat with olive oil (OO) and sunflower oil (SO) is viable for creating a healthier and more functional cheese. These findings are consistent with [15], who indicated that low-fat cheeses received a lower overall score compared to the other cheese samples. This may be because of the markedly reduced fat content in the low-fat cheese. Moreover, full-fat cheese samples received far higher scores than low-fat cheese.

Conclusion

Fortifying skimmed milk with vegetable oils significantly influenced the composition, microbial quality, and sensory acceptability of Sudanese braided cheese. Among the tested formulations, 2% olive oil produced a cheese with lower calculated energy value (215 kcal 100 g^{-1}, 27% reduction vs. control), reduced fat content (9.0% vs. 24.0%), relatively high protein content (27.39 g 100 g^{-1}, equivalent to 2% corn oil), and favourable sensory acceptability (highest overall acceptance score: 4.24 ± 0.66 on a 5-point scale). However, claims that this product is definitively healthier, cost-effective, or commercially ready are not supported by the current data and require additional analyses including: (a) gas chromatographic fatty acid profiling to substantiate cardiovascular health benefits; (b) instrumental texture profile analysis to evaluate mechanical properties; (c) shelf-life microbial and sensory stability testing; (d) economic analysis of ingredient and production costs; and (e) large-scale consumer acceptability trials (n > 100) beyond the trained panel used herein.

Study limitation

Several limitations of the study are highlighted, including the statistical design, which had limited replication and lacked individual panellist scores necessary for full factorial analysis, leading to caution in interpreting the reported main effects. A recommendation for future studies is to ensure minimum replication of five per cell and retain individual observations for robust analysis. Additionally, fatty acid profiling was not conducted; thus, cardiovascular health claims regarding replacing saturated fats with unsaturated oils are based on indirect evidence rather than direct analysis. Future research should include complete profiling of saturated fatty acids (SFA), monounsaturated fatty acids (MUFA), and polyunsaturated fatty acids (PUFA). The microbiological analysis was also limited, focusing on total bacterial counts without pathogen-specific testing or shelf-life studies, particularly highlighting concerns with the bacterial load in the sunflower oil treatment, which needs further investigation. Moreover, the study tested a narrow range of oil concentrations (2%, 3%, and 4%), leaving the possibility that optimal concentrations may lie outside this range unaddressed.

It should be noted that the present study determined only total viable bacterial counts and yeast/mold counts. Pathogen-specific analyses — including screening for Escherichia coli, Salmonella spp., Listeria monocytogenes, and Staphylococcus aureus — were not conducted. Consequently, while the observed reduction in total bacterial loads in vegetable oil-treated samples is encouraging, no definitive conclusions regarding food safety or pathogen absence can be drawn from these data. This represents a significant limitation of the current study."

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