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CHANGES IN THE QUALITY OF PLAIN YOGURT MADE FROM COW'S, GOAT'S, AND SHEEP'S MILK WITHIN THE SHELF LIFE

– Research paper –

Tomasz DASZKIEWICZ[1*], Sylwia KOCENKA[1], Jan MICIŃSKI[2]

[1] *Department of Commodity Science and Processing of Animal Raw Materials, Faculty of Animal Bioengineering, University of Warmia and Mazury in Olsztyn, Oczapowskiego 5, 10-719 Olsztyn, Poland*

[2] *Department of Sheep and Goat Breeding, Faculty of Animal Bioengineering, University of Warmia and Mazury in Olsztyn, Oczapowskiego 5, 10-719 Olsztyn, Poland*

Abstract: The aim of this study was to compare selected physicochemical properties, the fatty acid profile, and the content of vitamins A and E in plain yogurt (Y) made from cow's (YC), goat's (YG), and sheep's milk (YS), and to monitor changes in these parameters within the shelf life of the analyzed products. The products were supplied by three manufacturers. Each group consisted of yogurts from three different batches, and each batch was represented by two products. The quality of the first product was analyzed in the middle of shelf life, and the quality of the second product was analyzed at the end of shelf life (E, last day). The products were stored at a temperature of 4°C until analysis. An analysis performed at date M demonstrated that YC had the highest ($p \leq 0.05$) values of yellowness (b*) and titratable acidity, and the lowest ($p \leq 0.05$) content of vitamins A and E; YG had the highest ($p \leq 0.05$) values of redness (a*) and the lowest ($p \leq 0.05$) value of b*; YS had the highest ($p \leq 0.05$) values of lightness (L*) and pH, the highest ($p \leq 0.05$) content of vitamins A and E, and the lowest ($p \leq 0.05$) values of a* and titratable acidity. YC and YS were characterized by higher ($p \leq 0.05$) values of chroma (C*) than YG. YC and YG were characterized by higher ($p \leq 0.05$) values of UFA/SFA, MUFA/SFA, DFA/OFA, and n-6/n-3 PUFA ratios, compared with YS. The n-6/n-3 PUFA ratio was also higher ($p \leq 0.05$) in YG than in YC. In comparison with YC, YG and YS had higher ($p \leq 0.05$) values of the PUFA/SFA ratio and EFA concentrations, and the highest ($p \leq 0.05$) values were noted in YS. Measurements conducted at date E revealed a decrease ($p \leq 0.05$) in the value of a* and vitamin E content in YC, an increase in the value of L* in YG, and an increase in the value of a*, a decrease in the values of b*, C* and pH, and a decrease in vitamin E content in YS. Titratable acidity increased ($p \leq 0.05$) in all types of Y. Changes in the nutritional value of fat (a decrease in the values of UFA/SFA, MUFA/SFA, and PUFA/SFA ratios, a decrease in EFA concentrations, and an increase in the n-6/n-3 PUFA ratio) were significant ($p \leq 0.05$) only in YC. The results of the study indicate that YG was characterized by the highest stability, and YC was characterized by the lowest stability during storage.

Keywords: cow's milk, goat's milk, sheep's milk, plain yogurt, storage, quality

INTRODUCTION

Yogurt is one of the oldest dairy products that continues to be popular with modern consumers (Aryana and Olson 2017, Le Roy et al. 2022). According to Data Bridge Market Research, the yogurt market was valued at USD 107.2 billion in 2021 and is projected to reach USD 162.04 billion in 2029 (Data Bridge Market Research 2023). Yogurt is widely consumed due to the high nutritional value of milk used in the production process. Yogurt is a rich source of proteins, micronutrients, macronutrients (including Ca, Fe, Mn, and Zn), and vitamins B_2, B_6, and B_{12} (Lin et al. 2022). During yogurt production, processing operations not only increase the content of nutrients (mainly protein) (McKinley 2005), but also improve nutrient digestibility and bioavailability. Protein and, to a lesser degree, fat are partly broken down into simpler chemical compounds by the enzymes produced by bacterial starter cultures (Wang et al. 2021), mostly *Lactobacillus delbrueckii* subsp. *bulgaricus* and *Streptococcus thermophilus* (Rul 2017). In turn, the major part of lactose is broken down by lactic acid bacteria during milk fermentation. According to

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* Corresponding author.
E-Mail address: tomasz.daszkiewicz@uwm.edu.pl

Barros et al. (2019), yogurt contains around 30% less lactose than milk.

Yogurt components (mostly protein) are more effectively broken down by digestive enzymes due to direct and prolonged contact between the enzymes and the substrate. After ingestion, yogurt forms a loose curd with a large surface area in the stomach, and it is easily available to enzymes. Yogurts characterized by higher viscosity remain longer in the stomach, which also aids digestion (Desobry-Banon et al. 1999). Yogurt minerals are easily absorbed from the digestive tract because they occur in the form of partly soluble salts (Fe, Cu, Zn) or are bound by protein hydrolysis products (Ca, Mg, P) (Sánchez et al. 2023).

In addition to its high nutritional value, yogurt is also characterized by health-promoting properties due to the activity of selected probiotic bacterial cultures that are used in the production process (Cifelli et al. 2020). Bacterial cultures modify the quantitative and qualitative composition of intestinal microflora, decrease cholesterol levels, inhibit the growth of undesirable bacteria by decreasing pH and the redox potential and producing compounds with bacteriostatic and bactericidal properties (H_2O_2, antibiotics, and bacteriocins), and stimulate the immune system (Desobry-Banon et al. 1999, Nazir et al. 2018, Das et al. 2022). Yogurt and other fermented dairy products deliver therapeutic benefits by promoting lactose digestion and alleviating the symptoms of lactose intolerance (Ibrahim et al. 2021). Research has shown that yogurt may also play an important role in the prevention of lifestyle diseases such as colorectal cancer (Sun et al. 2022), osteoporosis (Laird et al. 2017), type 2 diabetes (Yanni et al. 2020), and cardiovascular disease (Buendia et al. 2018), although the underlying mechanisms of action have not yet been fully elucidated. Based on the results of an observational cohort study, Lin et al. (2022) concluded that yogurt consumption was associated with a lower risk of all-cause mortality.

Yogurt quality (sensory attributes, rheological properties, chemical composition, and nutritional value) is directly influenced by the type of milk used in the production process. Yogurt is most commonly made from cow's milk, but goat's and sheep's milk yogurts are also available on the market. Milk from various mammalian species differs in chemical composition (Arrichiello et al. 2022), which affects not only the nutritional value of yogurt, but also its technological and health-promoting properties. Sheep's milk is most abundant in protein and fat which is a rich source of conjugated linoleic acid (CLA) (Filipczak-Fiutak et al. 2021). Due to a higher content of casein and minerals, sheep's milk is characterized by stronger gelation properties (both acid and rennet induced) than cow's and goat's milk. In turn, goat's milk forms gels with a weaker consistency because it is less abundant in casein (mainly αS1-casein) and contains larger casein micelles than cow's milk (Roy et al. 2020). In comparison with cow's milk, sheep's and goat's milk contain fat globules with a smaller diameter, which affects fat composition, digestion and absorption (Thuma et al. 2023), technological processes (separation of milk components, churning), and the quality of the end-product (emulsion stability, optical properties - color, and rheological properties -viscosity) (El-Zeini 2006). Milk fat from small ruminants (goats and sheep) is also more abundant in short- and medium-chain fatty acids (Park et al. 2007). An analysis of the mineral composition of sheep's and goat's milk revealed that it has a higher content of Ca, P, Mg, and Mn than cow's milk (Sanz Ceballos et al. 2009, Shu et al. 2021). Sheep's and goat's milk is more abundant in vitamin A, vitamin C and niacin, and sheep's milk is also a richer source of vitamin B_2 (riboflavin) in comparison with cow's milk. In turn, goat's milk contains less folic acid and biotin, whereas sheep's milk contains less biotin and vitamin B_6 than cow's milk (Sanz Ceballos et al. 2009, Prosser 2021).

Food products, including yogurt, have a limited shelf life (Rasul et al. 2022). During storage, yogurt quality can be affected by the growth of undesirable microorganisms (mainly yeasts and molds) (Narayana and Gupta 2018) and oxidative changes (Citta et al. 2017). These processes are closely linked with hygiene standards during yogurt production (Vidakovic, Knezevic et al. 2021), type of packaging (Rasul et al. 2022), storage temperature (Jakubowska and Karamucki 2019), and the applied food preservation methods (Deshwal et al. 2021). It should also be noted that yogurt contains viable and active lactic acid bacteria throughout the entire shelf life. Bacterial enzymes and metabolites can also modify the quality of stored yogurt (Deshwal et al. 2021). The extent of those changes could be associated with the quality and source of milk (animal species) used in yogurt production. In view of the above, the present study was undertaken to verify the research hypothesis postulating that changes in the quality of plain yogurt during storage are influenced by the type of milk (animal species) used in the production process. This research hypothesis was tested by comparing selected physicochemical properties, the fatty acid profile, and the content of vitamins A and E in plain yogurt (Y) made from cow's (YC), goat's (YG), and sheep's milk (YS),

and by monitoring changes in these parameters within the shelf life of the analyzed products.

MATERIALS AND METHODS

Materials

The experimental materials comprised YC (n=6), YG (n=6) and YS (n=6), supplied by three manufacturers. The products were purchased in a hypermarket (city of Olsztyn, north-eastern Poland) belonging to a popular European retail chain. Each group consisted of yogurts from three different batches, and each batch was represented by two products. The products were packaged in polystyrene tubs (YC and YG) and glass jars (YS) with aluminum foil lids. *Lactobacillus delbrueckii* subsp. *bulgaricus* and *Streptococcus thermophilus* were used as starter cultures. The products were stored at a temperature of 4°C until laboratory analyses (performed in the middle of shelf life - M, and at the end of shelf life - E, last day). The chemical composition and energy value of the products, as declared by the manufacturers, are presented in Table 1.

Table 1. Chemical composition and energy value of plain yogurt, as declared by manufacturers

Component	Yogurt made from cow's milk	Yogurt made from goat's milk	Yogurt made from sheep's milk
Protein	4 g	3.5	4.4 g
Fat	2 g	2.5 g	6.4 g
Carbohydrates	5.5 g	5 g	4 g
• including sugars	5.5 g	4.1 g	1.4 g
Salt	0.10 g	0.09 g	0.27 g
Energy value	236 kJ / 56 kcal	237kJ / 57 kcal	380 kJ / 91 kcal

Methods

Color

The color of yogurts was analyzed by the reflectance method in the CIELAB color space (CIE 1978) with the MiniScan XE Plus spectrophotometer (Hunter Associates Laboratory Inc., Reston, Virginia, USA). The values of lightness (L*), redness (a*), and yellowness (b*) were measured in yogurt samples (temperature of approx. 20°C) placed in a glass cuvette. The final result was the arithmetic mean of three measurements of each sample. The values of L*, a* and b* were used to calculate chroma (C*): $C^* = (a^{*2} + b^{*2})^{1/2}$.

pH

The values of pH were measured in yogurt samples (50 g) transferred to a glass beaker, with the use of a Polilyte Lab electrode and an inoLab Level 2 pH meter with the TFK 325 temperature sensor (WTW Wissenschaftlich - Technische Werkstätten, Weilheim, Germany).

Titratable acidity

The titratable acidity of the products (expressed in Soxhlet-Henkel degrees, °SH) was determined by potentiometric titration (ISO/TS 11869:2012) using the TitroLine easy automatic titrator (SCHOTT Instruments GmbH, Mainz, Germany) and the SenTix 81 pH electrode (WTW, Germany).

Content and vitamins A and E

The content of vitamin A (retinol) and vitamin E (α-tocopherol) in fat extracted from yogurts was determined by the method described by Hewavitharan et al. (1996) using external reference standards supplied by Sigma. Separation was carried out by reverse-phase high-performance liquid chromatography (SHIMADZU-Japan, HPLC system) using a Nucleosil C_{18} column (250 x 4 mm) and a mixture of methanol and water (95:5, v/v) as the mobile phase. Retinol content was measured with a UV-VIS detector (wavelength: 326 nm), and α-tocopherol content was measured with a fluorescence detector (excitation wavelength: 295 nm, emission wavelength: 330 nm).

Fatty acid profile

Fat was extracted from yogurt samples by the Röse-Gottlieb method (ISO 1211 | IDF 1:2010), and fatty acid methyl esters (FAMEs) were obtained by the IDF method (IDF standard 182:1999) using KOH solution in methanol. The FAMEs were separated by gas chromatography (PU-4600 gas chromatograph; flame ionization detector – FID; capillary column: length - 2.1 m, inner diameter - 4 mm; detector temperature 250°C, injector temperature 225°C, column temperature 200°C; carrier gas – argon, flow rate - 50 cm^3/min).

Statistical analysis

The results were analyzed statistically using the STATISTICA ver. 13.3 program (TIBCO Software Inc., Palo Alto, CA, USA). The effect of the type of milk (animal species) used in the production of yogurt was determined by one-way analysis of variance (ANOVA) at $p \leq 0.05$. The significance of differences ($p \leq 0.05$) between the mean values of YC, YG and YS parameters analyzed at dates M and E was determined by Student's t-test.

RESULTS

The results of instrumental color analysis (CIELab) of the compared products are presented in Table 2. Measurements performed at date M (middle of shelf-life) revealed significant differences in the color parameters of yogurts. YS had the highest ($p \leq 0.05$) value of L* and the lowest ($p \leq 0.05$) value of a*. The highest ($p \leq 0.05$) value of a* and the lowest ($p \leq 0.05$) value of b* were noted in YG. YC was characterized by the highest ($p \leq 0.05$) value of b*. YC and YS had higher ($p \leq 0.05$) values of C* than YG.

Measurements performed at date E (end of shelf-life, last day) revealed a significant ($p \leq 0.05$) decrease in the value of a* in YC, an increase in the value of L* in YG, and an increase in the value of a* accompanied by a decrease in the values of b* and C* in YS. The observed changes in the color parameters of yogurts contributed to differences in the average values of a* between dates M and E. At date E, YC was characterized by the lowest ($p \leq 0.05$) value of a*, because it decreased relative to date M and increased in YG and YS over the analyzed period. The active acidity (pH) and titratable acidity of the compared products are presented in Table 2. Measurements performed at date M demonstrated significant ($p \leq 0.05$) differences in the titratable acidity of yogurts, which was highest in YC and lowest in YS. YS was characterized by a higher ($p \leq 0.05$) value of pH than YC and YG.

Further refrigerated storage of yogurts induced an increase ($p \leq 0.05$) in their titratable acidity, whereas pH decreased ($p \leq 0.05$) in YS. As a result, at date E, the compared products differed significantly ($p \leq 0.05$) only in titratable acidity, just like at date M.

The content of vitamins A and E in yogurts is shown in Table 3. At date M, the content of both vitamins was highest ($p \leq 0.05$) in YS, and considerably lower in YC. The difference in average vitamin E content between YC and YG was not significant ($p \leq 0.05$) due to high variability in this parameter in YG.

Table 2. Color parameters of the compared products

Parameter	Analysis[1]	Yogurt made from		
		cow's milk (YC)	goat's milk (YG)	sheep's milk (YS)
L* (lightness)	M	$94.223^{b} \pm 0.060$	$93.497^{cy} \pm 0.015$	$95.160^{a} \pm 0.026$
	E	90.947 ± 5.843	$93.610^{x} \pm 0.020$	95.113 ± 0.064
a* (redness)	M	$-2.133^{bx} \pm 0.025$	$-1.427^{a} \pm 0.025$	$-2.253^{cy} \pm 0.015$
	E	$-2.217^{cy} \pm 0.035$	$-1.397^{a} \pm 0.032$	$-2.123^{bx} \pm 0.012$
b* (yellowness)	M	$11.127^{a} \pm 0.110$	$8.737^{c} \pm 0.045$	$10.940^{bx} \pm 0.026$
	E	$11.083^{a} \pm 0.142$	$8.793^{c} \pm 0.049$	$10.800^{by} \pm 0.050$
C* (chroma)	M	$11.330^{a} \pm 0.113$	$8.853^{b} \pm 0.040$	$11.170^{ax} \pm 0.026$
	E	$11.303^{a} \pm 0.133$	$8.900^{c} \pm 0.044$	$11.007^{by} \pm 0.045$
pH	M	$4.193^{b} \pm 0.032$	$4.178^{b} \pm 0.052$	$4.321^{ax} \pm 0.021$
	E	4.143 ± 0.021	4.086 ± 0.087	$4.209^{y} \pm 0.018$
Titratable acidity (°SH)	M	$48.570^{ay} \pm 0.078$	$43.533^{by} \pm 0.248$	$42.040^{cy} \pm 0.364$
	E	$51.343^{ax} \pm 0.150$	$45.817^{bx} \pm 0.603$	$43.053^{cx} \pm 0.266$

[1] Analysis performed in the middle (M) and at the end (E, last day) of shelf life.

[a,b,c] Means with different superscripts within the row are different at $p \leq 0.05$.

[x,y] Means with different superscripts within the column are different at $p \leq 0.05$.

Table 3. Vitamin A and E content of the compared products

Parameter	Analysis[1]	Yogurt made from		
		cow's milk (YC)	goat's milk (YG)	sheep's milk (YS)
Vitamin A (µg/100 ml)	M	$8.452^{c} \pm 1.043$	$13.175^{b} \pm 1.535$	$38.679^{ax} \pm 1.208$
	E	$8.686^{b} \pm 0.054$	$11.836^{b} \pm 0.468$	$27.653^{ay} \pm 3.342$
Vitamin E (µg/100 ml)	M	$25.190^{bx} \pm 1.795$	$27.873^{b} \pm 4.612$	$44.611^{a} \pm 1.782$
	E	$20.396^{cy} \pm 2.153$	$28.228^{b} \pm 0.093$	$44.993^{a} \pm 2.986$

[1] Analysis performed in the middle (M) and at the end (E, last day) of shelf life.
[a,b,c] Means with different superscripts within the row are different at $p \leq 0.05$.
[x,y] Means with different superscripts within the column are different at $p \leq 0.05$.

An analysis conducted at date E revealed a significant ($p \leq 0.05$) and a minor decrease in the vitamin A content of YS and YG, respectively. Vitamin E content did not change significantly ($p \leq 0.05$) in YS or YG, whereas it decreased considerably in YC. As a result of changes observed in YC and YG, the difference in vitamin A content between these products was not significant ($p \leq 0.05$), whereas the difference in vitamin E content was significant ($p \leq 0.05$).

The fatty acid profile of the analyzed yogurts is presented in Tables 4 - 6.

Table 4. Proportion of saturated fatty acids (%) in the total content of fatty acids in the fat of the compared products

Parameter	Analysis[1]	Yogurt made from		
		cow's milk (YC)	goat's milk (YG)	sheep's milk (YS)
C4:0	M	$2.897^{a} \pm 0.134$	$2.217^{b} \pm 0.127$	$3.140^{ax} \pm 0.061$
	E	$3.127^{a} \pm 0.112$	$2.100^{b} \pm 0.072$	$2.950^{ay} \pm 0.044$
C6:0	M	$2.093^{c} \pm 0.087$	$2.493^{b} \pm 0.101$	$2.773^{ax} \pm 0.035$
	E	$2.193^{c} \pm 0.035$	$2.357^{b} \pm 0.032$	$2.663^{ay} \pm 0.025$
C8:0	M	$1.363^{b} \pm 0.035$	$2.987^{ax} \pm 0.091$	$2.850^{ax} \pm 0.026$
	E	$1.407^{b} \pm 0.015$	$2.820^{ay} \pm 0.044$	$2.780^{ay} \pm 0.017$
C10:0	M	$3.237^{c} \pm 0.055$	$9.987^{a} \pm 0.150$	$9.160^{b} \pm 0.111$
	E	$3.267^{c} \pm 0.038$	$9.650^{a} \pm 0.243$	$9.117^{b} \pm 0.050$
C12:0	M	$3.770^{b} \pm 0.017$	$5.263^{a} \pm 0.060$	$5.227^{a} \pm 0.015$
	E	$3.767^{b} \pm 0.025$	$5.193^{a} \pm 0.080$	$5.250^{a} \pm 0.053$
C14 *iso*	M	$0.130^{a} \pm 0.000$	$0.097^{b} \pm 0.021$	$0.150^{a} \pm 0.000$
	E	0.130 ± 0.000	0.080 ± 0.000	0.150 ± 0.000
C14:0	M	$12.100^{b} \pm 0.036$	$10.903^{c} \pm 0.029$	$12.657^{ay} \pm 0.006$
	E	$12.043^{b} \pm 0.021$	$10.957^{c} \pm 0.057$	$12.733^{ax} \pm 0.031$
C15:0	M	$1.260^{a} \pm 0.000$	$0.877^{b} \pm 0.055$	$1.217^{a} \pm 0.006$
	E	$1.250^{a} \pm 0.000$	$0.840^{c} \pm 0.017$	$1.210^{b} \pm 0.000$
C16 *iso*	M	0.297 ± 0.015	0.253 ± 0.012	0.263 ± 0.025
	E	0.273 ± 0.006	0.273 ± 0.012	0.270 ± 0.010
C16:0	M	$35.430^{a} \pm 0.130$	$27.833^{b} \pm 0.055$	$27.930^{by} \pm 0.072$
	E	$35.327^{a} \pm 0.074$	$28.123^{b} \pm 0.275$	$28.120^{bx} \pm 0.075$
C17:0	M	0.700 ± 0.000	0.623 ± 0.075	0.717 ± 0.006
	E	$0.693^{b} \pm 0.006$	$0.583^{c} \pm 0.006$	$0.717^{a} \pm 0.006$
C18:0	M	$9.447^{b} \pm 0.055$	$9.293^{b} \pm 0.100$	$9.817^{a} \pm 0.061$
	E	$9.520^{b} \pm 0.030$	$9.393^{c} \pm 0.038$	$9.897^{a} \pm 0.049$
C20:0	M	$0.170^{c} \pm 0.000$	$0.193^{b} \pm 0.006$	$0.320^{a} \pm 0.000$
	E	$0.170^{c} \pm 0.000$	$0.197^{b} \pm 0.006$	$0.323^{a} \pm 0.006$
C22:0	M	$0.100^{a} \pm 0.000$	$0.017^{b} \pm 0.006$	$0.023^{b} \pm 0.006$
	E	$0.100^{b} \pm 0.000$	$0.020^{a} \pm 0.010$	$0.020^{a} \pm 0.000$
SFAs	M	$72.993^{by} \pm 0.111$	$73.037^{b} \pm 0.594$	$76.243^{a} \pm 0.081$
	E	$73.267^{bx} \pm 0.093$	$72.587^{c} \pm 0.132$	$76.200^{a} \pm 0.089$

[1] Analysis performed in the middle (M) and at the end (E, last day) of shelf life.
SFAs - saturated fatty acids. [a,b,c] Means with different superscripts within the row are different at $p \leq 0.05$.
[x,y] Means with different superscripts within the column are different at $p \leq 0.05$.

Table 5. Proportion of unsaturated fatty acids (%) in the total content of fatty acids in the fat of the compared products

Parameter	Analysis[1]	Yogurt made from		
		cow's milk (YC)	goat's milk (YG)	sheep's milk (YS)
C10:1	M	$0.347^{a} \pm 0.012$	$0.263^{b} \pm 0.023$	$0.287^{b} \pm 0.006$
	E	$0.343^{a} \pm 0.006$	$0.253^{c} \pm 0.006$	$0.287^{b} \pm 0.006$
C12:1	M	0.110 ± 0.000	0.080 ± 0.000	0.110 ± 0.000
	E	$0.117^{a} \pm 0.012$	$0.083^{b} \pm 0.006$	$0.110^{a} \pm 0.000$
C14:1	M	$1.110^{cx} \pm 0.000$	$0.177^{b} \pm 0.006$	$0.190^{a} \pm 0.000$
	E	$1.097^{ay} \pm 0.006$	$0.200^{b} \pm 0.035$	$0.197^{b} \pm 0.012$
C16:1	M	$2.013^{a} \pm 0.006$	$0.943^{b} \pm 0.029$	$0.970^{by} \pm 0.000$
	E	$1.997^{a} \pm 0.012$	$0.993^{b} \pm 0.032$	$0.983^{bx} \pm 0.006$
C17:1	M	$0.457^{a} \pm 0.006$	$0.407^{b} \pm 0.012$	$0.380^{c} \pm 0.000$
	E	$0.450^{a} \pm 0.000$	$0.403^{b} \pm 0.006$	$0.380^{c} \pm 0.000$
C18:1 *c*9	M	$19.897^{b} \pm 0.104$	$21.047^{a} \pm 0.615$	$17.307^{c} \pm 0.103$
	E	$19.727^{b} \pm 0.074$	$21.460^{a} \pm 0.142$	$17.367^{c} \pm 0.087$
C18:2	M	$1.757^{c} \pm 0.006$	$2.730^{a} \pm 0.026$	$2.207^{b} \pm 0.012$
	E	$1.737^{c} \pm 0.012$	$2.687^{a} \pm 0.067$	$2.197^{b} \pm 0.015$
CLA	M	$0.437^{c} \pm 0.006$	$0.617^{b} \pm 0.015$	$0.700^{a} \pm 0.000$
	E	$0.433^{c} \pm 0.006$	$0.630^{b} \pm 0.000$	$0.703^{a} \pm 0.006$
C18:3	M	$0.450^{b} \pm 0.000$	$0.353^{c} \pm 0.006$	$1.180^{a} \pm 0.010$
	E	$0.440^{b} \pm 0.000$	$0.353^{c} \pm 0.006$	$1.177^{a} \pm 0.015$
C20:1	M	$0.110^{a} \pm 0.000$	$0.000^{b} \pm 0.000$	$0.047^{b} \pm 0.040$
	E	$0.110^{a} \pm 0.000$	$0.003^{b} \pm 0.006$	$0.000^{b} \pm 0.000$
C20:2	M	0.020 ± 0.000	0.030 ± 0.017	0.020 ± 0.000
	E	0.020 ± 0.000	0.013 ± 0.006	0.020 ± 0.000
C20:4	M	$0.163^{b} \pm 0.006$	$0.213^{a} \pm 0.006$	$0.143^{c} \pm 0.006$
	E	0.160 ± 0.000	0.210 ± 0.000	0.150 ± 0.000
C20:5	M	$0.040^{b} \pm 0.000$	$0.030^{b} \pm 0.000$	$0.080^{a} \pm 0.010$
	E	$0.040^{b} \pm 0.000$	$0.037^{b} \pm 0.012$	$0.083^{a} \pm 0.006$
C22:5	M	$0.073^{b} \pm 0.006$	$0.083^{b} \pm 0.006$	$0.133^{a} \pm 0.006$
	E	$0.073^{c} \pm 0.006$	$0.090^{b} \pm 0.000$	$0.133^{a} \pm 0.006$
MUFAs	M	$24.043^{a} \pm 0.103$	$22.917^{b} \pm 0.615$	$19.290^{c} \pm 0.060$
	E	$23.840^{a} \pm 0.079$	$23.397^{b} \pm 0.070$	$19.323^{c} \pm 0.067$
PUFAs	M	$2.940^{cx} \pm 0.010$	$4.057^{b} \pm 0.021$	$4.463^{a} \pm 0.032$
	E	$2.903^{cy} \pm 0.006$	$4.020^{b} \pm 0.061$	$4.463^{a} \pm 0.029$
UFAs	M	$27.007^{ax} \pm 0.111$	$26.963^{a} \pm 0.594$	$23.757^{b} \pm 0.081$
	E	$26.733^{by} \pm 0.093$	$27.413^{a} \pm 0.132$	$23.800^{c} \pm 0.089$

[1] Analysis performed in the middle (M) and at the end (E, last day) of shelf life.
MUFAs - monounsaturated fatty acids. PUFAs - polyunsaturated fatty acids. PUFAs - polyunsaturated fatty acids. UFAs - unsaturated fatty acids (MUFA + PUFA).
[a,b,c] Means with different superscripts within the row are different at $p \leq 0.05$.
[x,y] Means with different superscripts within the column are different at $p \leq 0.05$.

At date M, YC had higher ($p \leq 0.05$) concentrations of C16:0 and C20:0 than YS and YG, whereas YC and YS had higher ($p \leq 0.05$) concentrations of C4:0, C14-*iso* and C15:0 than YG. YS had the highest ($p \leq 0.05$) content of C6:0, C14:0, C18:0, C20:0 and total SFAs, whereas YG had the highest ($p \leq 0.05$) content of C10:0. An analysis of SFA composition demonstrated that YS and YG had a higher ($p \leq 0.05$) content of C8:0 and C12:0 than YC.

An analysis conducted at date E revealed that the total proportion of SFAs increased ($p \leq 0.05$) in fat extracted from YC. In turn, the percentage of C8:0 decreased ($p \leq 0.05$) in YG. The most profound changes were noted in the SFA profile of YS, including a decrease ($p \leq 0.05$) in the concentrations of C4:0, C6:0 and C8:0, and an increase ($p \leq 0.05$) in the levels of C14:0 and C16:0.

Table 6. Nutritional value of fat in the compared products

Parameter	Analysis[1]	Yogurt made from		
		cow's milk (YC)	goat's milk (YG)	sheep's milk (YS)
UFA/SFA	M	$0.370^{ax} \pm 0.002$	$0.369^{a} \pm 0.011$	$0.312^{b} \pm 0.001$
	E	$0.365^{ay} \pm 0.002$	$0.378^{b} \pm 0.003$	$0.312^{c} \pm 0.002$
MUFA/SFA	M	$0.329^{ax} \pm 0.002$	$0.314^{a} \pm 0.011$	$0.253^{b} \pm 0.001$
	E	$0.325^{ay} \pm 0.001$	$0.322^{a} \pm 0.002$	$0.254^{b} \pm 0.001$
PUFA/SFA	M	$0.040^{cx} \pm 0.000$	$0.056^{b} \pm 0.000$	$0.059^{a} \pm 0.000$
	E	$0.0396^{cy} \pm 0.000$	$0.055^{b} \pm 0.001$	$0.059^{a} \pm 0.000$
DFA/OFA	M	$0.574^{a} \pm 0.004$	$0.569^{a} \pm 0.017$	$0.505^{b} \pm 0.003$
	E	$0.569^{b} \pm 0.002$	$0.582^{a} \pm 0.003$	$0.508^{c} \pm 0.003$
EFAs	M	$2.643^{cx} \pm 0.006$	$3.700^{b} \pm 0.010$	$4.087^{a} \pm 0.021$
	E	$2.610^{cy} \pm 0.010$	$3.670^{b} \pm 0.070$	$4.077^{a} \pm 0.032$
n-6/n-3	M	$4.874^{by} \pm 0.013$	$9.474^{a} \pm 0.194$	$2.463^{c} \pm 0.013$
	E	$4.932^{bx} \pm 0.023$	$9.387^{a} \pm 0.164$	$2.465^{c} \pm 0.024$

[1] Analysis performed in the middle (M) and at the end (E, last day) of shelf life.
SFAs - saturated fatty acids, MUFAs - monounsaturated fatty acids, PUFAs - polyunsaturated fatty acids, UFAs - unsaturated fatty acids (MUFAs + PUFAs), DFAs - desirable fatty acids (UFAs + C18:0), OFAs - hypercholesterolemic fatty acids (SFAs – C18:0), EFAs - essential fatty acids (C18:2 + C18:3).
[a,b,c] Means with different superscripts within the row are different at $p \leq 0.05$.
[x,y] Means with different superscripts within the column are different at $p \leq 0.05$.

A comparison of UFA composition in the analyzed products at date M revealed that YC contained more ($p \leq 0.05$) C10:1, C16:1, C17:1, C20:1, and total MUFAs than YG and YS. The UFA profile of YS was characterized by the highest ($p \leq 0.05$) proportions of C14:1, CLA, C18:3, C20:5, C22:5, and total PUFAs. YG had the highest ($p \leq 0.05$) content of C18:1 *c9*, C18:2, and C20:4. The proportion of total UFAs was higher ($p \leq 0.05$) in YC and YG than in YS.

An analysis of the UFA profile in fat extracted from YC at date E revealed a decrease ($p \leq 0.05$) in the content of C14:1, total PUFAs, and total UFAs. The concentration of C16:1 increased significantly ($p \leq 0.05$) in YS.

The changes in SFA and UFA composition in YC and YG, observed during refrigerated storage, contributed to significant ($p \leq 0.05$) differences in the proportions of total SFAs and total UFAs between these products at date E.

At date M, YC and YG were characterized by higher ($p \leq 0.05$) values of the UFA/SFA, MUFA/SFA, DFA/OFA, and n-6/n-3 PUFA ratios than YS. The n-6/n-3 PUFA ratio was also higher ($p \leq 0.05$) in YG than in YC. The PUFA/SFA ratio and EFA concentrations were higher ($p \leq 0.05$) in YS and YG than in YC, and the highest ($p \leq 0.05$) values of these parameters were noted in YS.

The changes in the parameters characterizing the nutritional value of fat, observed during refrigerated storage, were significant only in YC. In most cases, their values decreased ($p \leq 0.05$) (excluding the n-6/n-3 PUFA ratio), and only the difference between the average values of the DFA/OFA ratio was not significant ($p \leq 0.05$). The value of the n-6/n-3 PUFA ratio increased ($p \leq 0.05$) in YC. It should be stressed that the above changes were minor, and the significance of differences between group means resulted from low variability in the calculated values of the analyzed parameters.

The changes in the average content of SFAs and UFAs in YC and YG contributed to a significant ($p \leq 0.05$) difference in the average values of the UFA/SFA ratio between these products at date E. The same trend was noted when comparing the values of the DFA/OFA ratio in YC and YG at dates M and E.

DISCUSSION

In milk and dairy products, color lightness is related to the physical processes of light reflectance and scattering by milk components, mainly protein particles and fat globules (Grasso et al. 2020). The number and size of protein particles and fat globules, and the degree of their agglomeration affect the total area available for light reflectance and scattering. A correlation between the value of L* and the fat content of plain yogurt was observed by Rój and Przybyłowski (2012) who found that L*

values ranged from 87.00 to 92.58 and were higher in high-fat products (7.5-10%) than in fat-free products. In dairy products made from coagulated milk, light reflectance is correlated with curd structure (Milovanovic et al. 2020). Such a correlation was also described by Bierzuńska et al. (2019) who reported that yogurt with the addition of whey proteins was characterized by higher firmness and a higher value of the whiteness index. The color of milk and dairy products is also determined by the presence of natural compounds such as riboflavin (vitamin B_2) and carotenoids, which impart a yellowish green (Lee et al., 1998) and yellow color (Conboy Stephenson and Ross, 2021) to milk, respectively. According to Laurent et al. (2023), milk from small ruminants is poorer in carotenoids than cow's milk, are therefore less yellow, which could explain the lower values of b* in YG and YS noted in the present study. In turn, the average values of a* in the analyzed products (YS < YC < YG) could be associated the different riboflavin content of sheep's, cow's and goat's milk. According to Flis and Molik (2021), the average riboflavin content of sheep's, cow's and goat's milk is 0.3, 0.2, and 0.175 mg/100 g, respectively.

In the current experiment, the changes in the color parameters of yogurts noted at date E were minor, and the significance of differences between group means was due to low variability in measurement results. Insignificant changes in the values of L*, a*, and b* of yogurts during storage were also observed by Mani-Lopez et al. (2014), and Jakubowska and Karamucki (2019). Time-related changes in yogurt color may result from carotenoid transformations. During storage, carotenoid loss is affected by time, temperature, light, oxygen, water activity, and packaging material (Pénicaud et al. 2011, Meléndez-Martínez et al. 2022).

Domagała (2009), Mahmood and Usman (2010), and Arrichiello et al. (2022) observed no significant differences in pH between cow's, goat's and sheep's milk. However, milk from these animal species differed in titratable acidity. Domagała (2009), Mahmood and Usman (2010) demonstrated that sheep's milk had considerably higher titratable acidity, which points to its higher buffering capacity. In turn, goat's milk is characterized by low buffering capacity (Martín-Diana et al. 2003, Teichert et al. 2015). The buffering capacity of milk does not translate directly to the buffering capacity of yogurt because the chemical composition of milk used for yogurt production is modified by, among other factors, an increase in the content of total solids. As a result, the composition and concentrations of the constituents (mostly protein) responsible for the buffering properties of milk and dairy products also vary (Salaün et al. 2005). The above processes could lead to the lower titratable acidity of both YS and YG, relative to YC, in the present study.

A decrease in pH and an increase in titratable acidity in all compared products during storage were noted in this experiment and in previous research (Kailasapathy 2006, Eissa et al. 2010, Erkaya and Şengül 2012, Dimitrellou et al. 2019, Vianna et al. 2019). The observed changes resulted from lactose conversion to lactic acid by bacterial starter cultures used in yogurt production. Starter cultures remain active during refrigerated storage, and they are able to carry out lactic acid fermentation, leading to further acidification of the product (Kailasapathy 2006). However, the activity of these microorganisms and their enzymes is reduced in low temperatures, therefore the increase in acidification is not significant, as confirmed by the measurements of yogurt pH and titratable acidity in the present study. According to Deshwal et al. (2021), the active acidity (pH) of commercial yogurt should range from 4.0 to 4.44 to avoid an excessively sour taste. In the current study, the average pH values of the compared products decreased during storage, but remained within the above range. The pH of YS decreased significantly at date E, compared with date M, but similar changes were noted in YC and YG, and the significance of differences between group means resulted from the lower variability of pH values in YS. Dimitrellou et al. (2019) suggested that changes in yogurt acidity could be caused by different activity levels of bacterial starter cultures in products manufactured with milk from different animal sources. In the cited study, the survival rates of *Lactobacillus delbrueckii* spp. *bulgaricus* were higher in YC than in YG during storage at 4°C.

Literature data (Michlová et al. 2015, Flis and Molik 2021, Cimmino et al. 2023) show that sheep's milk is a richer source of vitamins A and E than goat's and cow's milk, and that the content of these vitamins tends to be higher in goat's milk than in cow's milk. Such observations were also made in the present study. The relatively high concentration of vitamin A in sheep's milk and its products may result from increased conversion of β-carotene to retinol by the enzyme β-carotene-15-15'-dioxygenase in the intestinal epithelium and liver of sheep (Aslan et al. 2021). Previous research has also shown that the natural content of vitamins A and E in milk may be affected not only by animal species but also by breed, season (availability of green fodder) and stage of lactation (Michlová et al. 2015, Aslan et al. 2021, Cimmino et al. 2023).

Moreover, the concentrations of vitamins A and E decrease during milk processing and storage of dairy products. Temperature, oxygen and light play an important role in these processes (Allwood and Martin 2000, Lucas-Aguirre and Cortes-Rodriguez 2020). In a study by Michlová et al. (2015), the content of vitamins A and E in goat's and sheep's milk subjected to high-temperature short-time (HTST) pasteurization decreased by 13% and 14%, and 23% and 14%, respectively. Khan et al. (2020) found that the pattern of post-fermentation cooling had a significant influence on the antioxidant properties of yogurt and the concentrations of vitamins A and E. Both vitamins are highly sensitive to light. Vitamin A is degraded by photolysis, whereas vitamin E is degraded by photo-oxidation (Allwood and Martin 2000). This could explain the considerable decrease in the vitamin A content of YS, noted in the current study, because YS was packaged in a glass jar and exposed to light.

The fatty acid profile of yogurt is affected by the concentrations of fatty acids in milk used in the production process (Pecová et al. 2019). The lipolytic activity of lactic acid bacteria in yogurt is limited, and therefore it exerts a minor impact on the fatty acid profile (Ribeiro et al. 2011, Chen et al. 2017). In general, SFAs predominate in ruminant milk (approx. 70%), and the proportion of PUFAs is low (Mollica et al. 2021). As shown by a detailed analysis of milk fat, myristic acid (C14:0), palmitic acid (C16:0), and stearic acid (C18:0) are present in the highest concentrations (Kalač & Samková, 2010). Milk from small ruminants (goats and sheep) is also characterized by a high proportion of short-chain SFAs (Sepe and Argüello 2019, Djordjevic et al. 2019). Ribeiro et al. (2011) demonstrated that goat's milk, in comparison with cow's milk, has a higher content of caprylic acid (C8:0), capric acid (C10:0), lauric acid (C12:0), and palmitic acid (C16:0), but a lower content of butyric acid (C4:0), which in turn is present in higher concentrations in sheep's milk (Mollica et al. 2021, Mohapatra et al. 2019). In the group of UFAs (Mollica et al. 2021, Mohapatra et al. 2019, Djordjevic et al. 2019), CLA content is higher in goat's and sheep's milk than in cow's milk, whereas the proportion of n-3 fatty acids is higher in sheep's milk than in milk from other ruminants. An analysis of the fatty acid profile of yogurts, conducted in the present study, confirmed the above observations. Differences in the fatty acid composition of cow's, sheep's and goat's milk may result from different production systems. In most cases, small ruminants are not fed intensively and their diets are based on green forage (Djordjevic et al. 2019).

The changes in the fatty acid profile of yogurts made from different types of milk, observed in this study, are consistent with those reported by other authors. Serafeimidou et al. (2013) found no significant changes in the content of SFAs, MUFAs or PUFAs in YS stored for 14 days at 5°C. During storage, SFA content increased significantly, whereas the concentrations of MUFAs and PUFAs decreased in YC. The concentration of CLA decreased in YC and increased in YS. Similar changes in the fatty acid profile of yogurts made from cow's milk and milk from small ruminants (goats and sheep) were noted by Paszczyk et al. (2020). In the cited study, the content of MUFAs and PUFAs decreased in YC after 21 days of storage at 8°C, whereas changes in the concentrations of these fatty acids in YS and YG did not follow a regular pattern. The above authors also found that CLA content decreased in YC, increased in YG, and remained unchanged in YS during storage. The results of this study and the findings of other authors suggest that fatty acids in YG and YS are less susceptible to transformations during refrigerated storage. Their stability is associated with higher levels of vitamins A and E in these products.

CONCLUSIONS

It was found that the quality of the analyzed yogurts varied considerably depending on the properties of raw material (cow's milk, goat's milk, sheep's milk) used in the production process. The extent of changes in quality attributes during refrigerated storage also varied across the compared products, which could be arranged in the following order based on storage stability: YC < YS < YG. The changes in the quality characteristics of the yogurts noted during refrigerated storage (an increase in titratable acidity) resulted from the activity of bacterial cultures used in the production process. The changes in UFA concentrations, and in the content of vitamins A and E could also be associated with the processes induced by exposure to oxygen and light. However, further research is needed to confirm this hypothesis.

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