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Original Paper

The effect of six-week consumption of full-fat yogurt made from the milk of sheep fed with iodine-enriched feed on indicators of thyroid function and selected biochemical and anthropometric parameters

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The purpose of the study was to determine what changes will occur under the influence of six-week consumption of full-fat yogurt made from sheep's milk from ewes fed with iodine-enriched feed in relation to indicators of thyroid function – thyroid-stimulating hormone (TSH), free triiodothyronine (fT3), free thyroxine (fT4), but also to selected biochemical and anthropometric parameters. The intervention group consisted of nineteen women aged 54 ±7 years. It was a hyper-cholesterolemic group with a non-atherogenic lipid profile. Six-week consumption of sheep's yogurt contributed to the intake of an important element in human nutrition, but did not cause changes in the function of the thyroid gland, nor in the state of the hormones that produce or regulate its activity. TSH decreased from 2.6 ±1.0 mIU.l^{-1} to 2.4 ±1.0 mIU.l^{-1}, fT4 increased from 15.2 ±1.5 pmol.l^{-1} to 15.3 ±1.7 pmol.l^{-1}, but there were no statistically significant changes (P >0.05). The value of fT3 did not change at all (4.8 pmol.l^{-1}). The intervention had no significant negative impact either on the lipid profile or other biochemical and anthropometric parameters. Our findings indicate that the consumption of full-fat sheep's yogurt not only contributes to the intake of iodine in the diet, but in terms of fat content does not cause health complications and deterioration of the lipid profile or other biochemical or anthropometric parameters.

Keywords: yogurt, sheep, iodine, thyroid, nutritional status, women

1 Introduction

The human body contains approximately 15–20 mg of iodine. The thyroid gland uses 70–80% of it (Zimmerman, 2020). Iodine is an essential dietary component required for the production of the important thyroid hormones triiodothyronine (T3) and thyroxine (T4) (Zimmermann et al., 2008), without which the functionality of many critical and vital organs would be compromised (Dunn, 2006). In Slovakia and in most countries of the world, the daily recommended dose for iodine intake is set at 150 µg for men and non-pregnant women older than fourteen years (Institute of Medicine, 2001; Kajaba et al., 2015). The most valuable food sources of iodine include seafood, eggs, milk and milk products. However, salt with iodine content is its main source for all population groups. Even in spite of extensive programs of salt iodization and efforts to reduce the prevalence of iodine deficiency, almost 30% of the world's population is still at risk (Pearce et al., 2004; Řehůřková and Ruprich, 2013; Niwattisaiwong et al., 2017; Herrick et al., 2018). In addition, in recent years we have witnessed a tendency to reduce salt intake due to the prevention of cardiovascular diseases and hypertension and its replacement with other flavorings (Lee et al., 2016; Pehrsson et al., 2022), which makes the issue of iodine deficiency relevant again.

However, research results in recent years also point to a connection between the consumption of milk and milk

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products and the state of iodine in the body (Kaufmann et al., 1998; Gostas et al., 2020).

The share of milk and milk products in total iodine intake varies from 6 to 7% in Germany to 37% in Great Britain (Schöne et al., 2009), in some cases the authors report a range of 25–70% (Arrizabalaga et al., 2015; Pastorelli et al., 2015), or 13–64% (Gostas et al., 2020). However, milk and milk products are an unpredictable food source of iodine due to its fluctuating content. The concentration of iodine in milk and milk products depends on its content in feed (transfer from soil to fodder plant sources; fortification), in water, as well as on the use of iodine preparations in the disinfection of teats. It is iodophor preparations that largely contribute to changes in the iodine content of milk (Soriguer et al., 2011; Schöne et al., 2017; Pehrsson et al., 2022).

Dietary recommendations include the consumption of milk and milk products as an important part of a healthy and balanced diet mainly because they are a valuable source of complete proteins, calcium, iodine, riboflavin and vitamin B_{12} (Hite et al., 2010). Among the most popular dairy products is yogurt, which forms an integral part of the diet of many population groups. Its high consumer demand is primarily due to its health-promoting effects, whether they are probiotic, digestive, metabolic, immune, anti-cancer, etc. (Mackowiak, 2013; Shakerian et al., 2015). In addition to cow's milk, sheep's and goat's milk is also used to make yogurt. Their producers thus support the variability of the offer of dairy products on the market with significant dietary properties, but at the same time contribute to ensuring sufficient intake of iodine from the diet (Fazilah et al., 2018).

The aim of our work was to investigate the effect of six-week consumption of full-fat yogurt made from sheep's milk from ewes fed with iodine-enriched feed on selected biomarkers of thyroid function, but also on selected biochemical, somatic and anthropometric indicators of nutritional and health status. According to our information, no study of this type has been published so far.

2 Material and methods

2.1 Characteristics of the participants and study design

Based on the inclusion and exclusion criteria, twenty women between the ages of 40 and 67 were included in the clinical study with a pre-post intervention nature. However, one person was excluded from the group due to the diagnosis of health problems with the thyroid gland. The study dietary intervention consisted in the daily consumption of full-fat yogurt made from sheep's milk from ewes fed with iodine-enriched feed for six weeks in the months of June and July 2022. The subject of the intervention was the daily consumption of full-fat white yogurt without flavours in a dose of 150 g. The average nutritional value of yogurt per 100 g of edible portion was as follows: dry matter – 16.4 g; proteins – 5.7 g; fats – 6.6 g; saturated fatty acids – 4.4 g; monounsaturated fatty acids – 1.7 g; polyunsaturated fatty acids – 0.2 g; carbohydrates – 3.2 g; sugars – 2.8 g; sodium – 32 mg; iodine – 9.6 µg; energy value – 396 kJ. In three control samples taken during the milking period, the concentration of iodine in sheep yogurts was on average 101.8 ±4.5 $\mu g.l^{-1}$ (range 94.5–110.0 $\mu g.l^{-1}$).

The study participants were asked not to change their eating habits or lifestyle in any way during the entire intervention period. They were asked to complete a 4-day/24-hour nutritional protocol consisting of two days during the work week and two days during the weekend. It is a detailed retrospective record containing a list of foods consumed by a person over a specified period of time. We used the program Mountberry – Nutrition & Fitness Software (2011, Version 1.1; Wellberry, s.r.o., Tuchyňa, Slovak Republic) to process the nutritional protocol. For the purposes of the study, we evaluated the average intake of total energy, carbohydrates, fats, proteins and iodine.

The study was conducted according to the guidelines of the Declaration of Helsinki and approved by the Slovak University of Agriculture (SUA) in Nitra, Institute of Animal Husbandry and Institute of Nutrition and Genomics, Slovak Republic; and by the hospital´s ethical review board – Ethical Committee of the Specialized Hospital of St. Zoerardus Zobor in Nitra, Kláštorská 131, 94901 Nitra, Slovak Republic (study protocol No. 031219_2019). A written informed consent was obtained from all the participants prior to their involvement in the study.

2.2 Anthropometric and somatic measurements

In order to evaluate the body composition before the intervention, we used the method of multi-frequency bioelectrical impedance analysis (MFBIA) using the device InBody 720 (Biospace Co. Ltd., Seoul, Korea). All participants signed an informed written consent form and gave their consent to the processing of personal data using the Lookin'Body 3.0 software. To assess the body composition, the following parameters were measured directly by bioimpedance analysis: basal metabolic rate (BMR, kJ); body condition status (BCS, points); waist circumference (WC, cm); hip circumference (HC, cm); neck size (NS, cm); fat free mass (FFM, kg); skeletal muscle mass (SMM, kg); body fat mass (BFM, kg); percent of body fat (PBF, %); visceral fat area (VFA, cm^2); intra-/extra-cellular

and total body water (ICW, ECW, TBW, liter). Body mass index (BMI) was calculated as weight (kg) divided by the square of the height (m^2). Waist-to-hip ratio (WHR) was calculated as waist circumference (cm) divided by hip circumference (cm) (Skrzypczak et al., 2007; WHO, 2008; 2020; DAPA, 2022).

Systolic and diastolic blood pressure was measured three times using a sphygmomanometer OMRON M7 Intelli IT with AFIBM (OMRON Healthcare Co., Ltd., Shiokoji Horikawa, Shimogyo-ku, Kyoto 600-8530, Japan) in a remained seated and relaxed position (participants rested for at least 15 min before each measurement). For the purposes of the study, the resulting average value of three measurements was used.

2.3 Blood sampling and analysis of biochemical parameters

Blood sampling was performed at the beginning of the study before the start of the intervention (day 0) and after its immediate end after six weeks of consumption (day 42). Sampling was always done in the morning after at least 8 hours of fasting. For the purposes of the study, fasting venous blood was collected from the peripheral vein of the elbow fossa in a standard manner. As part of the biochemical analysis of the blood, we focused primarily on biomarkers of thyroid gland function (thyroid-stimulating hormone, TSH; free triiodothyronine, fT3; free thyroxine, fT4); lipid profile (total cholesterol, T-C; low density lipoproteins, LDL; high density lipoproteins, HDL; triglycerides, TG), glycaemia, GLU; high-sensitivity C-reactive protein, hs-CRP; uric acid, UA. Analyzes were performed using a Biolis 24i Premium biochemical analyzer (Tokyo Boeki Machinery, Tokyo, Japan).

Reference values for monitored parameters were as follows: TSH 0.27–4.2 $mU.l^{-1}$; fT3 3.1–6.8 $pmol.l^{-1}$; fT4 11.9–21.6 $pmol.l^{-1}$; T-C 3–5.2 $mmol.l^{-1}$; LDL 0–3.9 $mmol.l^{-1}$; HDL 1.2–2.7 $mmol.l^{-1}$; TG 0.2–1.92 $mmol.l^{-1}$ (according to NCEP ATP III (Cleeman et al., 2001); GLU 3.9–5.6 $mmol.l^{-1}$; hs-CRP 0–6 $mg.l^{-1}$; UA 154–357 $\mu mol.l^{-1}$. Elevated TSH concentration is generally a symptom of hypothyroidism, while low TSH levels indicate hyperthyroidism (Zimmerman, 2020).

LDL3-7 lipoprotein subfractions were determined in blood serum using the Lipoprint® analyzer (Quantimetrix Corp., Redondo Beach, CA, USA) with the Quantimetrix Lipoprint System LDL Subfractions Kit "Lipoprint LDL Kit" (Quantimetrix, Redondo Beach, CA, USA) according to the procedure provided by the manufacturer. Based on LDL subfraction particle size, Lipoprint® reports the LDL phenotype as non-atherogenic phenotype A (size greater than 26.8 nm), intermediate phenotype AB (size 26.53–26.79 nm), and atherogenic phenotype B (size less than 26.5 nm) (Muñiz et al., 2023).

To estimate the intake of iodine in the diet, in addition to the nutritional record method, we also used the urinary iodine excretion (UIE) method. Instead of determining iodine content from spot urine, we chose a 24-hour urine collection (Soldin, 2002). Urine samples were analyzed spectrophotometrically by the Sandell-Kolthoff method modified by Bednář et al. (1964). A UIE value of 100–199 $\mu g.l^{-1}$ is considered adequate iodine status for non-pregnant, non-lactating adult women (Niwattisaiwong et al., 2017; WHO, 2023). Severe iodine deficiency is defined as UIE concentration <20 $\mu g.l^{-1}$ (WHO, 2023).

2.4 Statistical analysis

Microsoft Office Excel 2016 (Los Angeles, CA, USA) in combination with XLSTAT (Version 2019) was used to process data. Statistical analysis was carried out using the STATISTICA 13 computer software (TIBCO Software, Inc., Palo Alto, CA, USA) and MedCalc® Statistical Software version 20.218 (MedCalc Software Ltd, Ostend, Belgium). The normality of variable distribution was checked with Shapiro-Wilk test. A descriptive analysis was carried out using the mean ±standard deviation. Levels of statistical significance were determined at $P < 0.05$. With a one-factor variance analysis (ANOVA), we tested the differences between variables and compared using Fisher's Post Hoc Test. To evaluate the relationship between variables we used Pearson correlation.

3 Results and discussion

As we mentioned above in the methodological part, the intervention group consisted of nineteen women with an average age of 54 ±7 years and a height of 166 ±5 cm. The energy intake was 7,788 ±1,960 kJ, which can be described as a below-limit intake in terms of OVD (Recommended Dietary Intake in Slovakia) for the Slovak female population in the given age category (Kajaba et al., 2015). Similarly, we found insufficient intake in the case of carbohydrates (243 ±100 g). In terms of fat and protein intake, however, the intake was above the limit (72 ±35 g and 77 ±20 g, respectively). Iodine intake was evaluated as sufficient on the basis of nutritional protocols (158 ±80 µg per day), as well as on the basis of urinary iodine excretion (204 ±44 $\mu g.l^{-1}$). Baseline characteristics of the participants are summarized in Table 1.

The average values of thyroid function indicators did not change significantly during the intervention and were within the range of reference values. Although TSH decreased from 2.6 ±1.0 $mlU.l^{-1}$ to 2.4 ±1.0 $mlU.l^{-1}$, it was not a statistically significant decrease ($P > 0.05$). Free thyroxine (fT4) also changed insignificantly (increase from 15.2 ±1.5 $pmol.l^{-1}$ to 15.3 ±1.7 $pmol.l^{-1}$). The value of fT3 did not change at all (4.8 $pmol.l^{-1}$). Basic descriptive and statistical data are presented in Table 2. Figures 1, 3

Table 1 Baseline characteristics of study group (n = 19)

Parameters	Mean	±SD	Min	Max	Med	Mode
Age (years)	54	7	40	67	53	53
Height (cm)	166	5	158	174	165	164
Body mass index (kg.m^{-2})	29.3	5.3	22.1	39.3	29.5	NA
Energy value (kJ.day^{-1})	7,788	1,960	3,735	11,194	7,706	NA
Carbohydrates intake (g.day^{-1})	243	100	91	522	252	148
Fats intake (g.day^{-1})	72	35	28	129	54	NA
Proteins intake (g.day^{-1})	77	20	30	105	77	NA
Iodine intake (µg.day^{-1})	158	80	52	305	142	NA
Urinary iodine excretion (µg.l^{-1})	204	44	111	274	206	237

Data are expressed as mean ±standard deviation. NA – non-available

Table 2 Pre-post changes in TSH, fT3 and fT4

Parameters	Pre-post	Mean	±SD	Min	Max	Med	Mode	P-value
Thyroid-stimulating hormone, TSH (mU.l^{-1})	day 0	2.6	1.0	1.1	4.7	2.4	NA	0.363
	day 42	2.4	1.0	0.9	4.7	2.2	NA	
Free triiodothyronine, fT3 (pmol.l^{-1})	day 0	4.8	0.6	3.9	5.9	4.8	5.4	0.917
	day 42	4.8	0.4	4.1	5.6	4.9	NA	
Free thyroxine, fT4 (pmol.l^{-1})	day 0	15.2	1.5	12.9	19.2	15.1	16.6	0.810
	day 42	15.3	1.7	12.5	18.6	15.7	NA	

Data are expressed as mean ±standard deviation. NA – non-available

and 5 graphically show pre-post intervention changes of TSH, fT3 and fT4, respectively. Figures 2, 4 and 6 show the relationships between urinary iodine excretion and the state of TSH, fT3 and fT4 in the blood, respectively. As can be seen from the figures, up to 53% of women had a UIE higher than 199 µg.l^{-1}. In two cases, TSH values exceeded the maximum limit of reference values (>4.2 mlU.l^{-1}). For fT3 and fT4, no values exceeded the lower or upper reference limit.

As can be seen from the data in Table 3, which shows pre-post intervention changes in anthropometric parameters, the group of women had average values of several critical parameters outside the range of optimal reference values. Based on waist circumference (100 ±13 cm vs 100 ±14 cm, P >0.05), waist-to-hip ratio

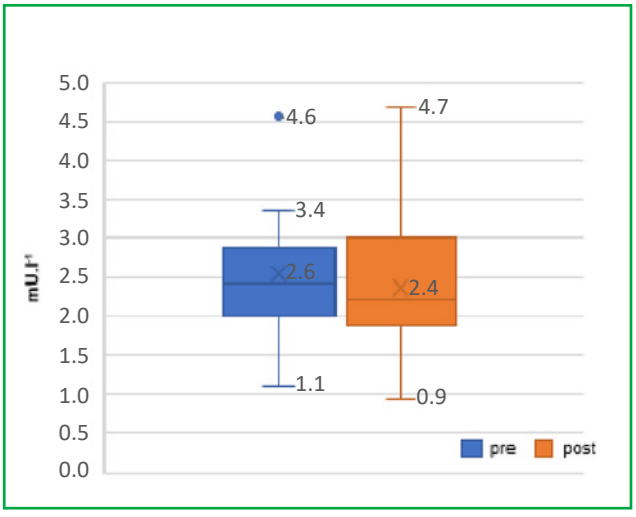

Figure 1 Pre-post intervention changes of TSH

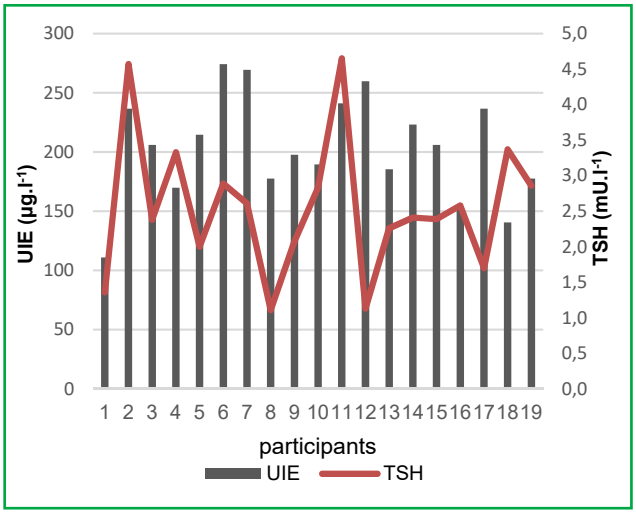

Figure 2 Relationship between UIE and TSH

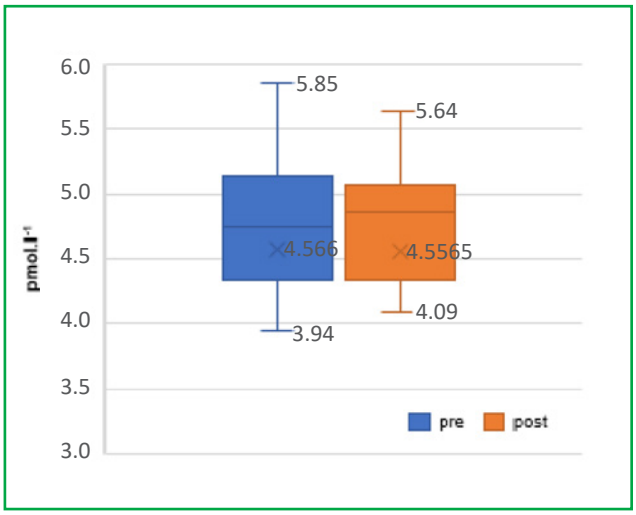

Figure 3 Pre-post intervention changes of fT3

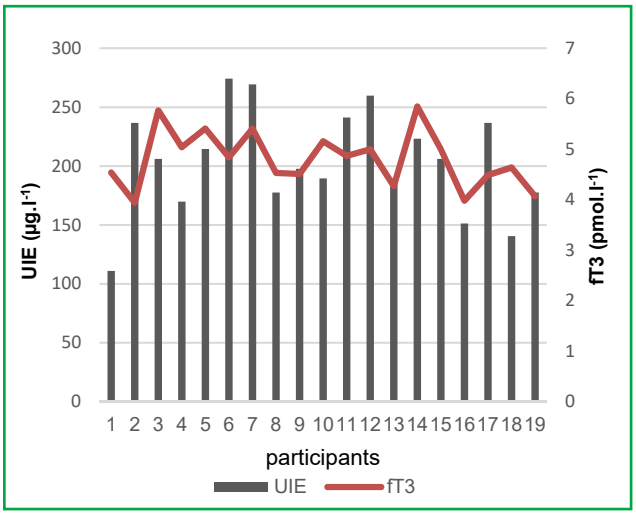

Figure 4 Relationship between UIE and fT3

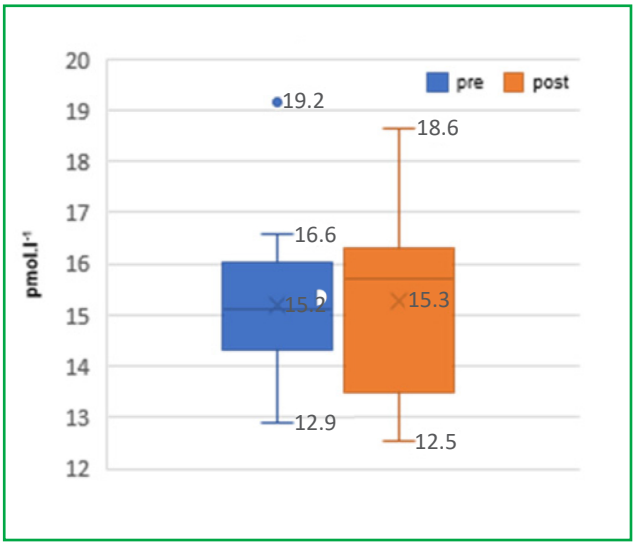

Figure 5 Pre-post intervention changes of fT4

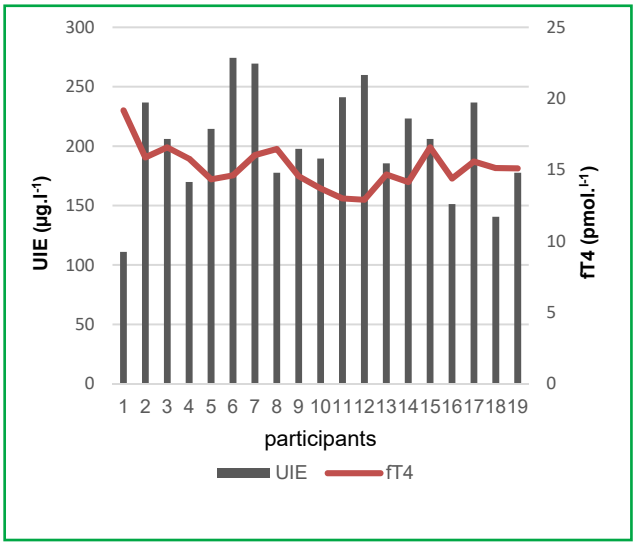

Figure 6 Relationship between UIE and fT4

(0.96 ±0.07 vs 0.96 ±0.07, P >0.05), body mass index (29.3 ±5.3 kg.m^{-2} vs 29.2 ±5.5 kg.m^{-2}, P >0.05), percentage of body fat (37.3 ±7.2% vs 37.3 ±7.6%, P >0.05) and visceral fat area (121 ±34 cm^2 vs 121 ±35 cm^2, P >0.05) were predominantly obese or overweight women. What is very positive, however, is that the consumption of full-fat yogurt did not result in a significant increase in the values of any anthropometric parameter (P >0.05).

Table 4 shows pre-post changes in biochemical and somatic parameters. The total sample already showed an increased value of total cholesterol at the beginning of the study (5.4 ±1.0 mmol.l^{-1}), which significantly increased to 5.6 ±0.9 mmol.l^{-1} after the intervention (P <0.01). We found a significant increase in values also in the case of LDL (2.8 ±0.7 mmol.l^{-1} vs 3.0 ±0.7 mmol.l^{-1}, P <0.001), HDL (1.7 ±0.3 mmol.l^{-1} vs 1.9 ±0.4 mmol.l^{-1}, P <0.001), glycaemia (4.8 ±0.6 mmol.l^{-1} vs 5.0 ±0.4 mmol.l^{-1}, P <0.05) and diastolic blood pressure (81 ±7 mmHg vs 84 ±9 mmHg, P <0.05), but not in the case of triglycerides (0.98 ±0.4 mmol.l^{-1} vs 1.16 ±0.58 mmol.l^{-1}, P >0.05). A significant increase in T-C (P <0.01), LDL (P <0.001), GLU (P <0.05) and DBP (P <0.05) can be evaluated as a potentially negative consequence, on the other hand, there was a significant increase in HDL (P <0.001) and a decrease in LDL/HDL ratio and CVD-RF (P <0.001), which we can evaluate as a potentially positive change.

In the following table 5 we present the correlation relations between TSH, fT3 and fT4 in relation to selected anthropometric and biochemical parameters. In the case of TSH, we found a significant direct relationship with body weight (r = 0.332), hip circumference (r = 0.384), neck circumference (r = 0.387), body mass index (r = 0.404),

Table 3 Pre-post changes in anthropometric parameters

Parameters	Pre-post	Mean	±SD	Min	Max	Med	Mode	*P*-value
Basal metabolic rate (kcal)	day 0	1,441	101	1,278	1,618	1,425	NA	0.584
	day 42	1,437	108	1,252	1,653	1,412	NA	
Body condition status (points)	day 0	68.1	7.4	52.0	80.0	68.0	61.0	0.700
	day 42	67.9	7.9	54.0	79.0	68.0	54.0	
Weight (kg)	day 0	80.2	13.4	61.1	100.0	81.8	NA	0.541
	day 42	80.1	13.9	61.8	103.7	80.5	NA	
Fat-free mass, FFM (kg)	day 0	49.6	4.7	42.0	57.8	48.8	47.6	0.601
	day 42	49.4	5.0	40.8	59.4	48.2	46.7	
Visceral fat area, VFA (cm^2)	day 0	121	34	72	183	129	83	0.894
	day 42	121	35	72	182	126	NA	
Percentage of body fat, PBF (%)	day 0	37.3	7.2	23.7	50.5	38.0	NA	0.999
	day 42	37.3	7.6	24.6	49.6	37.0	NA	
Body fat mass, BFM (kg)	day 0	30.7	10.3	14.8	50.5	30.7	20.7	0.941
	day 42	30.7	10.8	15.3	51.4	30.5	NA	
Skeletal muscle mass, SMM (kg)	day 0	27.3	2.8	23.1	32.5	26.8	NA	0.592
	day 42	27.2	3.0	22.2	33.3	26.3	NA	
Waist-to-hip ratio, WHR	day 0	0.96	0.07	0.85	1.08	0.95	1.05	0.845
	day 42	0.96	0.07	0.84	1.07	0.98	1.03	
Body mass index, BMI ($kg.m^{-2}$)	day 0	29.3	5.3	22.1	39.3	29.5	NA	0.583
	day 42	29.2	5.5	21.9	40.8	29.2	NA	
Neck size (cm)	day 0	38.2	3.5	33.5	45.3	38.6	NA	0.360
	day 42	38.1	3.7	32.7	46.1	38.2	34.7	
Waist circumference, WC (cm)	day 0	100	13	83	124	104	NA	0.931
	day 42	100	14	80	124	104	NA	
Hip circumference, HC (cm)	day 0	103	8	92	115	103	NA	0.670
	day 42	103	8	92	117	103	NA	
Intra-cellular water, ICW (l)	day 0	22.4	2.1	19.2	26.4	22.1	22.2	0.590
	day 42	22.4	2.3	18.5	27.1	21.7	21.1	
Extra-cellular water, ECW (l)	day 0	13.9	1.3	11.6	16.1	13.7	13.6	0.525
	day 42	13.8	1.4	11.5	16.3	13.6	13.2	
Total body water, TBW (l)	day 0	36.4	3.4	30.8	42.1	35.7	36.4	0.553
	day 42	36.2	3.6	30.0	43.4	35.3	34.2	
TBW/FFM (%)	day 0	73.4	0.2	72.8	73.6	73.4	73.3	0.312
	day 42	73.3	0.2	72.9	73.6	73.3	73.3	

Data are expressed as mean ±standard deviation. NA – non-available

Table 4 Pre-post changes in biochemical and somatic parameters

Parameters	Pre-post	Mean	±SD	Min	Max	Med	Mode	*P*-value
Total cholesterol, T-C (mmol.l^{-1})	day 0	5.4	1.0	3.5	7.0	5.4	NA	0.001
	day 42	5.6	0.9	3.9	7.4	5.7	NA	
High density lipoprotein, HDL (mmol.l^{-1})	day 0	1.7	0.3	1.1	2.5	1.7	NA	0.000
	day 42	1.9	0.4	1.4	3.0	1.9	2.2	
Low density lipoprotein, LDL (mmol.l^{-1})	day 0	2.8	0.7	1.7	4.3	2.7	NA	0.000
	day 42	3.0	0.7	1.9	4.6	2.9	2.8	
Low density lipoproteins 3–7 (mmol.l^{-1})	day 0	0.06	0.11	0.00	0.47	0.03	0.00	0.376
	day 42	0.08	0.16	0.00	0.57	0.00	0.00	
Mean LDL size (nm)	day 0	27.2	0.3	26.4	27.5	27.2	27.4	0.235
	day 42	27.1	0.4	26.1	27.5	27.2	27.4	
LDL/HDL	day 0	1.7	0.5	1.0	3.2	1.6	NA	0.000
	day 42	1.6	0.5	0.9	3.0	1.5	NA	
CVD risk factor, CVD-RF	day 0	2.3	0.7	1.3	4.1	2.1	NA	0.000
	day 42	2.0	0.7	1.0	3.8	1.8	NA	
Triglycerides, TG (mmol.l^{-1})	day 0	0.98	0.40	0.58	1.86	0.79	0.59	0.055
	day 42	1.16	0.58	0.54	3.01	0.97	0.54	
Glycemia, GLU (mmol.l^{-1})	day 0	4.8	0.6	4.0	6.2	4.8	4.8	0.036
	day 42	5.0	0.4	4.3	6.0	4.9	5.3	
hs-C-reactive protein, hs-CRP (mg.l^{-1})	day 0	1.6	1.0	0.0	2.6	0.9	NA	0.241
	day 42	1.7	1.5	0.8	3.3	1.1	NA	
Uric acid, UA (μmol.l^{-1})	day 0	289	78	177	453	293	NA	0.183
	day 42	269	74	147	438	263	NA	
Systolic blood pressure, SBP (mmHg)	day 0	121	13	103	149	120	110	0.861
	day 42	121	11	106	153	118	126	
Diastolic blood pressure, DBP (mmHg)	day 0	81	7	68	94	81	83	0.034
	day 42	84	9	72	97	86	95	
Aspartate aminotransferase, AST (μkat.l^{-1})	day 0	0.34	0.08	0.23	0.48	0.32	0.28	0.424
	day 42	0.35	0.08	0.25	0.53	0.32	0.31	
Alanine aminotransferase, ALT (μkat.l^{-1})	day 0	0.31	0.12	0.14	0.56	0.29	0.26	0.938
	day 42	0.32	0.15	0.16	0.68	0.28	0.25	
Gamma-glutamyl transferase, GGT (μkat.l^{-1})	day 0	0.37	0.21	0.19	1.02	0.33	0.19	0.266
	day 42	0.39	0.21	0.21	1.03	0.33	0.23	

Data are expressed as mean ±standard deviation. NA – non-available

body fat mass ($r = 0.401$), percentage of body fat ($r = 0.419$) and visceral fat area ($r = 0.327$), indirect dependence with body condition status ($r = -0.399$). Regarding biochemical parameters, we found an indirect linear relationship with T-C ($r = -0.372$) and LDL ($r = -0.389$).

In the case of fT3, we found a significant direct relationship with basal metabolic rate ($r = 0.347$), body weight ($r = 0.335$), waist circumference ($r = 0.396$), WHR ($r = 0.475$), visceral fat area ($r = 0.372$), fat-free mass ($r = 0.346$) and skeletal muscle mass ($r = 0.347$). In connection with biochemical parameters, we found a direct linear relationship with LDL ($r = 0.332$), LDL/HDL ratio ($r = 0.342$), CVD-RF ($r = 0.341$) and systolic blood pressure ($r = 0.370$).

In the case of fT4, in relation to anthropometric parameters, we did not find any significant correlation, in relation to biochemical parameters, a direct correlation was found with LDL subfractions 3–7 ($r = 0.380$) and indirect with the average size of LDL ($r = -0.378$) and systolic blood pressure ($r = -0.376$).

The primary aim of the study was to determine the effect of six-week consumption of full-fat yogurt made from sheep's milk from ewes fed with iodine-enriched feed on selected markers not only of thyroid function with an emphasis on the elimination of iodine insufficiency, but also on selected anthropometric parameters (especially in terms of the risk of developing or progressing overweight, or obesity), biochemical parameters (especially with regard to the lipid profile) and somatic parameters (risk of hypertension).

Yogurt is a dairy product that is a recognized and reliable, albeit variable, dietary source of iodine (Ovadia et al., 2018), but which, unlike iodized salt, does not have such a fundamental effect on the prevalence of hypertension (Jahreis et al., 2001; van der Reijden et al., 2017). Fortification of salt or other foods with iodine is necessary to meet the daily needs of the body (Charlton et al., 2016). However, due to the high intake of salt, especially through processed foods and semi-finished products, and the subsequent high incidence of hypertension, its consumption is limited based on various preventive programs (WHO, 2014), which creates a situation where solving one problem creates another problem. By reducing the amount of salt consumed, the intake of iodine is also reduced, which must then be taken from another food source. The results of our study indicate that the intake of full-fat sheep's milk yogurt contributed to the daily intake of iodine without apparent negative effects on indicators of thyroid function, which did not change significantly. At the same time, the results of the urine analysis indicate that, in the long term, the study participants have a sufficient/over-limit intake of iodine. Furthermore, we assume that if thyroid stores are insufficient due to a daily iodine intake of less than 50 µg, the iodine stores in the thyroid gland will be depleted (Gostas et al., 2020). This would mean that the thyroid gland would probably take in more iodine from food and less would be excreted in the urine, and thus the UIE values would be low. At the same time, it should be emphasized that if consumers have a long-term sufficient intake of iodine, and therefore also sufficient reserves, a short-term iodine deficit may not manifest at

Table 5 Correlation analysis of interrelationships between TSH, fT3, fT4 and other variables

Variables	TSH	fT3	fT4	Variables	TSH	fT3	fT4
	r				*r*		
Basal metabolic rate (kcal)	0.067	0.347*	-0.089	Total cholesterol (mmol.l^{-1})	-0.372*	0.289	0.237
Body condition status (points)	-0.399*	-0.148	-0.023	High density lipoprotein (mmol.l^{-1})	-0.044	-0.103	0.083
Weight (kg)	0.332*	0.335*	-0.04	Low density lipoprotein (mmol.l^{-1})	-0.389*	0.332*	0.286
Waist circumference (cm)	0.304	0.396*	-0.005	LDL 3–7 (mmol.l^{-1})	-0.251	0.245	0.380*
Hip circumference (cm)	0.384*	0.275	-0.021	Mean LDL size(nm)	0.292	-0.197	-0.378*
Neck circumference (cm)	0.387*	0.22	0.014	LDL/HDL (mmol.l^{-1})	-0.259	0.342*	0.212
Body mass index (kg.m^{-2})	0.404*	0.265	-0.023	CVD risk factor	-0.232	0.341*	0.145
Waist-to-hip ratio	0.179	0.475*	0.028	Triglycerides (mmol.l^{-1})	-0.016	0.297	-0.097
Body fat mass (kg)	0.401*	0.276	-0.011	Glycemia (mmol.l^{-1})	0.007	-0.008	0.085
Percentage of body fat (%)	0.419*	0.246	0.028	hs C-reactive protein (mg.l^{-1})	-0.155	0.133	-0.181
Visceral fat area (cm^2)	0.327*	0.372*	-0.028	Uric acid (µmol.l^{-1})	0.125	0.229	-0.041
Fat-free mass (kg)	0.067	0.346*	-0.088	Systolic blood pressure (mmHg)	0.133	0.370*	-0.376*
Skeletal muscle mass (kg)	0.054	0.347*	-0.064	Diastolic blood pressure (mmHg)	0.111	0.155	-0.315

Data are expressed as "*r*" in correlation analysis. * symbol indicates a significant relationship

all (Hetzel and Zimmermann, 1993; Rohner et al., 2014). The most sensitive marker of the functional state of the thyroid gland is TSH (Sheehan, 2016). However, its values can be influenced by many factors, such as gender, age, race, body weight, etc. (Brown et al., 2016; Chaker et al., 2016). Several authors have confirmed an increase in TSH values with increasing age, with results showing that TSH is related to age in a U-shape and its values are higher in women. It is therefore suggested to use different reference intervals for different age categories to avoid misdiagnosis of the disease in the elderly population (Hollowell et al., 2002; Atzmon et al., 2009). Subclinical thyroid disease includes subclinical hypothyroidism and subclinical hyperthyroidism. While the first mentioned state is defined by increased TSH values and normal free thyroxine values, the second state is defined by decreased TSH values with normal fT4 values (Biondi, 2012; Cooper and Biondi, 2012).

In our group, there were mostly older women with overweight or obesity. However, the results of the anthropometric parameters showed that the consumption of full-fat yogurt did not cause significant changes in body weight or any key and critical parameters of body composition. Other authors also investigated the effect of the consumption of full-fat dairy products on changes in body weight or adiposity compared to low-fat equivalents, while they did not find any significant differences or effects (Phillips et al., 2003; Noel et al., 2011; Bigornia et al., 2014; Dubois et al., 2016). Schwingshackl et al. (2016) found in their study that yogurt was the only dairy product whose higher consumption was inversely associated with reduced risk of obesity, changes in body weight or waist circumference. The researchers reported that this effect can be attributed to several components. High calcium intake can, for example, reduce lipogenesis and increase lipolysis through hormonal regulation (Zemel, 2005), but also affect the absorption of fatty acids from the digestive tract (Vaskonen, 2003). Conjugated linoleic acid can regulate adipogenesis and lipid metabolism (Noone et al., 2002). In addition, milk proteins are insulinotropic and promote satiety (Veldhorst et al., 2008). Milk and milk products are also important in the diet of older people because, in combination with physical activity, they can improve muscle mass and its functionality, thereby reducing the risk of sarcopenia (Geiker et al., 2020).

The consumption of full-fat dairy products, and therefore also yogurts, is associated with increased fat intake, which is associated with an increased risk of deterioration of the lipid profile and, consequently, an increased risk of cardiovascular diseases (Matsumoto et al., 2004; Dayimu et al., 2019; Khatana et al., 2020). The results of many studies over the past decades have pointed to the fact that a poor lipid profile is associated with an increased health risk and the progression of atherosclerosis. In particular, high values of T-C, LDL, TG and low values of HDL have been associated with these risks (Libby et al., 2019; Dayimu, 2019). Currently, it is being discussed whether an increase in LDL and HDL, and thus also in total cholesterol, or hyperlipoproteinemia and dyslipoproteinemia are also related to increased cardiovascular risk, as both types of lipoproteins (LDL and HDL) contain both atherogenic and non-atherogenic subfractions, which may or may not increase cardiovascular risk (Banach and Aronow, 2012; Otocka-Kmiecik, 2012). In view of current knowledge, the view on the lipid profile is changing, and it seems that the concentration of lipid components in the blood is no longer important, but their size, number and composition of individual LDL and HDL subfractions. The group of women in our study already had increased T-C values at the beginning before the start of the intervention, which increased significantly after six weeks of consumption; similarly, there was a significant increase in LDL and HDL values, even though their average values were still within the range of reference values. The TG values also increased, but it was not a significant change, and in this case too, the average value of the group was within the norm. It should be noted that despite the potential negative increase in T-C, LDL or triglycerides, we found a significant decrease in the LDL/HDL ratio and CVD-RF, which are indicators of cardiovascular risk. At the same time, the atherogenic subfractions of LDL 3–7 did not change significantly, which is especially positive from the point of view of full-fat yogurt consumption, and at the same time it is necessary to emphasize that there were no statistically significant changes even in the case of mean LDL size. Based on the average size of LDL particles, the investigated group of women had a non-atherogenic pre-post A phenotype.

HDL has long been considered a good lipoprotein, which resulted from its function and participation in the reverse transport of cholesterol from the peripheral parts of the body to the liver (Brites et al., 2017; Sirtori et al., 2019). Currently, however, increased HDL values should no longer be considered a positive and health-promoting condition (Sonmez, 2015; Rysz-Gorzynska, 2017; Kidawa, 2019). Studies have been conducted, the results of which indicate even the harmful effects of HDL in the body (Zanoni et al., 2016). Associations and potential positive/negative mechanisms of action of HDL subfractions in relation to cardiovascular diseases are still unclear and are the subject of current studies. Similarly, as in the case of LDL, HDL also shows heterogeneity and the existence of several subfractions with different biological activity. LDL and HDL subfractions differ in particle size, density and composition (Oravec et al., 2011; Li et al., 2016; Generoso

et al., 2019). Antiatherogenic properties are ensured by large subfractions of HDL 1–3 and LDL 1–2 (Otocka-Kmiecik, 2012; Muñiz et al., 2023). Small subfractions of HDL 8–10 and LDL 3–7 show a potential atherogenic effect (Otocka-Kmiecik, 2012; Hoogeveen et al., 2014; Martin et al., 2015; Ivanova et al., 2017; Sekimoto et al., 2021). In the case of LDL 3–7 subfractions, the risk of cardiovascular diseases increases 3–4 times. However, there are still many controversial and conflicting results for HDL (Madsen, 2017).

Consumption of low-fat products is generally recommended precisely because of the strong association of increased fat intake with cardiovascular health risks. The collective of authors Chiu et al. (2016) compared the effectiveness of a typical DASH diet and a modified high-fat, low-carbohydrate DASH diet on, among other things, the lipid profile. They found that the modified DASH reduced blood pressure, triglyceride concentration and increased the concentration of large LDL particles without affecting HDL. Drouin-Chartier et al. (2016) investigated the effect of dairy product consumption on cardiovascular disease risk factors. The authors concluded that the harmful effects of saturated fatty acids can be nullified when they are consumed as part of complex food matrices, such as cheeses, yogurts and other dairy foods (Drouin-Chartier et al., 2016). The results of similar studies also support our findings, which indicate that the consumption of full-fat sheep's yogurt not only contributes to the intake of iodine in the diet, but in terms of fat content does not cause health complications and deterioration of the lipid profile or other biochemical or anthropometric parameters.

4 Conclusions

Based on the results, we can conclude that the consumption of full-fat yogurt made from sheep's milk does not have a negative effect on the function of the thyroid gland due to insignificant changes in the levels of thyroid-stimulating hormone, free triiodothyronine and free thyroxine. Six-week consumption of sheep's yogurt contributed to the intake of an important element in human nutrition, but did not cause changes in the function of the thyroid gland, nor in the state of the hormones that produce or regulate its activity. Within the framework of the addressed issue, further extensive research is needed aimed at solving the issue of food iodization with minimal or no negative impact on the health of the consumer, but also a more detailed analysis of the risks of consuming full-fat dairy products in terms of fat intake and their impact on atherogenic and non-atherogenic subfractions of LDL and HDL with a focus on revealing real cardiovascular risks. Current knowledge is changing the view of experts on the lipid profile, especially on the concentration of LDL and HDL, while it seems that it is no longer their concentration in the blood that is important, but the size, number and composition of their subfractions. In conclusion, we can conclude that the six-week consumption of full-fat sheep's yogurt had no significant negative impact on either the lipid profile or other biochemical and anthropometric parameters.

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