The protein and fat quality of thigh muscles from Polish goose varieties

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ABSTRACT This study aimed to evaluate the nutritional value of thigh meat from 4 Polish geese varieties. Protein, fat, and cholesterol content, as well as amino acid and fatty acid profiles, were determined. Based on the percentage of amino acid in protein and fatty acids in meat lipids, the health lipid indices were calculated. The experimental material covered thigh muscles from 17-week-old Kartuska (**Ka**), Suwalska (**Su**), Lubelska (**Lu**), and Kielecka (**Ki**) geese reared in a semi-intensive system. Muscle protein content did not differ significantly between varieties. The protein content of the Ka, Su, Lu, and Ki goose meat was deemed high-value as it contained all the essential amino acids in the proportions consistent with standard protein values. The muscles of all the researched geese varieties were characterized by a high level of Lys, which indicates that this meat is a good source of it (AAS_{Lys} 240–280%). Current findings showed that polyunsaturated fatty acids (**PUFA**)/saturated fatty acids (**SFA**) and PUFA n-6/n-3 ratios in Ka, Su, Lu, and Ki muscles were found to be within the optimum values for human diets. No significant differences were observed in monounsaturated fatty acids, PUFA, and unsaturated fatty acids (**UFA**) between the analyzed muscles. The meat of Ka and Su contained significantly more lipids than Lu and Ki. A more beneficial amino acid profile was found in Ka meat due to a higher content of PUFA n-3 and the best n-6/n-3 ratio in comparison with other varieties. The muscles of the Ka variety also contained the least cholesterol. However, the Ki goose muscles stood out among other varieties with the least percentage of SFA, the highest share of docosahexaenoic acid (C 22:6 n-3), as well as the most beneficial value of the following indices: UFA/SFA, hypocholesterolemic fatty acid/hypercholesterolemic fatty acid ratio, and nutritive value index. The thigh muscles of Ka, Su, Lu, and Ki were characterized by an atherogenicity index that met the levels of recommended values (<1) in the diet of a human being, while the thrombogenicity index was slightly higher than the recommended value (<0.5).

Key words: goose meat, fatty acid profile, amino acid profile, thigh muscle, health index

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INTRODUCTION

Meat constitutes an essential ingredient of a human's diet and is a source of protein and fat. The quality of meat is influenced by many different factors, but its amino acid composition depends primarily on the species and the breed or variety within the species (Okruszek et al., 2013; Cui et al., 2015; Korish and Attia, 2019; Gumułka and Połtowicz, 2020).

In the case of fat as a component of human diet, its quality is more important than quantity. The type of dietary fat in the diet of humans is an essential determinant of plasma lipid concentration. Individual acids affect the synthesis and metabolism of blood lipoproteins in various ways. The more the monounsaturated fatty acids (**MUFA**) and polyunsaturated fatty acids (**PUFA**) in the diet, the lower the risk of cardiovascular heart disease because they favor a higher high-density lipoprotein cholesterol content and/or a lower low-density lipoprotein cholesterol content in the blood. In turn, a higher saturated fatty acid (**SFA**) proportion in the diet (except for C18:0 acid) has the opposite effect and thus increases the atherogenicity of diet. All SFAs have a thrombogenic impact—they increase the tendency of platelets to aggregate, which can form blood clots. Measures of the extent to which a given fat containing diet component contributes to an increase in the incidence of risk of cardiovascular disease include the atherogenicity (**IA**) and thrombogenicity (**IT**)

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indices. IA is the ratio of the total, atherosclerotic, SFA to the antiatherogenic, unsaturated acids. IT is defined as the relationship between the pro-thrombogenic (saturated) and the antithrombogenic fatty acids. The lower their value, the lower the likelihood of contributing to atherosclerosis and blood clot formation (Ulbricht and Southgate, 1991). Higher PUFA content makes the product better in terms of nutritional value; however, it is more susceptible to oxidative processes (Attia et al., 2017). The more double bonds are present in the carbon chain, the higher the oxidation of the fat, which progresses over time. It results in the deterioration of taste and aroma characteristics, a loss of nutritional value, and the shortening of the shelf life of products. The peroxidizability index (**PI**) is a measure of the susceptibility of lipids contained in a product to the oxidation process.

Consumption of processed foods rich in saturated fats (the so-called western diet), observed for years in the general population, not only increases the risk of cardiovascular disease but also contributes to dysbiosis of the gastrointestinal microbiome (its composition and function), which results in a number of metabolic disorders, including obesity (Riaz Rajoka et al., 2017; Zinöcker and Lindseth, 2018; Wytrychowski et al., 2020). The number of people suffering from lifestyle diseases in well-developed countries in the past few years has dramatically increased; thus, the need for knowledge on the nutritional properties of consumed food products is of crucial importance.

There is little information in academic publications on the nutritional value of meat of Polish native goose varieties. Therefore, the purpose of this study was to determine and compare the content of fat, protein, cholesterol, and the fatty acid and amino acid profiles of goose thigh muscles of the local varieties—Kartuska (**Ka**), Suwalska (**Su**), Lubelska (**Lu**), and Kielecka (**Ki**). On the fatty acid profile basis, the health lipid indices IA, IT, hypocholesterolemic fatty acids/hypercholesterolemic fatty acid ratio (**h/H**), desirable fatty acids (**DFA**), nutritive value index (**NVI**), and PI were calculated. Based on the content of exogenous amino acids, determining the protein nutritional value, the amino acid score (**AAS**) and essential amino acid index (**EAAI**) were calculated.

MATERIALS AND METHODS

Animals, Diets, and Experimental Procedure

The study involved 17-week-old female geese of 4 indigenous breeds: Ka, Su (native to northern Poland), Lu, and Ki (native to southern Poland). The Ka, Su, Lu, and Ki geese are internationally unique native populations of birds. They are characterized by good health and resistance to adverse climatic conditions, and the proper conversion of farm-produced feeds. They use open range so that they can handle the rigors of outdoor production. Geese kept on grassland (pastures) and fed various feeds fulfill the requirements of an ecological product (Wężyk et al., 2003). During the testing period, the geese were reared up to 6 wk of age in a brooder house (lighttight), on deep litter, with no access to the enclosure. For the first 3 d of geese rearing, 24-hour lighting was used (4–5 W/m^2) and temperature was kept at 25°C to 26°C (under the brooder 4°C–5°C higher). From the third to the sixth week, the geese were kept under illumination for 14 to 16 h a day (2–3 W/m^2) and temperature was gradually lowered from 20°C to 18°C. The relative air humidity was 60 to 70%. From the 7th to the 17th wk of age geese were kept outside, in partially roofed pens, covered with straw (stocking density ≈ 0.75–0.85/m^2). Each flock was reared separately. Geese from all flocks were fed ad libitum on the same complete feed in crumbled form (Table 1). Birds were then subjected to feed withdrawal for 12 h and then slaughtered according to the relevant regulations applied in the Polish poultry industry. The average body weights at slaughter of Ka, Su, Lu, and Ki geese were 4,443, 4,455, 4,123, and 4,152 g, respectively. After slaughter, the eviscerated carcasses were stored on-site in refrigerated conditions (0°C–4°C). The carcasses were jointed after a 24-hour chilling period. The Ka, Su, Lu, and Ki geese average carcass weights were 2,738, 2,722, 2,544, and 2,519 g, respectively. Thigh muscle percentage in carcasses of Ka, Lu, and Ki was similar (15.4, 15.7, and 15.5%, respectively) and lower in Su geese (14.6%). Portions of thigh muscles (18 samples from each genotype; total 72 samples), without skin and subcutaneous fat, cut out from the right side of the carcass were vacuum-packed and stored at −80°C until further chromatographic analysis. The total fat and protein content in the thigh muscles was determined approximately 48 h post slaughter.

Table 1. Nutrient contents of feed mixtures.

Item	Age of geese	
	1–6 wk	7–17 wk
Chemical composition (%/kg of all-mash)		
Crude protein	19.00	17.00
Crude fat	4.00	3.00
Ash	5.50	6.00
Crude fiber	3.50	5.00
Lys	1.05	0.820
Met	0.49	0.46
Calcium	0.85	0.86
Total phosphorus	0.70	0.80
Vitamin A (IU/kg)	15.000	14.000
Vitamin D_3 (IU/kg)	3.500	2.000
Vitamin E (mg/kg)	60	50
Metabolizable energy (MJ/kg of all-mash)	12	11.3
Fatty acid (% of total fatty acids)		
C16:0	12.20	11.80
C16:1 cis-9	0.37	0.31
C18:0	5.60	4.95
C18:1 cis-9	29.40	32.20
C18:2 n-6	37.60	34.40
C18:3 n-3	2.58	4.26
C20:5 n-3	0.62	0.70
C22:6 n-3	0.54	0.62

Chemical Analyses

Protein and Fat Content The analysis of protein was carried out using the Kjeldahl method (AOAC, 1995, Method 976.05), where the content of total nitrogen was multiplied by a 6.25 coefficient. Total lipid contents of thigh muscles were analyzed and quantified according to the Soxhlet procedure with the Soxtec System HT4 1045 (Tecator, Höganäs, Sweden) (AOAC, 1995, Method 960.39).

Amino Acid Analysis by HPLC The muscles (n = 18 for each genotype) were thawed at 4°C, trimmed of visible fat or connective tissue, and chopped. The sample (around 5.0 g) was homogenized in 20 mL of deionized water with a homogenizer T 25 model (ULTRA-TURRAX, Ika Corp., Staufen, Germany). Muscle homogenates were placed in 0.3 mL glass hydrolysis vials and evaporated under nitrogen (purity = 5.0) to dryness in a SpeedVac evaporator. Two milliliters of 6M HCl containing 0.02% phenol was placed at the bottom of the lower part, and the vessel was assembled, evaporated, and flushed with nitrogen. The vacuum tap was closed, and the vessel with vials was placed in an electric oven at 110°C for 24 h (Hirs et al., 1954; Blackburn, 1978; Petracci and Baéza, 2011). Cystine was determined as cysteic acid by performic acid oxidation before its digestion using 6M HCl (Moore, 1963). Tryptophan was established after the alkaline hydrolysis of each sample (Landry et al., 1992). Chromatographic analysis was performed according to Haraf et al. (2018).

Calculation of AAS and EAAI Indices The AAS was calculated by using the reference scoring pattern of the adult (Ile: 3, Leu: 6.1, Lys: 4.8, Met + Cys: 2.3, Phe + Tyr: 4.1, Thr: 2.5, Trp: 0.66, Val: 4.0, and His: 1.6 expressed in g/100 g of protein) (FAO, 2013) according to the following equation (WHO/FAO, 2002):

$$\text{AAS} = \frac{\text{g of amino acid in 100 g of a test protein}}{\text{g of amino acid in 100 g of requirement pattern}} \times 100\ [\%]$$

The amino acid with the lowest percentage is called the limiting amino acid. The EAAI is the geometric mean of the ratio of the essential amino acids (**EAA**) in the protein sample to their respective amounts in the protein pattern (Oser, 1959), as in the following equation:

$$\text{EAAI} = 100 \times \sqrt[n]{\frac{\text{Lys}_p}{\text{Lys}_s} \times \frac{\text{Trp}_p}{\text{Trp}_s} \times \ldots \times \frac{\text{Val}_p}{\text{Val}_s}}$$

where the subscript "p" refers to the protein sample, "s" to the standard protein, and "n" to the number of amino acids (counting pairs of Met + Cys and Phe + Tyr as one).

Fatty Acids and Cholesterol Analyses by Gas Chromatography Preliminarily ground thigh muscles (without skin) were homogenized in a T 25 homogenizer (ULTRA-TURRAX, Ika Corp.). Lipid extraction for fatty acids and cholesterol content determination was carried out according to the procedure described by Folch et al. (1957). For determining the fatty acid composition, lipid samples (n = 18 for each genotype) were converted to their corresponding methyl esters by the American Oil Chemists' Society official method Ce 2-66 (AOCS, 1997). The fatty acid methyl esters were quantified by the gas chromatography method using a fused silica capillary column—100 m × 0.25 mm × 0.20 μm film thickness—(HP-88 J&W Scientific series, Agilent Technologies Inc., Santa Clara, CA) and a flame-ionization detector (**FID**) in a gas chromatograph (6890 A series, Agilent Technologies Inc.) at an injection volume of 1.0 μL and split ratio of 1:50, respectively. Helium was used as the carrier gas at a head pressure of 2.0 mL/min constant flow. Air, hydrogen, and helium makeup gas flow rates by the FID detector were 450, 40, and 30 mL/min, respectively. The detector and injector temperatures were 280°C and 250°C, respectively. The initial column temperature of 120°C was maintained for 1 min, raised to 175°C at the rate of 10°C/min and held for 10 min. Then, it was increased to 210°C at 5°C/min, held for 5 min, and finally scaled up to 230°C at a rate of 5°C/min, and maintained for 5 min. Fatty acid peaks were identified by a comparison of retention times to those of a mixture of external standard methyl esters (Supelco 37 FAME Mix C4–C24 Component, Sigma-Aldrich, St. Louis, MI). The fatty acids were calculated as the percentage of a sum of fatty acids with the ChemStation program (Agilent Technologies Inc.).

For cholesterol analysis, an HP-5 capillary column (30 mm × 0.32 mm × 0.25 μm) (Agilent Technologies Inc.) and an FID were used. Makeup gas flow rates by the FID were 30 mL/min (H_2) and 300 mL/min (air). The carrier gas (nitrogen) flow rate was 3 mL/min. Detector and injector temperatures were chosen as 300°C. The column temperature was 290°C (15 min) initially and then increased to 320°C at 15°C/min. Then, it was decreased to 290°C (15°C/min) and then held for 2 min. The peaks of cholesterol were identified by comparing retention times to the standard (5α-cholestane).

Calculation of Health Lipid Indices

Based on the fatty acid profile in the thigh muscle lipids, the following health lipid indices were calculated:

- DFA = Σ unsaturated fatty acids (**UFA**) + C18:0 n-6 (Díaz et al., 2002);
- P/S—PUFA/SFA ratio = (C18:2 n-6 + C18:3 n-3)/(C12:0 + C14:0 + C16:0) (HMSO, 1994);
- IA = [C12:0 +(4 × C14:0) + C16:0]/[Σ MUFA + Σ PUFAn-6 + Σ PUFAn-3] (Ulbricht and Southgate, 1991);
- IT = (C14:0 + C16:0 + C18:0)/(0.5 × MUFA) + (0.5 × PUFA n-6) + (3 × PUFA n-3) + (PUFA n-3/PUFA n-6) (Ulbricht and Southgate, 1991);
- h/H = [(Σ of C18:1 n-9, C18:1 n-7, C18:2 n-6, C18:3 n-6, C18:3 n-3, C20:3 n-6, C20:4 n-6, C20:5 n-3,

C22:4 n-6, C22:5 n-3, C22:6 n-3)/(Σ C14:0 + C16:0)] (Santos-Silva et al., 2002);
- PI = (% monoenoic acid×0.025) + (% dienoic acid×1) + (% trienoic acid×2) + (% tetraenoic acid×4) + (% pentaenoic acid×6) + (% hexaenoic acid×8) (Erickson, 1992);
- NVI = [(C18:0 + C18:1 n-9)/C16:0] (Sari et al., 2015).

Statistical Analysis

Significant difference levels between the genotypes of geese were determined by one-way ANOVA analysis, according to the following linear model: $Yij = \mu + Aj + eij$, where Yij = value of trait (the dependent variable); μ = overall mean; Aj = the genotype effect; and eij = random observation error. The statistical significance of differences between the mean groups was estimated using the Duncan multiple test at a significance level of $P \leq 0.05$ using the Statistica 13.1 program (StatSoft, Tulsa, OK). A single bird was the experimental unit in the statistical analysis.

RESULTS AND DISCUSSION

Protein Content and Amino Acid Profile

The amino acid profiles and protein content are shown in Table 2. Total protein content in the thigh muscles of the analyzed geese did not differ statistically and ranged from 21.14% (Ka) to 21.37% (Ki). Similar protein content was found in the thigh muscles of the other Polish geese of native varieties such as Rypinska (21.17%), Garbonosa (21.36%) (Okruszek et al., 2013), and Zatorska (20.91%) (Gumułka and Połtowicz, 2020), as well as for local Turkish goose varieties (21.21–22.79%) (Boz et al., 2019). A comparable protein level (21.07%) was determined also in the thigh muscles of White Kołuda geese which is the basic commercial cross for geese meat production in Poland. They are fattened with oats and therefore known in European markets as "Polish oat geese" (Gumułka and Połtowicz, 2020). Cartoni Mancinelli et al. (2019) reported lower protein percentages in the drumstick muscles of Romagnola geese (18.88–18.20%).

The protein amino acid profile in the examined muscles varied depending on the genotype of the birds. Northern goose muscle proteins (Ka and Su) contained significantly more EAA (Σ EAA), including Leu, Phe, Tyr, and Val than southern goose muscles (Table 2). Protein in the thigh muscles of Ka and Su also had a higher content of Asp, Pro, and Ser. Northern goose muscle proteins (Ki and Lu) contained more Glu, Arg, and Gly, and among the EAA, Lys. From among the genotypes studied, Ka goose muscles were characterized by the highest content of EAA (Σ EAA) and the highest EAAI (Table 3). There were no statistical differences in Ile, Cys, and His percentages in the analyzed goose muscles. The amino acid profile in the thigh muscles of the studied geese was consistent with the results of studies of other Polish varieties of Rypinska and Garbonosa geese (Okruszek et al., 2013). The percentage of

Table 2. Amino acid composition (g/100 g of protein) and total protein content of thigh muscle from 17-week-old geese.

	Genotype of goose							
	Ka		Su		Lu		Ki	
	n = 18		n = 18		n = 18		n = 18	
Amino acid	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Total protein (%)	21.14	0.27	21.36	0.34	21.30	0.16	21.37	0.29
Nonessential amino acid								
Glu	15.17^{b}	0.04	14.55^{b}	0.04	16.62^{a}	0.06	17.01^{a}	0.06
Asp	7.89^{a}	0.07	7.81^{a}	0.20	6.74^{b}	0.20	6.48^{c}	0.10
Arg	9.69^{b}	0.09	9.50^{b}	0.09	11.37^{a}	0.10	6.35^{c}	0.11
Pro	4.49^{a}	0.04	4.36^{a}	0.07	3.42^{b}	0.05	2.95^{c}	0.13
Ala	4.81^{c}	0.08	5.75^{b}	0.09	5.48^{b}	0.10	6.35^{a}	0.11
Ser	4.37^{a}	0.04	4.18^{a}	0.01	3.43^{b}	0.05	3.22^{b}	0.04
Gly	3.00^{b}	0.01	3.17^{a,b}	0.03	3.58^{a}	0.02	3.42^{a}	0.03
EAA								
Ile	3.65	0.08	4.00	0.06	3.69	0.05	3.71	0.02
Leu	10.20^{a}	0.10	10.45^{a}	0.10	8.25^{b}	0.25	9.31^{c}	0.29
Lys	12.50^{c}	0.05	11.53^{b}	0.06	13.13^{a}	0.11	13.44^{a}	0.23
Met	3.00^{a,b}	0.08	3.16^{a,b}	0.06	2.96^{b}	0.08	3.20^{a}	0.06
Cys	1.38	0.05	1.43	0.03	1.45	0.02	1.44	0.09
Phe	5.94^{a}	0.08	5.89^{a}	0.09	5.30^{b}	0.05	5.05^{b}	0.06
Tyr	3.46^{a}	0.03	3.36^{a}	0.04	2.92^{b}	0.04	2.97^{b}	0.02
Thr	4.85^{a}	0.10	4.26^{b}	0.07	4.15^{b}	0.08	3.52^{c}	0.08
Trp	1.21^{a}	0.02	1.12^{b}	0.06	1.05^{b}	0.06	1.15^{b}	0.04
Val	6.19^{a}	0.08	5.77^{b}	0.08	4.96^{c}	0.08	4.76^{c}	0.06
His	3.25	0.04	3.41	0.03	3.90	0.02	3.87	0.09
Σ EAA	55.63^{a}	0.11	54.38^{b}	0.31	51.76^{c}	0.27	52.42^{c}	0.23

$^{a–c}$Means with different letters in the same row differ at $P \leq 0.05$.

Abbreviations: EAA, essential amino acid; Lu, Lubelska goose; Ka, Kartuska goose; Ki, Kielecka goose; Su, Suwalska goose.

Table 3. AAS and EAAI of essential amino acids and His from thigh muscle protein.

Amino acid	Pattern protein; FAO (2013) (g/100 g of protein)	Genotype of goose			
		Ka n = 18	Su n = 18	Lu n = 18	Ki n = 18
		AAS (%)			
Ile	3.00	122	133	123	124
Leu	6.10	167	171	135	153
Lys	4.80	260	240	274	280
Met + Cys	2.30	190	137	129	139
Phe + Tyr	4.10	229	144	129	123
Thr	2.50	194	170	166	141
Trp	0.66	183	170	159	174
Val	4.00	155	144	124	119
His	1.60	203	213	244	242
		EAAI			
		185	182	173	174

Abbreviations: AAS, amino acid score; EAAI, essential amino acid index.

EAA (after conversion from mg/g dry matter) for the protein of goose broilers thigh muscles of the Zatorska and Polish oat goose White Koluda was lower than in the tested Ka, Su, Lu, and Ki goose muscles (41.85 and 42.99%, respectively), which is due to the lower content of amino acids such as Ile, Leu, Met, Phe, Tyr, and Thr (Gumułka and Połtowicz, 2020). Thigh muscles were also characterized by lower EAA (35.63–37.11%) as

Table 4. Total fat content, fatty acid profile, and lipid indices of thigh muscle from 17-week-old geese.

Fatty acid (% of the total fatty acid)	Genotype of goose							
	Ka		Su		Lu		Ki	
	n = 18		n = 18		n = 18		n = 18	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Total fat (%)	4.02^{a}	0.21	3.99^{a}	0.43	3.01^{b}	0.21	2.78^{b}	0.38
C12:0	0.117	0.01	0.152	0.02	0.118	0.01	0.140	0.02
C14:0	0.65	0.05	0.69	0.07	0.59	0.06	0.54	0.08
C16:0	21.35^{a}	0.96	20.99^{a}	1.18	19.65^{b}	0.95	17.57^{c}	0.52
C18:0	8.62^{a,b}	0.76	8.07^{b}	0.80	9.38^{a}	0.77	9.33^{a,b}	0.56
C14:1 cis-9	0.19^{b}	0.02	0.19^{b}	0.02	0.43^{a}	0.05	0.30^{b}	0.02
C 6:1 cis-9	2.83^{b}	0.26	3.35^{a}	0.37	2.57^{b}	0.26	2.39^{b}	0.12
C18:1 cis-9	42.90^{a}	3.41	39.46^{b}	3.78	40.61^{a,b}	2.86	41.89^{a,b}	1.61
C18:1 trans-11	0.34	0.03	0.44	0.04	0.40	0.03	0.38	0.04
C20:1 cis-9	0.41^{b}	0.03	0.24^{c}	0.01	0.33^{b,c}	0.03	0.55^{a}	0.05
C18:2 n-6	13.84^{b}	0.91	13.44^{b}	1.48	15.18^{a}	0.93	13.56^{b}	0.96
α C18:3 n-3	1.49^{a}	0.15	1.33^{a,b}	0.12	1.08^{b}	0.10	0.69^{c}	0.05
C20:4 n-6	3.75^{b}	0.30	4.74^{a,b}	0.39	4.22^{a,b}	0.45	5.15^{a}	0.49
C20:5 n-3 EPA	0.87^{a}	0.02	0.62^{b}	0.05	0.49^{b}	0.05	0.92^{a}	0.05
C22:4 n-6	0.75	0.06	0.92	0.09	0.89	0.06	0.88	0.07
C22:6 n-3 DHA	0.42^{b}	0.03	0.36^{b}	0.02	0.41^{b}	0.04	0.57^{a}	0.04
Σ SFA	30.74^{a}	0.62	29.90^{a}	0.69	29.73^{a}	0.77	27.57^{b}	0.12
Σ MUFA	46.66	3.67	43.68	3.30	44.34	2.79	45.51	1.63
Σ PUFA	21.12	1.74	21.41	2.13	22.27	1.69	21.76	2.13
Σ UFA	67.77	2.55	65.09	3.38	66.61	1.25	67.27	1.19
Σ PUFA/Σ SFA	0.66	0.05	0.70	0.02	0.74	0.05	0.76	0.10
Σ UFA/Σ SFA	2.19^{a}	0.07	2.17^{a}	0.08	2.23^{a}	0.002	2.41^{b}	0.05
Σ n-6	18.34	1.58	19.1	2.31	20.29	1.24	19.59	2.14
Σ n-3	2.78^{a}	0.25	2.31^{b}	0.20	2.00^{c}	0.28	2.18^{b,c}	0.21
Σ n-6/Σ n-3	6.62^{b}	0.51	8.35^{a,b}	0.79	10.93^{a}	1.17	8.97^{a,b}	0.53
P/S	0.694^{b}	0.02	0.679^{b}	0.02	0.801^{a}	0.03	0.782^{a}	0.03
DFA	76.40^{a,b}	0.50	73.16^{b}	1.07	75.99^{a,b}	0.32	76.60^{a}	0.33
IA	0.360^{a}	0.02	0.373^{a}	0.02	0.335^{a,b}	0.004	0.299^{b}	0.008
IT	0.80	0.02	0.81	0.03	0.80	0.01	0.75	0.02
h/H ratio	2.88^{b,c}	0.06	2.80^{c}	0.10	3.09^{b}	0.04	3.47^{a}	0.07
PI	44.53	1.44	46.45	1.71	45.13	1.56	50.26	3.00
NVI	2.42^{b,c}	0.05	2.28^{c}	0.09	2.55^{b,c}	0.04	2.92^{a}	0.05
Cholesterol (mg/100 g of muscle)	57.88^{b}	2.17	70.30^{a}	4.07	65.11^{a}	3.24	72.31^{a}	2.36

$^{a–c}$Means with different letters in the same row differ at $P \leq 0.05$.

Abbreviations: DFA, desirable fatty acids; DHA, docosahexaenoic acid; EAA, essential amino acid; EPA, eicosapentaenoic acid; h/H, hypocholesterolemic fatty acid/hypercholesterolemic fatty acid ratio; IA, index of atherogenicity; IT, index of thrombogenicity; Lu, Lubelska goose; Ka, Kartuska goose; Ki, Kielecka goose; MUFA, monounsaturated fatty acids; NVI, nutritive value index; PI, peroxidizability index; P/S, polyunsaturated/saturated fatty acid ratio according to HMSO (1994); PUFA, polyunsaturated fatty acids; SFA, saturated fatty acids; Su, Suwalska goose; UFA, unsaturated fatty acids.

well as Leu (6.10–6.72%) and Phe (3.09–3.43%) in 70-day-old Yangzhou goose and its crossbreeds (Cui et al., 2015). Goose meat Ka, Su, Lu, and Ki contained more Lys compared to the Yangzhou variety, and its crossbreeds (8.04–8.84%) (Cui et al., 2015).

Fat Content and Fatty Acid Lipid Profile

The lipid fatty acid profile and total muscle fat content are shown in Table 4. The origin of the goose influenced the total muscle fat content. Thigh muscles of geese varieties from northern Poland (Ka and Su) contained more fat (4.02 and 3.99%) than the southern varieties (Lu and Ki) (3.01 and 2.78%). This difference did not affect the fatty acid profile, as no significant correlation was found between the content of individual fatty acids and the fat content in muscle. Fat content similar to Ka and Su geese was also found in Rypinska goose from northern Poland (3.9%) (Okruszek et al., 2013) and 16-week-old female Eskildsen Schwer geese (3.66%) (Uhlířová et al., 2018). In contrast, Garbonosa goose muscles (from southern Poland) contained a similar amount of fat (2.84%) (Okruszek et al., 2013) as the southern varieties studied. In the Gumułka and Połtowicz (2020) study, the thigh muscles of Zatorska and Polish oat goose broilers contained 3.35 and 3.15% of fat, respectively. More fat than in the muscles of the studied varieties was determined in intensively raised 160-day-old Romagnola geese (4.93%) (Cartoni Mancinelli et al., 2019) and in 28-week-old White Turkish geese (5.3%) (Boz et al., 2019).

The number of identified fatty acids in the muscles of the tested genotypes was 98.52% for Ka, 94.99% for Su, 96.34% for Lu, and 94.84% for Ki. The remaining fatty acids were not identified. Leading representatives of SFA, MUFA, and PUFA in the muscles tested were C16:0, C18:1 cis-9, and C18:2 n-6, respectively. These results are consistent with those obtained previously by Okruszek (2011) for Polish local geese and by Gumułka et al. (2006) and Gumułka and Połtowicz (2020) for Zatorska and White Kołuda geese. The C12:0 and C14:0 acids are recognized as the most atherogenic agents, whereas C18:0 is also considered to be thrombogenic but neutral concerning atherogenicity. MUFA and PUFA have a positive influence on the blood lipid profile (Ulbricht and Southgate, 1991; Kien et al., 2014; Mensink, 2016; Attia et al., 2017). PUFA, especially n-3, are more effective than MUFA in lowering low-density lipoprotein and the total/high-density lipoprotein cholesterol ratio. In this study, no statistically significant differences were observed in the percentage of MUFA, PUFA, and UFA in muscle lipids of the geese tested. In turn, Ki goose muscle lipids showed the lowest content of SFA, including less C16:0 than the other genotypes ($P \leq 0.05$), which is conducive to preventing cardiovascular disease. Ki goose muscle lipids were also characterized by the highest content of nutritionally valuable, polyunsaturated long-chain n-3 docosahexaenoic acid (**DHA**) ($P \leq 0.05$).

Health lipid indices were calculated based on the fatty acid profile of thigh muscles from geese of native varieties. The value of the classical ratio of PUFA/SFA in a diet for the prevention of ischemic heart disease and cancer should be higher than 0.45 (Mapiye et al., 2011). In our research, muscle lipids of the genotypes studied were characterized by a favorable value of this index at a level of 0.66 to 0.76 and did not differ significantly. Significant differences arose in the case of the P/S index. This is the ratio of the sum of linoleic and linolenic acids (precursors from which the human body can produce the remaining n-3 and n-6 PUFA) to the amount of the most harmful health acids: C12:0, C14:0, and C16:0. The P/S index value for the analyzed muscles ranged from 0.694 to 0.801 and was more favorable for the muscles of southern geese (Lu and Ki). Compared to the other geese tested, Ki goose muscles also had a significantly higher UFA/SFA ratio ($P < 0.05$).

The n-3 PUFAs compete with the n-6 PUFAs for the same conversion enzymes, which is why the amount of n-6 acids ingested in the diet directly affects the conversion of n-3 α C 18:3 tissues to eicosapentaenoic acid and disease protecting DHA. Studies show that the biological availability and activity of n-6 PUFAs in the diet are inversely proportional to the amount of n-3 acids in tissues (Attia et al., 2017). Elevated intakes of PUFA n-6 are associated with an increase in all inflammatory diseases, for example, cardiovascular disease, diabetes, rheumatoid arthritis, asthma, cancer, etc. (Bhardwaj et al., 2016). As mentioned earlier, the n-3 PUFA content or n-6/n-3 value in the diet must be balanced appropriately, because this reduces the risk of many diseases (WHO/FAO, 2003; FAO/WHO, 2008). According to the latest academic updates in literature, the lower the n-6/n-3 ratio the better. A lower value of the ratio is more desirable in reducing the risk of many chronic diseases. The optimal ratio may vary with the disease under consideration, but generally, the closer to 1:1 the better (Bhardwaj et al., 2016). The n-6/n-3 ratios in the muscles of all analyzed goose muscles were higher than recommended, but at the same time, they were lower than in the so-called contemporary western diet, which is even 16.7:1 (Simopoulos, 2003, 2008). Ka muscle lipids contained the most n-3 acids, including α C18:3 n-3, and had the most favorable n-6/n-3 ratio among the genotypes tested ($P \leq 0.05$). The least beneficial n-6/n-3 was found in Lu goose thigh muscles (10.93).

Goose thigh lipids Ka, Su, Lu, and Ki had a similar percentage of C16:0, C16:1, and C18:0 acids, a lower C18:1 acid and higher C14:0 and C20:4 compared to lipids of thigh muscles of 17-week-old and 10-week-old White Kołuda goose and Zatorska goose (Gumułka et al., 2006; Gumułka and Połtowicz, 2020). The content of MUFA in the muscle lipids of tested geese was lower, and the PUFA content was higher than the data obtained by Gumułka et al. (2006), for 17-week-old White Kołuda W31 and Zatorska geese. The 10-week-old White Kołuda geese meat also had a higher content of MUFA (49.07%) (Gumułka and Połtowicz, 2020).

In turn, compared to the results of the Biesiada-Drzazga (2006) study, lipids of the analyzed geese muscles contained less UFA (by ca. 6%) and MUFA (by ca. 15%) but more PUFA (by ca. 9%) than muscles of the intensively reared 10-week-old White Kołuda W31 broilers, mentioned earlier. The differences arose due to the lower quantity of C18:1 by ca. 15% and higher C18:2 n-6 by ca. 4% and C20:4 n-6 by ca. 3 to 4% in the muscles of all analyzed genotypes, compared to White Kołuda geese broilers. Boz et al. (2019) found a higher content of MUFA (50.13%) and less PUFA (18.07%) including n-3 (0.34%) and n-6 (17.58%) in the thigh muscles of 28-week-old multicolored Turkish goose varieties compared to the muscle lipid profiles of Ka, Su, Lu, and Ki. These differences resulted from a greater amount of C18:1 cis 9 and a smaller amount of C18:3 n-3 and eicosapentaenoic acid and DHA in Turkish goose muscles. The thigh meat of females of native Czech goose and crossbred Novohradska goose in 8-week-olds were characterized by a higher percentage of Σ PUFA (27.51 and 25.04%, respectively) and total n-6 (24.99 and 22.53%, respectively), which resulted from a higher content of C18:2 n-6 (16.84 and 19.30%, respectively) and DHA (0.8 and 0.82%, respectively) (Uhlířová et al., 2019).

As reported by Yanovych et al. (2013), thigh muscle lipids of Arzamas geese aged 60 d (supplemented with soybean oil) contained similar amounts of SFA (29.31%) to Ka, Su, and Lu. In contrast, compared to all genotypes tested in this publication, it demonstrated much more PUFA (41.97%), including C18:3 n-3 (5.59%), and thus more n-3 (8.09%).

The n-6/n-3 values for Ki and Su geese were similar to those obtained for other Polish native geese: Rypinska (8.52–8.59) and Garbonosa (8.6–8.93) (Okruszek, 2011, 2012). As reported by Uhlířová et al. (2019), the thigh muscles of Novohradska and Czech geese at 8 wk were characterized by values of n-6/n-3 similar to Su, Lu, and Ki. Lower n-6/n-3 ratios were observed in the muscles of 14-week-old Turkish geese raised with 4 different fattening systems (0.55–0.56) (Sari et al., 2015), 60-day-old Arzamas geese supplemented with fish (1.07) and soybean oil (3.89) (Yanovych et al., 2013), and Romagnola geese reared in a free-range system under a vineyard (3.06) (Cartoni Mancinelli et al., 2019).

The fatty acid composition of the human diet can promote or protect against the development of coronary heart disease. The propensity of the dietary ingredient to influencing the incidence of coronary heart disease can be measured by IA and IT. The recommended value of IA in the human diet is below 1.0, and IT is below 0.5 (Fernandes et al., 2014; Wołoszyn et al., 2020). The IA value for goose meat Ka, Su, Lu, and Ki was within the recommended range (0.299–0.373), while the IT rate was slightly higher and ranged from 0.75 to 0.81. The examined goose muscles did not differ in terms of the IT value, while the most favorable, due to the smallest IA value and highest NVI, were in the Ki geese. The fatty acid profile of these geese muscles was also characterized by the most beneficial hypercholesterolemic index (h/H). Boz et al. (2019) found similar IT and DFA index values in the thigh muscles of 28-week-old female Turkish geese. The meat of these geese was also characterized by IA and h/H indices similar to Ka and Su, but less favorable compared to Ki goose muscles. In turn, as reported by Sari et al. (2015), the leg muscles of 14-week-old native Turkish geese raised with 4 different fattening systems were characterized by slightly lower values of NVI (2.09–2.24), and lower IA (0.19–0.22) and IT (0.56–0.6). The oxidative stability of fat can be estimated by calculating the PI—the lower the value, the less susceptible to oxidation of lipids of the product. For goose muscles of Ka, Su, Lu, and Ki, the index was in the range of 44.53 to 50.26, and these values did not differ significantly. Higher PI was reported by Uhlířová et al. (2019), for 8-week-old Czech and Novohradska geese (53.19–50.96).

It is known that people with hypercholesterolemia should limit cholesterol in their diet. The cholesterol content in the examined muscles ranged from 57.88 to 72.31 mg/100 g of muscle. The lowest cholesterol content among the geese studied (57.88 mg/100 g) was determined in Ka goose muscles. Higher cholesterol content in thigh meat was observed by Boz et al. (2019), for local Turkish goose varieties (74.95–77.85 mg/100 g). According to USDA (2019), cholesterol content in raw goose thighs, without skin, should equal 84 mg/100 g of muscle, which is higher than that determined in this study. In publications by the other authors, the cholesterol content in femoral muscles of broiler chickens was similar (60.5–68.15 mg/100 g of muscle) (De Oliveira et al., 2016) or higher (156.3–194.2 mg/100 g of muscle) (Salma et al., 2007).

CONCLUSION

The examined muscles of all geese varieties were characterized by high protein content. Variations from the same region had a similar amino acid composition of proteins. The thigh muscles of Ka, Su, Lu, and Ki contained all amino acids in the necessary proportions, following the protein standard of FAO (2013). The muscles of the geese of northern origin (Ka and Su) contained more lipids than geese of southern varieties (Lu and Ki). Goose thigh muscles of Ka and Ki were characterized by the most favorable profile of intramuscular fat. Ka goose muscles were characterized by a low cholesterol content, the highest percentage of n-3 acids, and the most beneficial value of the n-6/n-3 ratio. Ki geese had the smallest amount of SFA acids, the highest value of the UFA/SFA ratio and content of DHA (C22:6 n-3) (which is very important because of cardiovascular disease prevention), and more favorable values of h/H and NVI than the other varieties.

The IA values calculated for muscles of Ka, Su, Lu, and Ki were in the range of values recommended in the human diet (<1), while the IT was slightly higher than the recommended value (<0.5).

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DISCLOSURES

The authors declare no conflicts of interest.

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