PROCESSING AND PRODUCTS

Fatty acid profiles and health lipid indices in the breast muscles of local Polish goose varieties

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ABSTRACT The aim of this study was to evaluate the fatty acid profile and health lipid indices of meat from 3 Polish local goose varieties (Romanian–RO, Pomeranian–PO, and Subcarpathian–SB) and the commercial cross White Kołuda goose (W31). Birds were fed *ad libitum* with the same complete feeds until 17 wk of age. The geese (n = 72) with body weight close to the arithmetic mean in particular flock were fasted for 12 h and slaughtered in an experimental slaughterhouse (18 females in each flock). Carcasses were stored at 2 to 4°C for 24 h. The breast muscles (*m. pectoralis major*) were cut out from the left side of carcass, separately vacuum-packed, and stored at −80°C until analysis. Fatty acid profile of meat was determined by gas chromatography and health lipid indices were calculated. The W31 muscles had a higher percentage of C 18:0 and a lower of C 16:0 than those of RO, PO, and SB geese. The W31 muscles were characterized by a significantly higher proportion of monounsaturated fatty acids (46.5%) than remaining ones (43.28%–PO, 43.38%–SB, and 44.24%–RO). The lowest proportion of polyunsaturated fatty acids was established for W31 muscles (22.05%). The breast muscles of RO, SB, and PO had more favorable polyunsaturated n-6 and n-3 fatty acid (PUFA)/ saturated fatty acid (**SFA**) ratio (0.85, 0.82, 0.83, respectively) than W31 geese (0.72). The current findings showed that UFA/SFA, PUFA/SFA, and PUFA *n-6/n-3* ratios in RO and SB muscles were within the optimum values for human diets. No significant differences were observed in the atherogenic, thrombogenic, and hypocholesterolemic/hypercholesterolemic indices between the analyzed muscles. Commercial W31 geese breast muscles showed a lower value (43.90%) of peroxidizability index (**PI**) compared to SB (52.88%), PO (53.93%), and RO (53.47%). However, the higher values of the PUFA/SFA and PI in the meat of SB, PO, and RO birds may indicate a higher prohealth value of their meat.

Key words: goose, breast muscle, fatty acid profile, health lipid index

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INTRODUCTION

In the past century, livestock production has progressively shifted from providing large amounts of high-value proteins to nourish populations in promoting secure and highly convenient meats of consistent eating quality (Hocquette et al., 2010). Consumers are becoming increasingly aware of the nutritional quality and health benefits of the food they consume. One of the ways to improve their health is by changing lipid content and fatty acid composition of foods (Yang et al., 2010). Meat is an essential dietary component and forms a major proportion of consumer requirements for amino acids, fatty acids, some vitamins, and minerals (Costa et al., 2011). The amount of intramuscular, intermuscular, and subcutaneous fat, as well as its fatty acid profiles by specifying sensory quality and health considerations of meat.

The guidelines from FAO/WHO (2008) recommended that to reduce the incidence of diseases, such as type 2 diabetes, some cancers, and cardiovascular (**CVD**) diseases, the total fat should contribute to <15–30% of total energy intake, including precise recommendations concerning saturated (**SFA**), polyunsaturated n-6 and n-3 (**PUFA**), and trans fatty acids. There is considerable evidence to suggest that PUFA *n-3* is important to certain tissues such as the brain and retina. They are linked to the development and functionality of immune systems and have cardioprotective and anticarcinogenic functions. Moreover, the PUFA/SFA and PUFA *n-6/n-3* ratios, hypocholesterolemic and hypercholesterolemic fatty acids contents, and atherogenic and thrombogenic indices have become some of the most important

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parameters for evaluating the nutritional value and healthiness of foods (Yang et al., 2010; Mapiye et al., 2011; Attia et al., 2017).

Poultry meat contains all the nutrients that can meet recommended daily allowances for humans; therefore, in many countries, we can observe continuous increase in the consumption of poultry, primarily chicken and turkey and, to a lesser extent, ducks and goose meat (Witak, 2008; Attia et al., 2017). The waterfowl fat is considered to be safe for consumers because of its relatively low level of saturated fatty acids. Although the contribution of waterfowl meat to global poultry meat production was quite low together (ca. 6.93%), the waterfowl productions have been on an upward trend for many years and has become increasingly important around the world (Windhorst, 2011; Huang et al., 2012). Asia dominates global waterfowl production. The largest producers of goose meat in the world are China and Egypt, while in Europe–Poland. Poland, China, and Hungary account for 90% of global goose meat exports (c.a. 34.5% – 21,700 t; 33.5% – 15,300 t and 23.0% – 10,500 t, respectively). Germany imported 68.4% (i.e., ≈ 21,500 t., including 16,100 t. from Poland) of the goose meat. Poland exports goose also to the markets of Hong Kong, France, Denmark, and Russia (FAO database http://faostat.fao.org). Although goose meat contains fat, which is beneficial from a health point of view, the consumption of goose in Poland is low. It can be mainly due to the high price of this meat and lack of knowledge about the nutritional value of goose fat. In addition, goose meat is produced seasonally, and at that time, it is fresh, not frozen on the market. The basic breed used to produce goose meat in Poland is White Kołuda geese, which in commercial production is >90%. The geese are fed and maintained in a specific way and kept in open-air runs and at pasture. Moreover, they are reared up to 14 wk of age, then fattened freely with oats up to 16th–17th wk of age, which is why they are called "Polish oat geese." Fattening with oats results in good quality meat with excellent sensory properties (Biesiada-Drzazga et al., 2011; Buzała et al., 2014); furthermore, in Poland, there are 10 regional varieties of geese and 4 of foreign origin. They use an open range; therefore, they are able to handle the rigors of outdoor production. Geese kept on grassland (pastures) and fed diverse feeds fulfill the requirements of an ecological product. It is important because more and more consumers wish to have information about how food is produced and prefer ecological production that considers an animal's welfare (Kisiel and Książkiewicz, 2004; Haraf et al., 2018).

The purpose of this study was to compare and evaluate the nutritional value of commercial W31 White Kołuda goose and 3 native goose varieties (Pomeranian–PO, Subcarpathian–SB, and Romanian–RO) breast muscles by determining fatty acid profiles and by calculating health lipid indices such as UFA/SFA, PUFA/SFA, PUFA *n-6*/*n-3*, and peroxidizability index (PI) ratios, as well as atherogenic (AI), thrombogenic (**TI**), hypocholesterolemic/hypercholesterolemic (**h**/**H**), and nutritive value (**NVI**) indices.

MATERIALS AND METHODS

Birds, Diet, and Experimental Procedure

The experiment was conducted on 3 local Polish varieties (Pomeranian–PO, Subcarpathian–SB, and Romanian–RO) of goose and on commercial hybrid of White Kołuda goose (W31). PO is an old indigenous variety native to northern Poland, SB is native to southern Poland, and RO is a foreign strain parental material, which was purchased from Danish Poultry House in 1987 and included in the genetic resources of geese in Poland. The W31 is a commercial cross originating from the White Italian goose.

All the birds were reared in the Research Station of Waterfowl Genetic Resources in Dworzyska (belonging to National Research Institute of Animal production in Kraków, Poland) under similar environmental and feeding conditions. The experiment was carried out in one calendar year. During the testing period, the geese were kept up to sixth week of age in a brooder house having a controlled temperature environment. They were then kept afterward until they were aged 17 wk in an open-sided poultry shelter partially shaded and covered with straw (stocking density ≈ 0.75–0.85 per 1 m^2). The birds were fed *ad libitum* on complete feeds up to 6 wk of age all-mash KBR-Z/1 and from 7 to 17 wk of age all-mash KBR-Z/2 (Table 1).

At 17 wk of age, 18 female birds were taken for analysis from each genetic group. We selected birds with body weight close to the arithmetic mean in particular flock (Ro–4,255 g, Po–4,127 g, Sb–3,824 g, and W31–5,895 g). Twelve hours before slaughter, birds were submitted to feed withdrawal and only allowed access to water. The geese were slaughtered in an experimental slaughterhouse, according to Polish poultry industry regulations. The carcasses were bled, scalded (∼1.0 min at ∼63°C), plucked, and eviscerated. The eviscerated carcasses were placed immediately in a 2–4°C cooler (for 24 h). Next the breast muscles (without skin and subcutaneous fat) were cut out from all carcasses, separately vacuum packed, and stored at −80°C until analysis.

Sample Preparation

Each breast muscle (from left side) was thawed at 4°C, separately minced in a meat grinder. The intramuscular fat from muscles was extracted using the procedure described by Folch et al. (1957). According to this method, each ground sample (5 g) was separately homogenized using chloroform: methanol (2:1; v/v) solution. The extraction mixture contained 0.001% (w/v) of butylated hydroxytoluene as an antioxidant. The organic solvent was evaporated under a stream of nitrogen. The crude lipid extracts were then saponified with

Table 1. Diet composition used in the trial.

Item	All-mash KBR-Z/1	All-mash KBR-Z/2
Chemical composition (%/kg of all-mash)		
CP	19.0	17.0
Crude fat	4.00	3.00
Ash	5.50	6.00
Crude fiber	3.50	5.00
Lys	1.05	0.820
Met	0.490	0.460
Ca	0.850	0.860
Total P	0.700	0.800
Vitamin A (IU/kg)	15,000	14,000
Vitamin D_3 (IU/kg)	3,500	2,000
Vitamin E (mg/kg)	60	50
ME[1] (MJ/kg of all-mash)	12	11.3
Fatty acid (% of the sum fatty acids)		
C 16:0	12.2	11.8
C 16:1 *cis-9*	0.370	0.310
C 18:0	5.60	4.95
C 18:1 *cis-9*	29.4	32.2
C 18:2 *n-6*	37.6	34.4
C 18:3 *n-3*	2.58	4.26
C 20:5 *n-3*	0.620	0.700
C 22:6 *n-3*	0.540	0.620

[1]The caloric value of all-mashes calculated on the basis of percentage content of some analytical components of feed, expressed in megajoules of ME per 1.0 kg of fed mixture, with a level of nitrogen adjusted by the following method [Dz. U. Nr 63 (Journal of Laws, No. 63) item no. 589 of March 24, 2004]: MJ/kg of ME = 0.1551 × % CP + 0.3431 × % crude fat +0.1669 × % starch +0.1301 × % total sugar content (expressed as sucrose).

0.5 mol KOH solution in methanol. Afterward, the methyl esters of fatty acids (**FAMEs**) were prepared by transesterification with boron trifluoride ($\mathbf{BF_3}$) solution in methanol according to the AOCS official method Ce 2–66 (AOCS 1997).

Fatty Acid Analysis

The FAMEs were quantified by a gas chromatography method using a fused silica capillary column J&W Scientific HP-88 series 100 m × 0.25 mm × 0.20 µm (Agilent Tech. Inc., St. Clara, CA, USA) and flame-ionization detector (FID) from Agilent Tech. We used a 7,890 A series gas chromatograph (Agilent Tech. Inc.) at an injection volume of 1.0 mL and a split ratio of 1/50. Helium was used as the carrier gas at a head pressure of 2.0 mL/min at a constant flow. Air, hydrogen, and helium make-up gas flow rates by FID were 450, 40, and 30 mL/min, respectively. The detector and injector temperatures were chosen as 280°C and 250°C, respectively. The initial column temperature of 120°C was held for 1 min, increased to 175°C at 10°C/min and then held for 10 min. Then, it was increased to 210°C at 5°C/min, held for 5 min, increased to 230°C at a rate of 5°C/min, and maintained for 5 min.

The peaks were identified by comparing the retention times with those of a mixture of external standard methyl esters (Supelco 37 FAME Mix C 4–C 24 Component, Sigma-Aldrich, St. Louis, MI, USA). The fatty acids were calculated as the percentage of a sum of fatty acids using the ChemStation Agilent Technologies program (Agilent Tech. Inc.). Each sample was analyzed in triplicates.

Calculation of Health Lipid Indices

The fatty acid profile was used to determine several nutritional parameters of lipids in goose breast muscles. They were calculated according to the following equations:

- NVI = (C 18:0 + C18:1)/C 16:0 (Chen et al., 2016).
- AI = (C 12:0 + 4 × C 14:0 + C 16:0)/Σ UFA (Ulbricht and Southgate, 1991).
- TI = (C 14:0 + C16:0 + C18:0)/[(0.5 × MUFA) + (0.5 × Σ *n-6*) + (3 × Σ *n-3*) + (Σ *n-3*/Σ *n-6*)] (Ulbricht and Southgate, 1991).
- h/H (hypocholesterolemic/hypercholesterolemic index) = [(C 18:1 *n-9* + C 18:1 *n-7* + C 18:2 *n-6* + C 18:3 *n-6* + C 18:3 *n-3* + C 20:3 *n-6* + C 20:4 *n-6* + C 20:5 *n-3* + C 22:4 *n-6* + C 22:5 *n-3* + C 22:6 *n-3*)/(C 14:0 + C 16:0)] (Fernandes et al., 2014).
- PI was calculated as: (monoenoic acid × 0.025) + (dienoic acid × 1) + (trienoic acid × 2) + (tetraenoic acid × 4) + (pentaenoic acid × 6) + (hexaenoic acid × 8) (Erickson, 1992).

Statistical Analysis

The data were statistically analyzed (Statistica 10, StatSoft, Inc. Tulsa, OK, USA, 2010) by calculating arithmetic means (x) and SDs. The significant difference levels between the genotypes of geese were determined by ANOVA one-way analysis, according to the following linear model: Yij = µ + Aj + eij, where Yij = value of trait (the dependent variable); µ = overall mean; Aj = the treatment effect; and eij = random observation error. We used Duncan's multiple-range test to compare differences among treatment means ($P \leq 0.05$).

RESULTS AND DISCUSSION

Tables 2 and 3 list the composition of various individual fatty acids and nutritive indices in the breast muscles of the geese. In the muscles of all 4 geese varieties (RO, PO, SB, and W31), the main SFA, MUFA, and PUFA were C 16:0 (palmitic), C 18:1*n-9* (oleic), and C 18:2 *n-6* (linoleic) acids. The C 16:0 acid was the most abundant saturated fatty acid (21.48–23.16%), followed by C 18:0 (stearic acid) (6.47–8.34%). These fatty acids occur naturally in all animal fat and the major products are of the fatty acid synthase system (Karapanagiotidis et al., 2010). The SFA profile of breast muscles showed differences ($P \leq 0.05$) primarily in the proportion of C 16:0 and C 18:0. The C 12:0 (lauric) and C 14:0 (myristic) fatty acids, which promote hypercholesteremia, were detected at low concentrations in the studied species (C 12:0 + C 14:0 = 0.81–0.92%), thus demonstrating a positive factor in their consumption. The C 12:0 and C 14:0 acids are among the most atherogenic agents,

Table 2. The fatty acid profile (mean values ± standard errors) of geese breast muscles (% of total fatty acids).

	Genotype			
	RO	PO	SB	W31
Fatty acid	n = 18	n = 18	n = 18	n = 18
C 12:0	0.25 ± 0.01^{b}	0.29 ± 0.01^{ab}	0.27 ± 0.01^{b}	0.34 ± 0.02^{a}
C 14:0	0.56 ± 0.02	0.56 ± 0.01	0.58 ± 0.01	0.57 ± 0.02
C 16:0	22.21 ± 0.06^{b}	23.16 ± 0.06^{a}	22.04 ± 0.04^{b}	21.48 ± 0.09^{c}
C 18:0	6.47 ± 0.13^{c}	6.89 ± 0.11^{b}	7.02 ± 0.10^{b}	8.34 ± 0.12^{a}
Σ SFA	29.49 ± 0.23^{b}	30.90 ± 0.25^{a}	29.91 ± 0.25^{b}	30.49 ± 0.28^{a}
C 14:1	0.27 ± 0.01	0.29 ± 0.01	0.32 ± 0.01	0.30 ± 0.01
C 16:1 *cis-9*	3.93 ± 0.07^{a}	3.90 ± 0.04^{a}	3.85 ± 0.06^{a}	3.08 ± 0.08^{b}
C 16:1 *trans-9*	0.71 ± 0.02^{b}	0.88 ± 0.02^{a}	0.60 ± 0.02^{b}	0.62 ± 0.02^{b}
C 18:1 *cis-9*	37.77 ± 0.15^{b}	36.56 ± 0.20^{b}	37.03 ± 0.13^{b}	40.48 ± 0.27^{a}
C 18:1 *trans-9*	0.36 ± 0.01	0.33 ± 0.02	0.32 ± 0.02	0.33 ± 0.01
C 20:1	0.33 ± 0.01^{a}	0.35 ± 0.02^{a}	0.37 ± 0,01^{a}	0.25 ± 0.01^{b}
C 24:1	0.88 ± 0.01^{b}	0.97 ± 0.02^{a}	0.89 ± 0.01^{ab}	0.99 ± 0.02^{a}
Σ MUFA	44.25 ± 0.53^{b}	43.28 ± 0.59^{c}	43.38 ± 0.51^{c}	46.05 ± 0.38^{a}
C 18:2 *n-6*	16.26 ± 0.05^{b}	16.87 ± 0.08^{a}	16.10 ± 0.10^{b}	15.21 ± 0.09^{c}
α C 18:3 *n-3*	1.91 ± 0.03^{a}	1.05 ± 0.03^{c}	1.88 ± 0.04^{a}	1.39 ± 0.03^{b}
C 20:4 *n-6*	4.40 ± 0.04^{b}	4.76 ± 0.04^{a}	4.48 ± 0.06^{b}	3.69 ± 0.06^{c}
C 20:5 *n-3* EPA	1.54 ± 0.05^{a}	1.44 ± 0.05^{a}	1.37 ± 0.04^{a}	0.92 ± 0.02^{b}
C 22:4 *n-6*	0.58 ± 0.01^{b}	0.67 ± 0.01^{a}	0.63 ± 0.01^{a}	0.56 ± 0.01^{b}
C 22:6 *n-3* DHA	0.39 ± 0.01^{a}	0.44 ± 0.01^{a}	0.41 ± 0.01^{a}	0.28 ± 0.01^{b}
Σ PUFA	25.08 ± 0.21^{a}	25.23 ± 0.32^{a}	24.87 ± 0.44^{a}	22.05 ± 0.37^{b}
Σ PUFA *n-3*	3.84 ± 0.03^{a}	2.93 ± 0.03^{b}	3.66 ± 0.02^{a}	2.59 ± 0.04^{c}
Σ PUFA *n-6*	21.24 ± 0.05^{b}	22.30 ± 0.05^{a}	21.21 ± 0.05^{b}	19.46 ± 0.04^{c}
Σ UFA	69.33 ± 0.38	68.51 ± 0.52	68.25 ± 0.44	68.10 ± 0.29
Total other fatty acids	1.18 ± 0.02	0.59 ± 0.01	1.84 ± 0.02	1.41 ± 0.02

^{a,b,c}Means within a row with different superscripts differ significantly, $P \leq 0.05$.

Abbreviations: MUFA, monounsaturated fatty acid; PO, Pomeranian goose; PUFA, polyunsaturated fatty acid; RO, Romanian goose; SB, Subcarpathian goose; SFA, saturated fatty acid; UFA, unsaturated fatty acid; W31, White Kołuda goose.

whereas C 18:0 is thought to be neutral with respect to atherogenicity but instead considered to be thrombogenic (Attia et al., 2017). The W31 muscles showed higher ($P \leq 0.05$) percentage of C 18:0 and lower proportion of C 16:0 than those of RO, PO, and SB geese (Table 2.). The higher SFA level in PO muscles was primarily attributed to the higher percentage of C 16:0 than in the remaining goose muscles. Geldenhuys et al. (2015) reported that the breast muscles of Egyptian geese showed higher proportion of C 18:0 in (10.0–14.3%). Sari et al. (2015) found a higher (11.5–14.9%) percentage of C 18:0 for breast muscles of native Turkish geese raised with 4 different fattening systems. Similar to our findings, the C 16:0 proportion was established by Gumułka et al. (2006) for Zatorska (21.31%), White Kołuda (22.0%) breast geese muscles, and Oz and Celik (2015) for native Turkish geese (21.8%). In the present study, the sum of all identified SFA ranged from 29.49 to 30.90%, which is in agreement with values stated for other geese genotypes (Okruszek, 2011; Oz

Table 3. Nutritional quality indices (mean values ± standard errors) of the lipids in goose breast muscles.

	Genotype			
	RO	PO	SB	W31
Item	n = 18	n = 18	n = 18	n = 18
Σ UFA/Σ SFA	2.35 ± 0.02	2.22 ± 0.04	2.28 ± 0.04	2.23 ± 0.05
Σ PUFA/Σ SFA	0.85 ± 0.02^{a}	0.82 ± 0.01^{a}	0.83 ± 0.02^{a}	0.72 ± 0.02^{b}
Σ PUFA *n-6*/*n-3*	5.53 ± 0.09^{b}	7.61 ± 0.10^{a}	5.79 ± 0.07^{b}	7.51 ± 0.08^{a}
NVI	1.99 ± 0.02^{b}	1.88 ± 0.03^{c}	2.00 ± 0.03^{b}	2.17 ± 0.03^{a}
AI	0.36 ± 0.01	0.37 ± 0.01	0.36 ± 0.01	0.37 ± 0.01
TI	0.66 ± 0.02	0.73 ± 0.01	0.68 ± 0.02	0.74 ± 0.02
h	62.86 ± 0.62	61.79 ± 0.66	61.83 ± 0.54	62.53 ± 0.41
H	22.77 ± 0.23^{b}	23.72 ± 0.21^{a}	22.62 ± 0.18^{b}	22.15 ± 0.27^{c}
h/H	2.76 ± 0.03	2.60 ± 0.03	2.73 ± 0.03	2.82 ± 0.03
PI (%)	53.47 ± 0.55^{ab}	53.93 ± 0.52^{a}	52.88 ± 0.48^{b}	43.90 ± 0.60^{c}

^{a,b,c}Means within a row with different superscripts differ significantly, $P \leq 0.05$.

Abbreviations: AI, atherogenic index; h/H, hypocholesterolemic/hypercholesterolemic index; NVI, nutritive value index; PI, peroxidizability index; PO, Pomeranian goose; RO, Romanian goose; SB, Subcarpathian goose; TI, thrombogenic index; W31, White Kołuda goose.

and Celik, 2015). We reported higher values of SFA by Haraf et al. (2018) for breast muscles of 17-week-old regional varieties of geese (31.5–32.1%), by Liu and Zhou (2013) for Dongbei White geese reared with and without access to pasture (36.3–37.2%), and by Sari et al. (2015) for native Turkish geese reared with 4 different fattening systems (37.3–40.7%). Similarly, the breast muscles from different breeds of ducks were characterized by a higher (31–42%) percentage of SFA (Woloszyn et al., 2006; Juodka et al., 2018).

For preventing CVD, it is advantageous to consume a food including MUFA, which has favorable influence on the blood lipid profile (Kien et al., 2014). In the present study, the sum of all identified MUFA ranged from 43.28% (PO) to 46.05% (W31). As can be observed, the W31 muscles were characterized by a significantly ($P \leq 0.05$) higher proportion of MUFA than remaining ones (Table 2). The dominant MUFA in all muscles was C 18:1 *n-9* and C 16:1 *n-9* with variation among the investigated species ($P \leq 0.05$). These results are consistent with those obtained previously by Okruszek (2012) and Haraf et al. (2018) for Polish local geese and by Gumułka et al. (2006) for Zatorska and White Kołuda geese. The presented data were in line with those found by Sari et al. (2015) in breast muscles of native Turkish geese raised with 4 different fattening systems. Oleic acid was abundant in W31 muscles, whereas the lowest concentration was observed in PO muscles. The W31 muscles were characterized by a lower proportion of C 16:1 *n-9* and C 20:1 *n-9* compared to RO, PO, and SB ones. Biesiada-Drzazga (2006) presented higher values of C 18:1 *n-9* in White Kołuda geese muscles (54.68–55.68%) fed with forage containing soybean and rapeseed meal. Similarly, Oz and Celik (2015) demonstrated higher percent of C 18:1 *n-9* (45.95%) in breast muscles of native Turkish geese reared with commercial feed. Lower proportion of C 18:1 *n-9* was reported by Liu and Zhou (2013) in the meat of Dongbei White geese (26.9–27.3%) and by Geldenhuys et al. (2015) for Egyptian geese (24.4%) slaughtered in winter.

It has been emphasized that meat rich in *n-3* and *n-6* forms of Σ PUFA is beneficial for human health (Ackman, 2008). The proportion of Σ PUFA varied from 22.05% in W31 to 25.23% in PO muscles. Among Σ PUFA, the main *n-6* fatty acid in all samples was C 18:2 *n-6* followed by C 20:4 *n-6*, which agrees with data published for muscles from 10-week-old White Kołuda geese (Biesiada-Drzazga 2006) and 7 native Polish varieties (Gumułka et al., 2006, Okruszek, 2012; Haraf et al.; 2018). In relation to the individual fatty acids, W31 muscles showed lower percentage of C 18:2 *n-6* and C 20:4 *n-6* compared to remaining ones. Consequently, W31 was characterized by the lower ($P \leq 0.05$) proportion of total Σ PUFA *n-6* among the analyzed genotypes. The PO breast muscles showed the highest proportion of C 18:2 *n-6* and lowest C 18:3 *n-3* (Table 2.). In comparison to our findings, Turkish geese (Oz and Celik, 2015; Sari et al., 2015) were characterized by a lower percentage of Σ PUFA (by 3.9–9.5%) including C 18:2 *n-6* (by 3.11–5.3%), and C 20:4 *n-6* (by 1.63–4.25%), whereas the Chinese geese (Liu and Zhou, 2013), reared with and without access to pasture, showed the higher proportion of Σ PUFA (by 5.6–7.1%) including C 20:4 *n-6* (by 3.01%) in breast muscles.

Alpha linolenic acid (α C 18:3 *n-3*) is the principal PUFA that occurs in the green tissue of plants. In animals, α C 18:3 *n-3* is converted to a series of longer chain PUFA of which the most important are C 20:5 *n-3* (**EPA**) and C 22:6 *n-3* (**DHA**) acids (Ulbricht and Southgate, 1991) In our study, the major PUFA *n-3* fatty acids were α C 18:3 *n-3* and C 20:5 *n-3* (**EPA**), whose percentages did show significant differences between analyzed genotypes ($P \leq 0.05$). A significantly higher proportion of α C 18:3 *n-3* was found in RO and SB than in PO and W31 muscles. The lowest percentage of C 20:5 *n-3* was found in W31 muscles, while PO showed the lowest proportion of α C 18:3 *n-3*. High proportion of α C 18:3 *n-3*, C 20:5 *n-3* and total PUFA *n-3* was detected in RO muscles (Table 2).

Polyunsaturated n-6 and n-3 fatty acids differ in their antithrombogenicity activity, which is most pronounced in the *n-3* series, particularly EPA and DHA. The long chain EPA and DHA play a significant role in the prevention and treatment of certain diseases and disorders such as CVD, hypertension, type 2 diabetes, irritable bowel syndrome, muscular degeneration, rheumatoid arthritis, asthma, psychiatric disorders, and several cancers (Ulbricht and Southgate, 1991; Mapiye et al., 2011; Skałecki et al., 2016). In the present study, the contents of EPA + DHA in breast muscles varied from 1.2% in W31 to 1.93% in RO. The percentage of EPA + DHA established in this study for all samples was higher than for 17- and 24-week-old native Polish geese (0.93–1.08%) reported by Haraf et al. (2018) and Okruszek (2012). Moreover, Sari et al. (2015) observed lower proportion of EPA + DHA in the meat of Turkish local geese (1.05–1.23%). The lower proportion of EPA + DHA was found for other kinds of meat such as turkey (0.14%), rabbit (0.52%), and chicken (0.14–0.55%) (Skiepko et al., 2016; Kowalska et al., 2012; Chen et al., 2016). The sum of EPA and DHA for investigated muscles was lower in comparison to duck meat described by Onk et al. (2018) (2.56%) and Woloszyn et al. (2006) (4.57%); marine fish fillets established by Fernandes et al. (2014) (35.0–41.0%); edible parts of the shrimp presented by Rosa and Nunes (2003) (32.0–38.3%); and crab edible tissues observed by Barrento et al. (2010) (32.7%).

The Σ UFA/Σ SFA, Σ PUFA/Σ SFA, and Σ PUFA *n-6*/*n-3* ratios are commonly used parameters to judge meat nutritional value and healthiness of intramuscular fat for human consumption. In many studies, a balanced intake of dietary Σ PUFA to Σ SFA was thought to be very important in regulating serum cholesterol (Kang et al., 2005). In general, a ratio of Σ PUFA/Σ SFA greater than 0.45 is recommended in human diets to prevent the development of CVD and some chronic diseases such as cancer. Foods with Σ PUFA/Σ SFA ratios below 0.45 have been considered undesirable for human diet

because of their potential to induce cholesterol increase in the blood (Mapiye et al., 2011). In this study, Σ UFA/Σ SFA ratios ranged from 2.22 in PO to 2.35 in RO muscles (no significant differences) and were beneficial for human health. The Σ PUFA/Σ SFA ratios (0.72–0.85) found in all groups were consistent with the recommended values, which indicate improved balance of fatty acids in analyzed tissues. However, the meat of local varieties of geese (RO, SB, and PO) showed more favorable ($P \leq 0.05$) Σ PUFA/Σ SFA ratio (0.85, 0.82, and 0.83) than commercial strain W31 (0.72). The Σ UFA/Σ SFA ratio in breast muscles of all treated groups was similar to data obtained for 10-week-old White Kołuda geese by Biesiada-Drzazga (2006) and for local Polish geese by Okruszek (2012). A lower Σ UFA/Σ SFA and Σ PUFA/Σ SFA ratios were observed in the trials using Polish native (Kartuska, Kielecka, Lubelska, and Suwalska) geese (Haraf et al., 2018); Turkish native geese (Oz and Celik, 2015; Sari et al., 2015); white, grey, black, and multicolor local Turkish geese (Boz et al., 2019); and Egyptian geese (Geldenhuys et al., 2015).

More recently, nutritionists have focused on the type of Σ PUFA and the balance in the diet between Σ PUFA *n-3* formed from α C 18:3 *n-3* acid and Σ PUFA *n-6* formed from C 18:2 *n-6* (Wood et al., 2003). The high proportion of Σ PUFA is not necessarily healthy if it is not balanced in relation to the Σ PUFA *n-6/n-3* ratio. The ratio of Σ PUFA *n-6/n-3* is particularly beneficial in meats from animals that have consumed grass, which contain high levels of α C 18:3 *n-3*. The Σ PUFA *n-6* and *n-3* and their ratio (Σ PUFA *n-6/n-3*) are the principle fatty acids controlling the hypocholesterolemic index. The *n-3* plays a major role for regulating the thrombogenic index, whereas *n-6* is dominant for the atherogenic ones. A healthy animal product can be characterized by low AI and TI and high h/H index. Furthermore, animal products with low thrombogenicity decrease the threat of atrial fibrillation (Attia et al., 2017). In a diet, *n-6/n-3* ratio less than 4.0 for Σ PUFA indicates desirable quantities of *n-3* and *n-6* fatty acids and reduction of risk for cardiovascular diseases. The Σ PUFA *n-6/n-3* ratio ranged from 5.0 to 6.0 in meat is close to recommended values, suggesting that these species could be categorized as beneficial for human health consumption (Fernandes et al. 2014). The results concerning the Σ PUFA *n-6/n-3* ratios in our investigation for RO (5.53) and SB (5.79) strain were close to recommended values. Σ PUFA *n-6/n-3* ratios for PO (7.61) and W31 (7.51) were higher in comparison to RO and SB. It was a consequence of both the high amount of C 18:2 *n-6* and the low total sum of PUFA *n-3* acids. The Σ PUFA *n-6/n-3* ratios determined in our experiment were lower than those revealed for Chinese geese (8.7–12.3) by Liu and Zhou (2011), for Polish oat geese (10.9) by Orkusz et al. (2015), and for native Polish geese (7.8–9.7) by Haraf et al. (2018). However, the lower and more favorable Σ PUFA *n-6/n-3* ratios were reported for Turkish native geese (2.78) by Oz and Celik (2015) and for Egyptian geese (1.8–5.2) by Geldenhuys et al. (2015). The Σ PUFA *n-6/n-3* ratios determined in the present study for all geese muscles were higher than those previous obtained for duck meat by Woloszyn et al. (2006), Juodka et al. (2018), and Onk et al. (2018) (3.3–5.1, 3.3–3.39, and 5.0). The current results show that Σ UFA/SFA, Σ PUFA/SFA, and Σ PUFA *n-6/n-3* ratios in RO and SB groups were within the optimum values for human diets. The highest value of NVI was characteristic for the W31 muscles (Table 3). It was caused by the highest proportion of C 18:0, C 18:1 *n-9*, and the lowest percentage of C 16:0 in W31 muscles among all the investigated geese.

The AI indicates the relationship between the sum of the main SFA and that of main classes of UFA, the former being considered proatherogenic (favoring the adhesion of lipids to cells of the immunological and circulatory system), and the latter being antiatherogenic (inhibiting the aggregation of plaque and diminishing the levels of esterified fatty acid, cholesterol, and phospholipids, thereby preventing the appearance of microcoronary and macrocoronary diseases). The TI shows tendency to form clots in the blood vessels. This is defined as the relationship between the prothrombogenic (saturated) and antithrombogenic fatty acids (Σ MUFA, Σ PUFA *n-6,* and Σ PUFA *n-3*). The AI and TI indicate potential for stimulating platelet aggregation (Ghaeni et al., 2013). Thus, the smaller the AI and TI values, the greater the protective potential for coronary artery disease. In terms of human health, the AI and TI, which are less than 1.0 and 0.5, respectively, in the diet, are recommended (Fernandes et al., 2014). No significant differences ($P \leq 0.05$) were observed in the AI and TI values between the analyzed muscles (Table 3). The muscles studied in the present work showed AI and TI of 0.36–0.37 and 0.66–0.72, respectively. Our results concerning AI are lower than the recommended values; however, TIs are close to the expected values. This is very desirable from a human health point of view. The results concerning NVI, AI, and TI are in good agreement or close to those calculated on the basis of the fatty acid profiles for native Turkish geese by Cui et al. (2015) and Sari et al. (2015). However, higher TI values were calculated in the experiment conducted with local Chinese geese by Liu and Zhou (2013). The breast muscles of the investigated geese demonstrated lower value of AI and TI than those calculated for other kinds of meat such as rabbit (AI = 0.90; TI = 1.19) (Dal Bosco et al., 2001), chicken (AI = 0.49; TI = 1.14) (Puerto et al., 2017), turkey (AI = 0.47; TI = 0.91) (Skiepko et al., 2016), beef, (AI = 0.60; TI = 1.86) (Mapiye et al., 2011), pork (AI = 0.47; TI = 1.12) (Kasprzyk et al., 2015), and lamb (AI = 0.90; TI = 0.87) (Margetin et al., 2014).

No significant differences were found in the proportion of hypocholesterolemic fatty acids (h). The proportion of hypocholesterolemic fatty acids represent 61.79–62.86% of total fatty acids. The lowest percentage of hypercholesterolemic fatty acids (H) was observed in W31 muscles. The ratio between hypocholesterolemic and hypercholesterolemic fatty acids (h/H index) indicated the effects of specific fatty acids on cholesterol

metabolism. Nutritionally higher h/H values are considered more beneficial for human health. The h/H indices obtained in the present study ranged from 2.60 to 2.82 and did not significantly differ from each other. Furthermore, similar values of h/H indices for the meat of other goose genotypes were calculated based on the fatty acid profiles given by Biesiada-Drzazga (2006), Okruszek (2012), Yanovych et al. (2013), and Haraf et al. (2018). Higher h/H indices were observed for duck meat (3.5; Onk et al., 2018), marine fish fillets (3.1; Fernandes et al., 2014), common carp fillets (3.4; Skałecki et al., 2016), shrimp edible flesh (3.8; Rosa and Nunes, 2003), and crab edible tissue (5.9; Barrento et al., 2010). Considering the value of the h/H indices, the investigated goose meat (all varieties) was better for retarding atherosclerosis in comparison to rabbit (1.2) (Dal Bosco, 2001), chicken (1.8) (Attia et al., 2017), beef (1.8) (Mapiye et al., 2011), and pork (2.4) (Nevrkla et al., 2017) meat.

Peroxidizability index represents the relationship between the fatty acid composition of a tissue and its susceptibility to oxidation and indicates the technological quality of meat. The PI index is used to assess the stability of PUFA included in food products and to protect them from possible oxidation processes; however, the higher the PI value, the greater the protective potential for coronary artery disease. The excessive intake of PUFA has undesirable effects such as oxidative stress because of high susceptibility to lipid peroxidation. Oxidative stress, which is associated with the formation of lipid peroxides, has been suggested as contributing to pathological processes in aging and many diseases such as atherosclerosis (Kang et al., 2005; Sinanoglou et al., 2013; Skałecki et al., 2016). In the present study, commercial W31 geese breast muscles showed a lower ($P \leq 0.05$) value of PI (43.9%) compared to SB, PO, and RO muscles (52.88, 53.93, and 53.47%). Lower PI value in W31 indicates a lower level of fatty acids autooxidation in meat because of its longer shelf-life. However, significantly higher content of acids from the *n-3* group and higher values of the PI index in RO, PO, and SB meat may indicate a higher prohealth value of meat obtained from these birds. Concerning the PI, values obtained in the SB, PO, and RO muscles were higher than those calculated on the basis of the fatty acid profiles for native Turkish geese by Oz and Celik (2015); for Egyptian geese by Geldenhuys et al. (2015); and for Kartuska, Kielecka Lubelska, and Suwalska geese by Haraf et al. (2018). Moreover, the rabbit (Ramirez et al., 2005), chicken (Attia et al., 2017), beef (Mapiye et al., 2011), and pork (Grześkowiak et al., 2005) meat showed lower susceptibility to lipid oxidation. The higher tendency to lipid oxidation was found in different kinds of marine fish fillet by Ghaeni et al. (2013) and Fernandes et al. (2014), crab edible tissue by Barrento et al. (2010), and shrimp edible parts by Rosa and Nunes (2003) compared to our results for all investigated genotypes of geese. However, the marine fish and seafood have a higher protective potential for heart diseases.

CONCLUSION

The obtained results confirm that goose meat of all investigated geese genotypes could be considered to be beneficial from a nutritional point of view in relation to their fatty acid profiles and healthy lipid indices. Dissemination of this information may reduce customers' concerns about goose fat nutritional value and positive influence of their future purchasing decisions. The C 12:0 and C 14:0 fatty acids, which promote hypercholesteremia, were detected at low concentrations in the studied varieties, thus demonstrating a positive factor in their consumption. The Σ PUFA *n-6*/*n-3* ratios in our investigation for RO and SB geese were close to recommended values and for PO and W31 were slightly higher. The current results show that Σ UFA/SFA, Σ PUFA/SFA, and Σ PUFA *n-6*/*n-3* ratios in Ro and Sb breast muscles were within the optimum values for human diets. The results concerning NVI, AI, TI, and h/H index obtained in the present study were constant with respect to geese genotype. The AI and Σ PUFA/SFA ratios were better than the recommended values; however, TI indices were close to the expected values. The investigated goose meat demonstrated better AI, TI, and h/H index than meat from duck, rabbit, chicken, turkey, beef, pork, and lamb. This means that the breast muscles from all varieties, with low AI and TI and high h/H index, are good for retarding atherosclerosis and thus risk of cardiovascular disorders. The commercial W31 goose muscles showed less oxidation ability with a lower PI index. However, the higher values of the Σ PUFA/SFA and PI in meat of SB, PO, and RO geese may indicate a higher prohealth value of meat obtained from these birds.

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