Technological properties, chemical composition, texture profile, and sensory evaluation of goose muscles from Polish native breeds

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ABSTRACT The study aimed to determine the technological and sensory properties of the breast and thigh muscles of geese from the Polish native varieties: Kartuska (**Ka**) and Suwalska (**Su**) (from northern Poland) as well as Lubelska (**Lu**) and Kielecka (**Ki**) (from southern Poland). The color parameters: L*, a*, b*, ΔE, C, h°, total heme pigments (**THP**s), and share of myoglobin (**Mb**), metmyoglobin (**MMb**), and oxymyoglobin (**MbO_2**) in muscles were determined. In terms of technological properties, the following were determined: pH_{24}, water-binding capacity (**WBC**), water-holding capacity (**WHC**), cooking (**CL**), and roasting losses (**RL**). In addition, a sensory evaluation of the raw meat color was performed. In roasted meat, a sensory evaluation and texture profile analysis (**TPA**) were carried out, as well as the shear force (**SF**) and chemical composition were determined. Roasted muscles of varieties native to northern Poland (Ka and Su) were higher in lipids ($P \leq 0.05$) than the muscles of southern varieties (Lu and Ki). Ka meat had the highest protein content, and Lu meat had the lowest ($P \leq 0.05$). The raw muscle color sensory evaluation results, the THP, and the L* and ΔE values indicated that the darkest color among the studied genotypes were the Ka muscles, and the lightest was Ki meat ($P \leq 0.05$). Lu's muscles are distinguished by better usability for processing and culinary purposes than the muscles of the other genotypes due to high pH_{24}, WBC, WHC, and low RL and CL of thigh muscles, as well as high WHC and low RLs of the breast muscles ($P \leq 0.05$). Due to the tenderness, juiciness, and high general evaluation ($P \leq 0.05$), the best sensory features among the studied genotypes were found in the Ka breast and thigh muscles. The low SF value proved the higher tenderness of Ka geese muscles.

Key words: goose meat, technological trait, chemical composition, sensory property, texture profile

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INTRODUCTION

The sensory traits (color, juiciness, texture, and taste) of meat are essential features that make up the overall product quality assessment. Poultry meat quality depends, among other things, on anteslaughter and postslaughter factors as well as genotype.

The meat quality of high-yielding varieties and lines of slaughter animals is often insufficient. In the case of broiler chicken meat, PSE defects and myopathies of the pectoral muscles (DPM, WS, WB, the so-called spaghetti meat) reduce the quality of the raw meat material and constitute significant problems for the poultry industry (Berri et al., 2019; Tasoniero et al., 2020). An excellent alternative to the popular type of meat is goose meat. It is known that highly specialized poultry lines have limited adaptability to extensive rearing (Dal Bosco et al., 2021). Old, domestic varieties of geese are characterized by good health and fertility, high egg quality, the ability to use less valuable feed, and resistance to adverse climatic conditions to meet the extensive rearing (Książkiewicz, 2007). Because of good musculature and low fatness, these geese may serve as a natural gene resource, for example, for selecting improved qualitative traits of raw poultry meat material (Isguzar and Pingel, 2003).

The rearing of high-yielding breeds causes the displacement of native, local species with lower productivity from the market. This leads to the negative phenomenon of limiting biodiversity. Effective protection against the extinction of native poultry breeds depends on finding a place for them in the new economic situation. "Eat it to save it"—when the demand for the meat of local varieties of geese increases, producers will be interested in introducing them to commercial production, which will undoubtedly help save the old local breeds of poultry from extinction. Evaluating the

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physicochemical and sensory properties of goose meat from conservation flocks and disseminating the obtained results will help make consumers and poultry producers aware of the advantages of this meat.

The primary commercial crosses for geese meat production in Poland are White Kołuda geese bred from White Italian (Nowicka and Przybylski, 2018). They are fattened with oats and known as “Polish oat geese” in European markets. However, in Poland, there are also geese kept in flocks covered by the waterfowl genetic resource conservation program. Fourteen varieties of these birds are currently raised, and their population is about 5,600 females (Polak, 2017).

Studies on Polish domestic geese mainly concern reproductive and production traits such as reproduction performance, laying, live weight gain, dressing percentage, and proportions of carcass elements (Mazanowski and Bednarczyk, 2001; Mazanowski et al., 2004, 2005, 2006). This meat has already been tested for the nutritional value of fat and proteins and physicochemical properties (Okruszek, 2011; Okruszek et al., 2013; Haraf et al., 2018, 2021), but technological and sensory traits of the geese meat were the subject of little research (Lewko et al., 2017). Therefore, it was recognized as appropriate to undertake studies in this direction.

The present study aimed to characterize the physicochemical and sensory properties of the breast and thigh muscles of geese varieties from northern Poland—Kartuska and Suwalska, and southern Poland—Kielecka and Lubelska. The color of the muscles was characterized by sensory evaluation as well as the L *, a *, b * color parameters and the content of heme pigments. The technological properties were also determined, that is, pH_{24}, water-binding capacity (**WBC**), water-holding capacity (**WHC**), cooking (**CL**), and roasting losses (**RL**). After roasting, instrumental texture profile analysis (**TPA**) and sensory evaluation of the breast and thigh muscles were performed, and their chemical composition was determined. The above study results will also help to determine whether and how Polish geese's origin and muscle type affect the meat's quality characteristics.

MATERIALS AND METHODS

The study involved 17-wk-old female geese of 4 Polish native varieties registered on the FAO World Watch List (2000): Kartuska (**Ka**), Suwalska (**Su**) (native to northern Poland), Lubelska (**Lu**), and Kielecka (**Ki**) (native to southern Poland), maintained using the in situ method at the Research Station of Waterfowl Genetic Resources in Dworzyska, belonging to the Experimental Station of the National Research Institute of Animal Production in Kołuda Wielka. All geese were fed ad libitum on complete feeds (Table 1). Rearing conditions are described in the paper by Haraf et al. (2021). Eighteen birds from each genotype were chosen. Birds were subjected to feed withdrawal for 12 h and then slaughtered according to the relevant regulations applied in the Polish poultry industry. The average body weight at the slaughter of Ka, Su, Lu, and Ki geese was 4,443 g; 4,455 g; 4,123 g; and 4,152 g, respectively. After slaughter, the eviscerated carcasses were stored in refrigerated conditions (0°C−4°C). The carcasses were jointed after a 24-h 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 percentages in Ka, Su, Lu, and Ki carcasses were as follows: 15.4, 14.6, 15.7, and 15.5%, and the breast muscle percentages were 19.0, 18.1, 19.0, and 20.4 %, respectively. The number of muscles collected to determine individual features varied (18 or 12), and their number was given in the tables with the test results. Color parameters L, a*, b*, and pH_{24} were determined in raw muscles cut from the right side of the carcass. Next, the color sensory evaluation of the whole raw muscles was carried out. Then muscles were divided into 2 parts. One of them was frozen to determine the total heme pigments (**THPs**) content. The second part was preliminarily ground in a laboratory grinder (mesh size 3 mm), and the WBC, WHC, and CLs were determined.

The whole breast and thigh muscles cut from the left side of the carcass were wrapped in aluminum foil and roasted in a convection oven (model EB7551B Fusion, Amica Ltd., Wronki, Poland) until an internal temperature of 75°C was reached. The internal temperature in the center of each meat sample was monitored using Teflon-coated thermocouples (Type T, Omega Engineering Inc., Stamford, CT) attached to a Doric multichannel data logger (VAS Engineering Inc., San Diego, CA). Next, samples were cooled, and the RLs were calculated from the difference in weights before and after roasting. After 24-h refrigerated storage, instrumental TPA, shear force (**SF**), and sensory evaluation samples were cut out from roasted muscles. The rest of the muscles was ground, and the basic chemical composition was determined.

Table 1. Nutrient contents of feed mixtures.

Item	Age of geese: 1−6 wk	Age of geese: 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
Lysine	1.05	0.820
Methionine	0.49	0.46
Calcium	0.85	0.86
Total phosphorus	0.70	0.80
Vit. A (IU/kg)	15.000	14.000
Vit. D_3 (IU/kg)	3.500	2.000
Vit. E (mg/kg)	60	50
Metabolizable energy (ME)[1] (MJ/kg of all-mash)	12	11.3

[1]The caloric value of all-mashes calculated on the basis of percentage content of some analytic 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 (J. 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).

Color of Muscles

The color of muscles was characterized by the determination of THP concentration, the relative concentration of myoglobin (**Mb**), oxymyoglobin (**MbO_2**), and metmyoglobin (**MMb**); color parameters L* (lightness), a* (redness), and b* (yellowness); ΔE (color difference), C (saturation – chroma), h° (hue), and sensory evaluation of the surface color.

Heme pigments were extracted according to the procedure reported by Warris in the modification of Pikul et al. (1982). The muscles were frozen at −18°C for 24 h and subsequently (without thawing) cut into thin flakes. Next, about 10 g of sample were homogenized with 50 cm^3 of phosphate buffer (pH 6.8) at 4°C to 6°C for 1 min at 3,000 rpm (IKA homogenizer, SBS-MR-2500, IKA-Werke GmbH & Co, Staufen, Germany). The homogenate was stored at 4°C to 6°C for 1 h. After that time, it was centrifuged at 4,000 × g for 10 min. After supernatant decantation, the remainder was extracted again with 42.5 cm^3 of the buffer mentioned above and centrifuged (in the same conditions as previously). Both supernatants were mixed, and the volume was measured. The extract was centrifuged at 30,000 × g for 1 h (MPW-351 Centrifuge, Warsaw, Poland) and filtered with the Whatman 1 paper filters. The absorbance was measured at 525, 545, 565, and 572 nm using the Specord 210 (Analytic Jena AG, Jena, Germany). The percentages of Mb, MbO_2, and MMb were calculated with the equations given by Krzywicki (1982).

$$\mathrm{Mb} = 0,369\mathrm{A}_1 + 1,140\mathrm{A}_2 - 0,941\mathrm{A}_3 + 0,015$$

$$\mathrm{MbO}_2 = 0,882\mathrm{A}_1 - 1,267\mathrm{A}_2 + 0,809\mathrm{A}_3 - 0,361$$

$$\mathrm{MMb} = -2,514\mathrm{A}_1 + 0,777\mathrm{A}_2 + 0,800\mathrm{A}_3 + 1,098$$

where: $A_1 = A_{572}/A_{525}$; $A_2 = A_{565}/A_{525}$; $A_3 = A_{545}/A_{525}$.

Color parameters was measured on the muscle surface using the chromameter Minolta (model CR-310, Konica Minolta Co., Ltd., Osaka, Japan) in the CIE L*a*b* color system (CIE, 1986). The apparatus was calibrated according to the white reference standard $Y = 94.2$; $x = 0.313$; $y = 0.324$. The final value of color parameter was the average of 3 measurements taken at different locations in the muscle. Values of C, h°, and ΔE were calculated from the following formulas:

$$C = \left(a^{*2} + b^{*2}\right)^{\frac{1}{2}}$$

$$h^\circ = tg^{-1}\left(\frac{b^*}{a^*}\right)$$

$$\Delta E = [(\Delta L*)^2 + (\Delta a*)^2 + (\Delta b*)^2]^{1/2}$$

where $\Delta L = L_1 - L_2$; $\Delta a = a_1 - a_2$; $\Delta b = b_1 - b_2$.

The sensory evaluation of the muscle color was carried out by 7 trained panelists according to the international standard (ISO, 1988) using the 6-point scale expressed in conventional units (**CUs**; Stone et al., 1980). The scale criteria were as follows: 6—intense red, 5—red, 4—less intense red, 3—pink-red, 2—pink, and 1—light pink. The color was assessed on the dorsal side of the muscle.

Technological Traits of Muscles

The pH_{24} was measured in the muscle using a pH meter (Hach Lange S.L.U., Barcelona, Spain) with a dagger electrode (Double Pore Slim, Hamilton Company, Bonaduz, Switzerland). The measurement consisted in inserting an electrode into the muscle. The final result was the mean of 3 measurements taken in different locations in the muscle.

The determination of WBC consists in homogenizing the meat with the appropriate addition of water and then centrifuging the water that has not been bound (Wierbicki et al., 1962). Ground meat (20 g) was homogenized (10,000 rpm for 2 min) with 60 cm^3 of distilled water at 25°C. The obtained homogenate was poured into 2 tubes (35 cm^3 each) and centrifuged for 10 min at 4,000 rpm. The WBC of meat proteins was calculated from the average volume of the obtained clear liquids (v), using the formula:

$$WBC = 300 - (11.43 \times v)[\%]$$

WHC, defined as expressible juice, was determined based on the mass of free water squeezed from a ground meat sample by Grau and Hamm (1952) method. Ground meat samples (weighing about 300 mg) were placed on a weighed filter paper between 2 glass tiles. A force of 2 kg was applied on each sample. After 5 min of squeezing, the filter paper with a stain of squeezed meat juice was immediately weighed. WHC was calculated according to the following formula:

$$WHC = \frac{Z - U}{Z} \times 100\ [\%]$$

Z is the water content in the sample (mg).

U is the loss of meat juice in the sample due to the applied load (mg).

To determine the CL, 20 g of ground meat (with an accuracy of 0.01 g) was weighed, shaped into a ball, and placed in a metal tea strainer in a boiling water bath. The heat treatment was carried out for 20 min, after which the sample was cooled in water for 5 min and then allowed to drain for 10 min. CL was calculated from the difference in weight before and after heat treatment using the formula:

$$\mathrm{CL} = \frac{\text{weight before cooking} - \text{weight after cooking}}{\text{weight before cooking}} \times 100\ [\%]$$

RLs were calculated from the same formula, from the difference in weight before and after roasting.

Chemical Composition

The protein, fat, and moisture of roasted goose meat were determined using AOAC methods (AOAC, 2016).

Table 2. Descriptors and point scales used in sensory evaluation of goose meat.

Sensory trait	Meaning of scores on a 0–10 point scale
Smell and taste typical	0—extremely low desirability of the trait; 10—extremely high desirability of the trait
Tenderness	
Cohesiveness	
Juiciness	
Feeling of fattiness	0—extremely high desirability of the trait; 10—extremely low desirability of the trait
Springiness	
Overall palatability	0—dislike extremely; 10—like extremely

Before analysis, muscles were ground separately (mesh size 3 mm) and homogenized with an IKA homogenizer (SBS-MR-2500, IKA-Werke GmbH & Co, Staufen, Germany). The moisture (%) content was calculated by weight loss after 12-h oven drying of samples (3 g) at 102°C (to constant weight) in a Memmert laboratory dryer (UN 75, Schwabach, Germany) (950.46B, p. 39.1.02). Crude protein (%) content was determined by the Kjeldahl method with an automatic Kjeldahl nitrogen analyzer (Kjeltec 2300 Foss Tecator distiller Häganäs, Sweden) (992.15, p. 39.1.16). For conversion of nitrogen into crude protein, a factor of 6.25 was used. Fat (%) content was measured by the Soxhlet method with the petroleum ether extraction using a Hanon Automatic Soxhlet Extractor (SOX 606, Hanon Advanced Technology Group Co., Ltd, Jinan, China) (960.39 (a), p. 39.1.05).

Sensory Evaluation

The sensory evaluation of roasted goose meat was carried out using quantitative descriptive analysis with a 10-point scale expressed in CUs (Stone et al., 1974, 1980; Stone and Sidel, 2004). All sensory work was carried out at the sensory laboratory (ISO, 1988) in the Department of Food Technology and Nutrition in Wroclaw (Poland). A panel of 7 judges, based on previous experience with sensory analysis of meat, was selected. In the beginning, the panel members agreed on the descriptors. Samples for evaluation were cut into cubes with a side length of 1.5 cm, coded, and analyzed for the desirability of sensory traits. Descriptors and used scale are shown in Table 2.

Texture Profile Analysis and Warner-Bratzler Shear Force

Texture profile analysis was performed using methods published by Bourne (1978, 2002) at room temperature with the Instron Universal Testing Machine (model 5543, Instron Corp. Canton, Norwood, MA). Two samples parallel to the longitudinal orientation of the muscular fibers were cut from each muscle. Samples for TPA analysis were cylindrical in shape, 1 cm high, and 1.27 cm in diameter at the base. They were collected using a handheld steel cork borer. Each sample was compressed in 2 consecutive cycles of 70% compression with 5 s between cycles, using a cylindrical probe of 5.7 cm diameter. The crosshead moved at a constant speed of 50 mm/min. From the resulting force-time curve, the following parameters were determined (Bluehill 3—testing Software Instron): hardness (the maximum peak force during the first compression); springiness (the height that the sample recovers between the end of the first compression and the beginning of the second compression); cohesiveness (ratio of the force area during the second compression to that during the first compression); gumminess—the product of hardness and cohesiveness; and chewiness—the product of springiness and gumminess (Bourne, 1978). SF measurement was also performed at room temperature using an Instron Universal Testing Machine (model 5543, Instron Corp. Canton, Norwood, MA) equipped with a Warner-Bratzler blade. The meat cylinders (1 cm in height and 2.54 cm in diameter of the base) were sheared using a crosshead speed of 50 mm/min.

Statistical Analysis

One-way ANOVA was used for the statistical analysis of the results. 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

Color of Raw Muscles

The color of raw meat was established by sensory evaluation and by determining the color parameters (Table 3), ΔE (Table 4), and the content of THP (Table 5). The calculated ΔE values make it possible to assess the color differentiation of the breast and thigh muscles between genotypes. The highest value of ΔE was found for the breast and thigh muscles between the Ka and Ki geese (2.90 and 2.37, respectively). The Ka meat (both kinds of muscles) was more intense than Ki because of higher scores in the color sensory evaluation (4.23 vs. 3.85), higher THP (3.99 vs. 3.67 mg/g of meat), and low L* values (45.13 vs. 47.28) than Ki meat ($P \leq 0.05$).

The breast muscles' color (regardless of the genotype) was more intense than that of the thigh muscles, which confirms by lower metmyoglobin (0.25 vs. 0.30), higher oxymyoglobin (0.45 vs. 0.35), lower lightness (L*) (43.05 vs. 49.28), higher intensity of red (a*) (17.53 vs. 15.33), lower yellow color intensity (b*) (2.20 vs. 1.68), and higher scores in sensory evaluation (4.29 vs. 3.74 CU). Moreover, the breast muscles' color was more saturated than the thigh muscles (C value was higher by 2.09) ($P \leq 0.05$).

Table 3. Color sensory evaluation and color parameters (CIE-Lab) of raw goose muscles ($n = 18$ breast and $n = 18$ thigh muscles for each genotype).

Parameter	Muscle	Genotype Ka	Su	Lu	Ki	Total	SEM
Color sensory evaluation [CU]	B	4.52^{a}	4.21^{ab}	4.31^{ab}	4.10^{b}	4.29^{x}	0.06
	T	3.94^{a}	3.67^{ab}	3.75^{ab}	3.60^{b}	3.74^{y}	0.05
	Total	4.23^{a}	3.94^{ab}	4.03^{ab}	3.85^{b}		
	SEM	0.11	0.09	0.07	0.08		
L*	B	42.34	43.00	43.08	44.52	43.05^{y}	0.33
	T	47.92	49.22	49.24	50.04	49.28^{x}	0.48
	Total	45.13^{b}	46.11^{ab}	46.16^{ab}	47.28^{a}		
	SEM	1.09	0.78	0.78	0.74		
a*	B	18.35^{a}	17.95^{a}	16.78^{b}	16.50^{b}	17.53^{x}	0.20
	T	15.94^{a}	14.87^{b}	15.02^{ab}	15.80^{ab}	15.33^{y}	0.16
	Total	17.15^{a}	16.41^{ab}	15.90^{b}	16.15^{ab}		
	SEM	0.30	0.40	0.27	0.42		
b*	B	1.31	1.76	1.90	1.81	1.68^{y}	0.15
	T	3.15^{a}	1.79^{b}	2.23^{ab}	2.09^{ab}	2.20^{x}	0.20
	Total	2.23	1.77	2.07	1.95		
	SEM	0.24	0.18	0.24	0.45		
C	B	18.41^{a}	18.06^{a}	16.93^{b}	16.61^{b}	17.63^{x}	0.20
	T	16.35^{a}	15.00^{b}	15.23^{ab}	15.99^{ab}	15.54^{y}	0.17
	Total	17.38	16.52	16.08	16.30		
	SEM	0.39	0.29	0.26	0.41		
h°	B	4.05	5.47	6.51	6.22	5.47^{y}	0.48
	T	11.15^{a}	6.84^{b}	8.51^{ab}	7.50^{ab}	8.12^{x}	0.74
	Total	7.60	6.15	7.51	6.86		
	SEM	0.62	0.85	0.89	1.61		

Ka, Kartuska geese; Su, Suwalska geese; Lu, Lubelska geese; Ki, Kielecka geese; B, breast muscle; T, thigh muscle; L*, lightness; a*, red color intensity; b*, yellow color intensity; C, color saturation; h°, hue; CU, conventional unit.

[a-b]Different superscript letters in rows mean a significant difference between averages for genotypes ($P \leq 0.05$).

[x-y]Different superscript letters in columns mean a significant difference between averages for muscles ($P \leq 0.05$).

Technological Traits

The technological properties of the tested muscles are summarized in Table 6. The meat of Polish domestic varieties of geese has a high pH (5.7−6.0). It positively influences the course of biochemical changes in the carcass and is a vital and valuable feature in technological processes, classifying this product as "normal" meat. Ka and Lu geese thigh muscles showed higher pH_{24} (6.05 and 6.06) and WBC (103.21 and 105.45%) than Ki (5.89 and 86.92%, respectively). However, compared to Ka and Su, lower cooking and RLs were determined in Lu and Ki thigh muscles (by about: 2.5−3.0 and 0.5−2.25%, respectively) ($P \leq 0.05$).

Table 4. Color differences (ΔE) between genotypes within individual muscles.

	Breast Ka	Su	Lu	Ki
Ka				
Su	0.89			
Lu	1.83	1.18		
Ki	2.90	2.10	1.47	
	Thigh Ka	Su	Lu	Ki
Ka				
Su	1.27			
Lu	1.13	0.46		
Ki	2.37	2.16	1.85	

Ka, Kartuska geese; Su, Suwalska geese; Lu, Lubelska geese; Ki, Kielecka geese.

Breast muscles of Ki goose were the lowest in WHC value (53.46 vs. 58.53−59.45%) and, similar to Su, showed high RLs (42.92 and 42.90 vs. 41.11−41.21%, respectively). There were no significant differences in pH_{24}, WBC, and CLs in breast muscles of analyzed varieties.

Based on our studies, it can be concluded that the most favorable technological qualities among investigated geese were observed in Lu meat. Thigh muscles of Lu goose were characterized by relatively high pH_{24}, WBC, and WHC, and low cooking and RLs, while breast muscles were high in WHC and low in RLs. Muscles of Ki proved to be the least suited for processing because of the lower WBC of breast and thigh muscles and the low WHC of breast muscles.

The type of muscle had a significant influence on the technological properties. The thigh muscles had higher pH_{24} (6.00 vs. 5.76), higher WBC (97.19 vs. 51.99%), and WHC (66.65 vs. 58.31%), but at the same time had higher CLs (by 4%) and weight loss during roasting (by about 3%) ($P \leq 0.05$).

Chemical Composition, Sensory Traits, and Texture of Roasted Muscles

The highest content of protein was determined in roasted breast muscles of Ka geese (38.04 vs. 35.23−35.49%) and thigh muscles of Su geese (36.95 vs. 34.29−34.72%) (Table 7). Compared to roasted muscles of Ka and Su geese from northern Poland, muscles of geese

Table 5. Total heme pigment concentration (THP), the relative concentration of myoglobin, oxymyoglobin, and metmyoglobin in goose muscles ($n = 18$ breast and $n = 18$ thigh muscles for each genotype).

Parameter	Muscle	Genotype				Total	SEM
		Ka	Su	Lu	Ki		
THP (mg/g of meat)	B	4.09^{a}	4.00	3.87	3.68^{b}	3.91	0.06
	T	3.88	3.70	3.81	3.66	3.76	0.06
	Total	3.99^{a}	3.85^{ab}	3.84^{ab}	3.67^{b}		
	SEM	0.12	0.09	0.04	0.07		
Myoglobin	B	0.32^{a}	0.32^{a}	0.26^{b}	0.27	0.29^{y}	0.06
	T	0.42^{a}	0.36^{b}	0.35^{b}	0.27^{c}	0.35^{x}	0.06
	Total	0.37^{a}	0.34^{a}	0.29^{b}	0.27^{b}		
	SEM	0.08	0.07	0.08	0.02		
Oxymyoglobin	B	0.37^{a}	0.39^{a}	0.53^{b}	0.52^{b}	0.45^{x}	0.07
	T	0.25^{a}	0.33^{a}	0.32^{a}	0.50^{b}	0.35^{y}	0.07
	Total	0.31^{c}	0.36^{b}	0.43^{b}	0.51^{a}		
	SEM	0.11	0.08	0.15	0.05		
Metmyoglobin	B	0.31^{a}	0.29^{a}	0.21^{b}	0.20^{b}	0.25^{y}	0.06
	T	0.33^{a}	0.31	0.33^{a}	0.23^{b}	0.30^{x}	0.07
	Total	0.32^{a}	0.29^{a}	0.27^{a}	0.22^{b}		
	SEM	0.09	0.07	0.10	0.03		

Ka, Kartuska geese; Su, Suwalska geese; Lu, Lubelska geese; Ki, Kielecka geese; B, breast muscle; T, thigh muscle.
$^{a-c}$Different superscript letters in rows mean a significant difference between averages for genotypes ($P \leq 0.05$).
$^{x-y}$Different superscript letters in columns mean a significant difference between averages for muscles ($P \leq 0.05$).

Table 7. Basic chemical composition of roasted breast and thigh goose muscles ($n = 18$ breast and $n = 18$ thigh muscles for each genotype).

Parameter	Muscle	Genotype				Total	SEM
		Ka	Su	Lu	Ki		
Moisture	B	59.41^{a}	59.05^{ab}	59.99^{a}	58.27^{b}	59.18^{x}	0.18
	T	57.95^{a}	59.10^{b}	57.59^{a}	59.26^{b}	58.47^{y}	0.22
	Total	58.68^{b}	59.07^{a}	58.79^{ab}	58.76^{ab}		
	SEM	0.24	0.32	0.20	0.72		
Protein	B	38.04^{a}	35.23^{b}	35.49^{b}	35.33^{b}	36.02^{x}	0.33
	T	34.72^{b}	36.95^{a}	34.29^{b}	34.70^{b}	35.16^{y}	0.30
	Total	36.38^{a}	36.10^{ab}	34.89^{b}	35.02^{ab}		
	SEM	0.53	0.75	0.49	0.45		
Lipids	B	5.77^{a}	5.13^{ab}	4.08^{b}	5.07^{ab}	5.01^{y}	0.09
	T	6.49^{a}	6.98^{a}	6.13^{a}	5.90^{b}	6.37^{x}	0.11
	Total	6.13^{a}	6.05^{a}	5.11^{b}	5.48^{b}		
	SEM	0.22	0.55	0.16	0.5		

Ka, Kartuska geese; Su, Suwalska geese; Lu, Lubelska geese; Ki, Kielecka geese; B, breast muscle; T, thigh muscle.
$^{a-b}$Different superscript letters in rows mean a significant difference between averages for genotypes ($P \leq 0.05$).
$^{x-y}$Different superscript letters in columns mean a significant difference between averages for muscles ($P \leq 0.05$).

from the south (Lu and Ki) had less lipids (5.11−5.48 vs. 6.13−6.05%) ($P \leq 0.05$).

Table 8 shows the sensory evaluation results. The Ka breast and thigh muscles were the most tender (7.82 vs. 7.05−7.31) and received the highest score in overall palatability, although the differences were not always significant (8.89 vs. 8.48−7.88). The breast and thigh muscles of Ki geese were assessed as the least juicy (6.66 vs. 7.40 −8.08), cohesive (6.89 vs. 7.86−7.97), and numerically with the least perceptible smell and taste typical for goose meat (8.35 vs. 8.99−9.45). The Pearson's correlation coefficients, calculated using the Statistica 13.1, showed that decisive influence on a sensory general evaluation of muscles had tenderness ($r = 0.67$) and juiciness ($r = 0.54$), next cohesion ($r = 0.30$), and typical for goose meat smell and taste ($r = 0.26$).

Muscle type influenced some of the sensory traits (Table 8). The breast muscles of all genotypes were assessed as more tender (by 1.02 CU) but less juicy (by 1.33 CU) and less fatty (by 0.55 CU) than the thigh muscles. The lower moisture content (Table 7) and the higher cooking and RLs in the thigh muscles (Table 6) did not reduce the juiciness and overall score for these muscles, possibly due to the higher content of flavor-carrier lipids (Table 7).

Table 6. Technological traits of goose muscles ($n = 18$ breast and $n = 18$ thigh muscles for each genotype).

Parameter	Muscle	Genotype				Total	SEM
		Ka	Su	Lu	Ki		
pH_{24}	B	5.79	5.74	5.75	5.76	5.76^{y}	0.05
	T	6.05^{a}	5.98^{ab}	6.06^{a}	5.89^{b}	6.00^{x}	0.03
	Total	5.92	5.86	5.91	5.83		
	SEM	0.05	0.03	0.05	0.05		
Water-binding capacity (%)	B	55.27	51.31	51.82	47.58	51.99^{y}	1.7
	T	103.21^{a}	91.12^{ab}	105.45^{a}	86.92^{b}	97.19^{x}	3.06
	Total	78.10^{a}	71.64^{ab}	74.81^{ab}	67.25^{b}		
	SEM	5.98	3.72	4.93	5.18		
Water-holding capacity (%)	B	58.53^{a}	59.45^{a}	59.38^{a}	53.46^{b}	58.31^{y}	0.99
	T	67.56^{ab}	64.12^{b}	68.31^{a}	66.56^{ab}	66.65^{x}	0.78
	Total	63.04	61.79	63.85	60.01		
	SEM	1.46	1.05	1.17	2.32		
Cooking losses (%)	B	27.35	27.48	27.20	27.05	27.27^{y}	0.18
	T	32.83^{a}	32.46^{a}	29.94^{b}	29.86^{b}	31.27^{x}	0.33
	Total	30.09^{a}	29.97^{a}	28.57^{b}	28.46^{b}		
	SEM	0.84	0.82	0.55	0.65		
Roasting losses (%)	B	41.21^{b}	42.90^{a}	41.11^{b}	42.92^{a}	42.04^{y}	0.21
	T	45.35^{a}	45.96^{a}	43.71^{b}	44.89^{ab}	44.98^{x}	0.24
	Total	43.28^{ab}	44.43^{a}	42.41^{b}	43.91^{ab}		
	SEM	0.32	0.27	0.23	0.83		

Ka, Kartuska geese; Su, Suwalska geese; Lu, Lubelska geese; Ki, Kielecka geese; B, breast muscle; T, thigh muscle.
$^{a-b}$Different superscript letters in rows mean a significant difference between averages for genotypes ($P \leq 0.05$).
$^{x-y}$Different superscript letters in columns mean a significant difference between averages for muscles ($P \leq 0.05$).

Table 8. Sensory evaluation of goose muscles (CU) ($n = 12$ breast and $n = 12$ thigh muscles for each genotype).

		Genotype					
Parameter	Muscle	Ka	Su	Lu	Ki	Total	SEM
Smell and taste typical	B	9.00[a]	9.28[a]	8.96[a]	8.01[b]	8.81	0.07
	T	9.43[a]	9.62[a]	9.01[b]	8.70[b]	9.19	0.1
	Total	9.21[a]	9.45[a]	8.99[ab]	8.35[b]		
	SEM	0.15	0.12	0.16	0.17		
Tenderness	B	8.35[a]	7.80[b]	7.64[b]	7.52[b]	7.82[x]	0.09
	T	7.30[a]	6.82[b]	6.50[b]	6.57[b]	6.80[y]	0.12
	Total	7.82[a]	7.31[b]	7.07[b]	7.05[b]		
	SEM	0.28	0.26	0.34	0.29		
Cohesiveness	B	7.99[a]	7.63[a]	7.88[a]	6.92[b]	7.60	0.11
	T	7.96[a]	8.04[a]	7.84[a]	6.86[b]	7.67	0.12
	Total	7.97[a]	7.83[a]	7.86[a]	6.89[b]		
	SEM	0.39	0.28	0.32	0.15		
Juiciness	B	7.43[ac]	6.73[ad]	7.10[a]	5.85[b]	6.77[y]	0.11
	T	8.73[a]	8.47[a]	7.70[b]	7.48[b]	8.10[x]	0.10
	Total	8.08[ac]	7.60[a]	7.40[ad]	6.66[b]		
	SEM	0.32	0.27	0.33	0.29		
Feeling of fattiness	B	1.56[ab]	1.69[a]	1.22[b]	1.33[ab]	1.45[y]	0.06
	T	2.16[a]	2.20[a]	1.86[ab]	1.76[b]	2.00[x]	0.07
	Total	1.86[ab]	1.94[a]	1.54[b]	1.55[b]		
	SEM	0.01	0.20	0.24	0.24		
Springiness	B	1.36	1.75	1.66	1.90	1.66	0.11
	T	1.25	1.69	1.63	1.84	1.60	0.10
	Total	1.30	1.72	1.64	1.87		
	SEM	0.15	0.36	0.31	0.42		
Overall palatability	B	8.93[a]	8.28[b]	8.22[b]	7.97[b]	8.35	0.09
	T	8.85[a]	8.68[a]	7.99[b]	7.79[b]	8.32	0.12
	Total	8.89[a]	8.48[ab]	8.10[b]	7.88[b]		
	SEM	0.12	0.23	0.24	0.28		

Ka, Kartuska geese; Su, Suwalska geese; Lu, Lubelska geese; Ki, Kielecka geese; CU, conventional unit; B, breast muscle; T, thigh muscle.
[a-d]Different superscript letters in rows mean a significant difference between averages for genotypes ($P \leq 0.05$).
[x-y]Different superscript letters in columns mean a significant difference between averages for muscles ($P \leq 0.05$).

TPA parameters and SF of goose muscles are presented in Table 9. Values of texture components, that is, hardness and chewiness of Ki geese breast muscles, were significantly higher than for muscles of Su by 15.08 N and 7.12, respectively. In the case of thigh muscles, values of these traits for Ki geese were higher than for Ka

Table 9. TPA parameters and shear force of goose muscles ($n = 12$ breast and $n = 12$ thigh muscles for each genotype).

		Genotype					
Parameter	Muscle	Ka	Su	Lu	Ki	Total	SEM
Hardness (N)	B	62.43[ab]	50.80[b]	57.89[ab]	65.88[a]	59.25	1.86
	T	52.36[b]	55.26[ab]	54.22[ab]	60.03[a]	55.46	1.80
	Total	57.39[ab]	53.03[b]	56.05[ab]	62.95[a]		
	SEM	6.11	3.94	2.74	2.28		
Cohesiveness	B	0.40	0.39	0.43	0.45	0.42	0.02
	T	0.38	0.44	0.45	0.41	0.42	0.02
	Total	0.39	0.41	0.44	0.43		
	SEM	0.03	0.02	0.03	0.02		
Gumminess (N)	B	25.11[ab]	20.42[b]	25.18[ab]	30.90[a]	25.40	2.91
	T	19.05[b]	25.89[ab]	23.50[ab]	24.64[a]	23.27	1.45
	Total	22.08[b]	23.16[ab]	24.34[ab]	27.77[a]		
	SEM	4.75	2.80	2.54	1.54		
Springiness	B	0.71	0.71	0.71	0.70	0.71	0.01
	T	0.70	0.71	0.74	0.75	0.73	0.01
	Total	0.71	0.71	0.72	0.72		
	SEM	0.01	0.02	0.01	0.01		
Chewiness (N)	B	17.29[ab]	14.10[b]	17.80[ab]	21.22[a]	17.60	1.83
	T	15.15[b]	16.95[ab]	18.05[ab]	19.60[a]	17.44	1.01
	Total	16.22[ab]	15.52[b]	17.92[ab]	20.41[a]		
	SEM	2.98	1.72	1.88	0.84		
Shear force (N)	B	22.61[b]	25.25[ab]	26.78[ab]	29.47[a]	26.03[y]	1.60
	T	30.96[b]	33.99[ab]	35.23[ab]	38.47[a]	34.66[x]	2.00
	Total	26.78[b]	29.62[ab]	31.01[ab]	33.97[a]		
	SEM	2.15	2.05	1.93	1.89		

Ka, Kartuska geese; Su, Suwalska geese; Lu, Lubelska geese; Ki, Kielecka geese; B, breast muscle; T, thigh muscle.
[a-b]Different superscript letters in rows mean a significant difference between averages for genotypes ($P \leq 0.05$).
[x-y]Different superscript letters in columns mean a significant difference between averages for muscles ($P \leq 0.05$).

muscles by 7.94 N and 4.45 ($P \leq 0.05$). The breast and thigh muscles of Ki geese were characterized by higher SF than the Ka muscles ($P \leq 0.05$). In the case of breast muscles, the difference was equal to 6.86 N and in thigh muscles to 7.51 N.

The mean value of SF for breast muscles of all genotypes was lower than for thigh muscles (26.03 vs. 34.66 N) ($P \leq 0.05$). This suggests higher tenderness and confirms sensory evaluation results. The kind of muscle did not significantly affect the TPA results.

DISCUSSION

In the studies by Okruszek et al. (2008) and Okruszek (2012), the Ka and Su meat were lower in L* (43.0 for both), higher in b* (2.63 and 2.54), and comparable in a* (17.1 and 16.4), compared to the present study. Lewko et al. (2017) reported that the color of Lu and Ki breast and leg muscles was less red and more yellow (a* and b* values in the range 10.45−14.01 and 3.27−10.97, respectively). Moreover, breast muscles were darker in color (L* value about 42.0) compared to the present results. The breast muscles of the White Kołuda geese, popular in Poland and exported to other European countries as the "Polish oat geese," were characterized by a darker (L* 37.87−40.25) and redder color (a* 19.30 −20.02). In the case of the intensity of the yellow color, these values ranged from 3.23 to 1.33 (Orkusz et al., 2017; Wołoszyn et al., 2020). Breast muscles of 16-wk-old female geese of Czech domestic breeds, Eskildsen Schwer and Czech goose, were characterized by lower *L** value (36.87 and 35.85), lower intensity of red (12.16 and 10.53), and much higher intensity of yellow (10.15 and 10.44) (Uhlířová et al., 2018). However, breast and thigh muscles of local Lithuanian Vistines geese at the age of 10 wk had comparable redness (16.85 and 16.82) and C values (17.23 and 17.36) but higher yellowness (4.74 and 4.69) and h° values (12.68 and 14.56) (Razmaitė et al., 2022). Kirmizibayrak et al. (2011) reported lower L*, a*, and b* values in the female Turkish geese' breast and thigh meat (40.59, 12.30, 0.83 for breast and 43.86, 9.79, 0.91 for thigh respectively).

Similar to our results, Okruszek et al. (2008), Kirmizibayrak et al. (2011), Okruszek (2012), Oz and Celik (2015), and Lewko et al. (2017) also reported that the raw breast goose muscles are darker than the thigh.

Ka, Su, Lu, and Ki breast muscles were higher in THPs than Polish commercial hybrid White Kołuda geese (4.09−3.68 vs. 2.65 mg/g of meat). The meat of these geese was also characterized by a similar share of Mb (0.248), higher MbO_2 (0.569), and lower MMb (0.183). Moreover, White Kołuda breast muscles received 5.76 CU in the color sensory evaluation while Ka, Su, Lu, and Ki received slightly lower scores (4.10 −4.52 CU) (Orkusz et al., 2017).

The final pH values of the breast muscles of Polish geese Ka, Su, Lu, and Ki are consistent with the results of the research obtained for the Turkish, Czech, and Lithuanian geese (Kirmizibayrak et al., 2011; Oz and Celik, 2015; Sari et al., 2015; Uhlířová et al., 2018). According to Kapkowska et al. (2011), the breast muscles of White Kołuda and the Polish native Zatorska geese were characterized by a higher pH (6.16 and 6.12) than those analyzed in Ka, Su, Lu, and Ki's muscles. Liu et al. (2011) also determined higher pH in the breast muscles of female Yangzhou geese (6.4). In the case of thigh muscles, Oz and Celik (2015) and Razmaitė et al. (2022) reported higher pH values for Turkish (6.78) and Lithuanian (6.51) native geese compared to the present studies results.

In the present research, thigh muscles had a significantly higher pH value than breast muscles. A similar relationship was not found by Sari et al. (2015) for Turkish geese and Okruszek (2012) for Ka and Su.

The comparison of the obtained WHC values with the results of other authors presents some difficulties because it was most often expressed as a percentage of the initial weight loss of the sample. However, our research defined it as the percentage of own water remaining in the sample after compression. WHC values of the Ka, Su, Lu, and Ki breast muscles can be compared with those obtained by Skrabka-Błotnicka et al. (1997) and were higher than that of the White Italian goose WD-3 by approx. 5.5−7%. In turn, the WBC of breast muscles of the studied geese was higher than the muscles of females from parental strains of White Kołuda (W11 and W33) and their hybrids by approx. 7.4−36.4% (Rosiński et al., 1999; Biesiada-Drzazga, 2006).

Lewko et al. (2017) determined lower CLs for Lu and Ki's breast muscles than the present studies results. On the other hand, higher CL for breast muscles were shown in Polish White Kołuda (29.35−37.13%) and Zatorska (29.17−35.8%) geese as well as in Turkish (30.7−34.9), Lithuanian Vistines (38.5%), and Eskildsen Schwer and Czech geese (33.65 and 37.14%) (Kapkowska et al., 2011; Sari et al., 2015; Uhlířová et al., 2018; Gumułka and Połtowicz, 2020; Wołoszyn et al., 2020; Razmaitė et al., 2022). However, CL values for leg muscles of White Kołuda (30.12%), Zatorska (29.61%), Turkish (32.3 and 33.8%), and Lithuanian Vistines (31.52%) geese reported by other authors were comparable to values obtained for Ka, Su, Lu, and Ki (Sari et al., 2015; Gumułka and Połtowicz, 2020; Razmaitė et al., 2022).

RLs determined for Ka, Su, Lu, and Ki were higher than for Turkish domestic geese (33.81% in breast and 25.74% in thigh) and Polish White Kołuda goose (40.5 in breast) (Oz and Celik, 2015; Wołoszyn et al., 2020).

Compared to the Ka, Su, Lu, and Ki, the roasted breast and leg muscles of Turkish domestic geese were characterized by higher moisture content (61.70 and 63.04) and lower protein (26.19 and 24.60), and higher fat (5.94 and 7.96) (Oz and Celik, 2015). The Polish White Kołuda breast muscles contained less moisture (58.1%), less protein (33.8%), and a comparable amount of fat (5.5%) (Goluch et al., 100AD). In contrast, according to Belinsky and Kuhnlein (2000), the skinless meat of the Canadian regional geese contained a similar amount of water (58.9%), lower protein (30.8%), and higher fat (7.6%). The comparison of the data on chemical composition obtained by other authors shows that the analyzed roasted meat of Polish domestic geese contains more protein than all the geese genotypes mentioned.

In a sensory evaluation by Lewko et al. (2017), the Lu breast and thigh muscles were rated higher in tenderness and smell and received a higher total score than the Ki, but there were no significant differences in juiciness and taste. In our study, the Lu breast muscles, compared to Ki, were rated higher in smell, taste, and juiciness, but no significant differences in overall palatability were noted. In the case of the thigh muscles of Ka, Su, Lu, and Ki, there were no significant differences in all evaluated sensory traits. Compared with current breast muscles sensory evaluation results, Wołoszyn et al. (2020) reported lower scores of typical smell and taste, tenderness, juiciness, and overall palatability for White Kołuda geese.

In texture profile analysis by Razmaitė et al. (2022), the Lithuanian Vistines goose breast and leg muscles showed lower hardness (50.95 and 29.44 N) and gumminess (22.91 and 12.35 N) while higher cohesiveness (2.24 and 2.21) and springiness (0.87 and 0.86) than Ka, Su, Lu and Ki muscles. The muscle type in the studies mentioned above influenced all rheological parameters, including SF. The breast muscles had significantly higher values than the thighs, but no such relationship was observed in our study. TPA analysis of White Kołuda breast muscles revealed higher hardness (325.9 N), cohesiveness (0.49), gumminess (151.24 N), and chewiness (113.84 N), while lower springiness (0.56) than Ka, Su, Lu and Ki muscles (Wołoszyn et al., 2020). The SF of breast muscles of White Kołuda (50.26−72.58 N), the Polish, domestic Zatorska goose (43.22−50.22 N), and Eskildsen Schwer (39.22 N) and Czech geese (38.92) was higher than in the present study (Kapkowska et al., 2011; Uhlířová et al., 2018; Gumułka and Połtowicz, 2020; Wołoszyn et al., 2020).

CONCLUSIONS

Ka geese's breast and thigh muscles were the darkest, and Ki the lightest in color from the studied genotypes. Considering the least and the most favorable values of breast and thigh muscles' technological characteristics (high pH_{24}, high WBC and WHC, low RL and CL), the varieties can be ranked as follows: Lu > Ka > Su > Ki. Roasted breast and thigh muscles of northern varieties of geese (Ka and Su) had a higher concentration of lipids than geese of southern varieties (Lu and Ki). Both breast and thigh muscles of Ka geese were characterized by the best sensory traits because of high scores in tenderness, juiciness, and overall palatability. The low SF value proved the higher tenderness of Ka geese muscles. Considering the sensory and texture evaluation results for both kinds of muscles, analyzed genotypes can be ranked as follows: Ka > Su > Lu > Ki.

It is difficult to unequivocally summarize the influence of the type of muscle on the technological and sensory properties. Thigh muscles absorbed water better and were higher in WHC, but at the same time, weight losses during thermal treatment of these muscles were greater compared to breasts. The sensory panel assessed the breast muscles as more tender and less juicy, but no significant differences in the overall palatability were observed.

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DISCLOSURES

The authors declare no conflicts of interest.

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