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ASSESSMENT OF SUITABILITY AND LIPID QUALITY INDICATORS OF LAMB MEAT OF POLISH NATIVE BREEDS

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Abstract

The aim of our study was to evaluate the technological (pH, water holding capacity, cooking loss, oxidation-reduction potential, water activity, color parameters, and microbiological purity) and nutritional suitability of the meat of selected lamb breeds by analyzing the indicators (fatty acid profile, fat nutritional indices, lipid oxidation, basic meat composition) that determine the quality of lipids present in the meat. A comparative analysis of meat from native Polish breeds Uhruska, Świniarka, and Wrzosówka showed that these breeds are characterized by high-quality meat. The chemical composition of meat did not significantly differ between the studied breeds. However, the fatty acid composition and atherogenicity and thrombogenicity indices of meat differed significantly between the breeds with the meat of Wrzosówka lambs having a distinct advantage and the most significant potential to protect against cardiovascular problems. Furthermore, the meat of Wrzosówka breed had color parameters that are most desired by consumers. The results presented here are of practical importance as combining meat from different breeds of lambs can allow achieving high product quality. The meat of Wrzosówka breed can be successfully used for producing such products and can serve as flagship meat for export to other European and global markets.

Key words: Polish native lamb breeds, Wrzosówka lambs, lamb meat, lipid quality, technological suitability

Lamb is consumed relatively less compared to other types of meat (FAOSTAT, 2021). However, the production volume and consumption of lamb meat vary to a great extent around the world. Consumers in Western Asia and North Africa mostly prefer lamb. After a period of recession, there has been a steady and systematic increase in sheep production over the last 30 years (FAOSTAT, 2021). In 2020, 0.45 million tons of lamb were produced in the European Union (EU), compared to 23 million tons of pork, 13.6 million tons of poultry meat, and 5.9 million tons of beef (Eurostat, 2020). Sheep meat and its products are widely appreciated and consumed due to their high nutritional value and good sensory characteristics. Small ruminant meat is an essential source of protein with high biological value as it contains various bioactive ingredients such as taurine, carnosine, anserine, L-carnitine, coenzyme Q, creatine, and creatinine (Decker and Park, 2010). It is also rich in minerals such as potassium, zinc, iron, selenium, and phosphorous as well as vitamins such as niacin, pantothenic acid, and cobalamin (Prache et al., 2022).

Meat is the primary protein source in the human diet and plays a crucial role in our food culture. Mutton is associated with the traditional cuisine of some countries, where it has high social and cultural significance and the consumption of other types of meat is prohibited for religious reasons (Teixeira et al., 2020). In Mediterranean countries, Barani meat dishes are considered a delicacy (Ponnampalam et al., 2016). Among sheep breeds, native ones deserve a special mention as they are perfectly adapted to the local environmental conditions. They are less prone to illness, and their the raw materials and products are of better quality (Barłowska, 2011). Reviews by FAO and other international organizations have emphasized the importance of native breeds as both sustainable food resources and living reservoirs of biodiversity, describing the genetic characteristics of adaptive adaptation to improve mainstream agriculture (EEA, 2010; Cadavez et al., 2020; Gazzarin and El Benni, 2020).

Many studies from Poland and other countries have compared the quality of lamb between different breeds, including local breeds (Cadavez et al., 2020; Gonzales-Barron et al., 2021; Janiszewski et al., 2021; Romanov et al., 2021; de Sousa et al., 2022; Prache et al., 2022). Sheep population in Poland is estimated to be around 288,000 heads (Rocznik GUS, 2021). Despite the small

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scale of production, the country has a wide range of native sheep breeds that provide high-quality meat. Several international and local programs that aim to protect sheep genetic resources introduced in Poland (FAO, 2007; European Commission, 2012; MRiRW, 2012) provide opportunities for developing sheep breeding. Due to the high quality and the natural methods of its production and processing, Polish lamb can be a profitable product for export to global markets. Janiszewski et al. (2021) confirmed the high sensory quality of lamb meat of Polish native breeds, especially Świniarka, Uhruska, and Wrzosówka. However, these breeds showed large variations in the examined physicochemical characteristics. There is also a lack of knowledge about which sheep breeds can provide meat with the most desirable technological features (pH, water absorption, color). In addition, despite widespread acceptance of lamb meat, the main factor affecting its nutritional quality and durability is, among others, the fat content and fatty acid profile. Moreover, due to the high proportion of unsaturated fatty acids (45% monounsaturated and 10% polyunsaturated) in the total fatty acids (Cunha et al., 2018; Oliveira et al., 2022), sheep meat is more susceptible to lipid oxidation which is one of the main mechanisms causing non-microbial spoilage, resulting in changes in meat color, discoloration, off-flavors, and rancidity (Jia et al., 2021). There is also no information on the profile of fatty acids, nutritional quality of fats, and oxidative stability of fats in lamb meat of native Polish breeds. Therefore, in this study, we assessed the technological usefulness of lamb meat of native Polish breeds, including the quality and durability of lipids, in terms of its suitability for the production of high-quality meat products.

Material and methods

Experimental animals, management, and design

The lambs of the Wrzosówka (WRZ), Świniarka (SWI), and Uhruska (UHR) breeds were kept in farm conditions that met the organic farming criteria (regulation EU 2018/848) in Lubelskie Voivodeship in Poland. From the second week of life, apart from mothers' milk, the lambs were fed with solid fodder (meadow hay and crushed oat grain), and from the fifth week with hydrated pulp. After 56 days, Uhruska rams reached an average weight of 20.7 kg, and Wrzosówka and Świniarka rams weighed 14.1 kg and 15.7 kg, respectively. On the 90th day of life, the lambs were separated from their mothers, and their only source of nutrition was unlimited meadow hay. Simultaneously, green forage from field crops (a mixture of grasses with alfalfa) supplemented with crushed oat grains was standardized and corrected every two weeks for the development of lambs. Four-month-old lambs were allowed to use the xerothermic grassland in the Natura 2000 area. Five lambs of equal age and weight were selected from a flock of each breed. The average weight of Świniarka and Wrzosówka rams (7 months) sent to slaughter was 29 and 27 kg, respectively, whereas Uhruska rams (6 months) weighed 36 kg and were characterized by the highest slaughter efficiency (45.5%). The slaughter age of lambs was based on the breeding efficiency and the processing needs of meat. Animal husbandry was carried out in such a way that routine farm activities were not disturbed, while ensuring that all the conditions for animal care were in line with the standards recommended in the Guide for the Care and Use of Laboratory Animals, Directive 2010/63/EU, and Directive 1998/58/EU. A specialized company transported the animals and carried out the slaughter in a small-scale slaughterhouse under the control of the state Veterinary Inspection, in accordance with the current regulations in force in the EU. Lamb carcasses were kept at 10–15°C during the first 4 hours after slaughter and then chilled at 3–4°C for the next 20 hours. Trimmed meat, also known as stew meat, was obtained from five carcasses of each breed. The meat from each carcass was separately vacuum-packed, transported, stored at 4–6°C, and finally tested. Immediately before testing, the portions were unpacked, minced, mixed, packed in plastic resealable boxes, and stored in a refrigerator.

Proximate composition of meat

Samples of trimmed meat were analyzed with a FoodScan™ near-infrared spectrometer (Foss Analytical, Hillerød, Denmark) in transmittance mode to simultaneously determine the content of moisture, fat, and protein by following the Anderson method (2007) for meat and meat products. Briefly, a 180 g sample of ground, homogenized meat (20°C) was placed in FoodScan™ cups with a diameter of 140 mm and a height of 17.5 mm. Subsequently, the samples were placed in the FoodScan™ chamber, and spectra were obtained in the near-infrared region, from 850 to 1050 nm with an interval of 2 nm. Each sample was scanned 20 times, and the scans were averaged by the equipment software and stored as the reciprocal of transmittance [log (1/T)].

Fatty acid profile

The fatty acid profile was analyzed as described by Cieślak et al. (2009) with a slight modification. Briefly, 3 ml of 2M NaOH was added to 50 mg (± 3 mg) of the homogenized sample, which was placed in an incubator for 40 minutes at 90°C and stirred every 10 minutes. Then, 2 ml of diethyl ether was added to the samples and the extraction was performed three times. Derivatization was carried out with boron trifluoride. The separation and quantification of the fatty acid methyl esters (FAMEs) was performed using a Bruker 456-GC gas chromatograph equipped with an FID flame ionization detector and a CP 7420 capillary column (100 m long, 0.25 mm diameter, and 0.25 μm porosity). Hydrogen was used as carrier gas at a constant flow rate of 1.3 ml/min. The injector temperature was maintained at 200°C and the detector temperature at 250°C. The oven temperature of the chromatograph was kept at 120°C for the first 7 minutes,

and then it was increased to 140°C at a rate of 7°C/min; after 10 minutes, the temperature was increased further to 240°C at a rate of 4°C/min. The results are presented as peaks. Individual FAME were identified by comparing their retention times with those of validated standards (37 FAME Mix, Sigma Aldrich, Bellefonte, PA, USA) and results are expressed as a percentage of total FAMEs.

The total contents of saturated fatty acids (SFAs), monounsaturated fatty acids (MUFAs), polyunsaturated fatty acids (PUFAs, PUFA n-6, PUFA n-3 and PUFA n-6/n-3) were calculated. The method described by Medeiros et al. (2014) was used to calculate the content of desirable hypocholesterolemic fatty acids (DFAs):

$$DFA = MUFA + PUFA + C18:0$$

and hypercholesterolemic fatty acids (OFAs)

$$OFA = C12:0 + C14:0 + C16:0$$

Atherogenicity (AI) and thrombogenicity (TI) indices (Ulbricht and Southgate, 1991) were also calculated according to the following equations:

$$AI = \frac{(C12:0 + 4 \times C14:0 + C16:0)}{MUFA + \Sigma PUFA(n\text{-}6) + \Sigma PUFA(n\text{-}3)}$$

$$TI = \frac{C14:0 + C16:0 + C18:0}{0.5 \times MUFA + 0.5 \times (n\text{-}6) + 3 \times (n\text{-}3) + \frac{(n\text{-}3)}{(n\text{-}6)}}$$

The ratio of DFAs to OFAs (h/H) was calculated according to Ivanova and Hadzhinikolova (2015):

$$\frac{h}{H} = \frac{C18:1n\text{-}9 + C18:2n\text{-}6 + C18:3n\text{-}3}{C12:0 + C14:0 + C16:0}$$

pH value

The pH value of meat was measured 24 hours after slaughter according to ISO 2917:1999. For this, a 10 g sample of freshly minced raw meat was homogenized with 10 times the weight of the potassium chloride solution. The pH was measured using a CPC-501 digital pH-meter (Elmetron, Zabrze, Poland) equipped with a pH electrode (ERH-111, Hydromet s.c., Gliwice, Poland) with temperature compensation.

Water holding capacity

The centrifuge method was used to measure water holding capacity (WHC) of meat (Oswell et al., 2021). For this, 15 g of minced meat was added to 75 ml of distilled water. The mixture was homogenized (3000 rpm for 1 minute) and centrifuged at 2400 × g for 10 minutes. WHC was determined using the formula proposed by Zhang et al. (1995).

$$WHC(\%) = \frac{\text{water added into to sample (g)} - \text{free water after centrifugation (g)}}{\text{meat sample mass (g)}} \times 100$$

Cooking loss

To determine cooking loss, 30 g samples of trimmed raw meat were put into separate cooking bags and heated at 98±1°C in a water bath until the internal temperature of the samples reached 71°C (Fabre et al., 2018). The entire heating process took about 20 minutes. After heating, the cooked samples were cooled down upon running water until they reached room temperature and then wiped dry with a filter paper and weighed. The weight difference between raw and cooked samples was defined as cooking loss (%).

Oxidation-reduction potential

Oxidation-reduction potential (ORP) was measured in meat homogenates as described by Łaszkiewicz et al. (2021). Briefly, a 10 g sample of trimmed meat was mixed with 50 ml of distilled water and homogenized (12,500 rpm) for 1 minute with a T25 digital Ultra-Turrax blender (IKA® Werke GmbH & Co. KG, Staufen, Germany). The redox potential was determined using a digital pH-meter (CPC-501, Elmetron, Zabrze, Poland) set to millivolt scale and equipped with a platinum electrode filled with a 4 M KCl solution saturated with AgCl (ERPt-13, Hydromet s.c., Gliwice, Poland). The ORP readings (mV) were recorded exactly 3 minutes after the electrode was inserted into the sample.

Lipid oxidation

The content of secondary lipid oxidation products was measured following the method described by Fan et al. (2019). Briefly, 3 g of minced meat was homogenized with mixture of 12 ml of 4% cold trichloroacetic acid (POCH S.A., Gliwice, Poland) with 0.2 ml of 0.01% alcoholic butylated hydroxytoluene (Sigma-Aldrich, Chemie GmbH, Steinheim am Albuch, Germany). Next, samples were shaken, filtered, and heated at 100°C for 20 min after adding 0.65 ml 2-thiobarbituric acid (POCH S.A., Gliwice, Poland). After cooling and centrifugation of samples, the content of thiobarbituric acid-reactive substances (TBARS) were measured with a U-5100 UV-VIS spectrophotometer (Hitachi High America Inc., Dallas, TX, USA). The TBARS value was estimated using the following equation:

$$TBARS = 5.5 \times A_{532}$$

where A_{532} refers to the absorbance measured at 532 nm. The result was expressed as mg malondialdehyde (MDA)/kg sample.

Water activity

The water activity (a_w) parameter was assessed in the minced raw meat at 25°C using a LabMaster-a_w (Novasi-

na AG, Lachen, Switzerland) analyzer with a temperature-controlled measuring chamber. Novasina SAL-T humidity standards based on saturated salt solutions were used for calibration. The meat samples were applied to a special testing vessel (about 10 g, up to half the height of the vessels) for determining water activity.

Color parameters

The color parameters of freshly minced meat were measured in the CIE L*, a* and b* system following the reflection method using an 8200 Series (X-Rite Inc., Grand Rapids, MI, USA) spherical spectrophotometer with a D65 illuminant, 10° standard observer, and 12 mm port/viewing area. About 20 g of minced meat was placed in a thin, transparent cling film and then the sample was placed such that the measuring hole was completely covered. The results were expressed as lightness (L*, 100 = white and 0 = black), redness (a*) and yellowness (b*). Due to the heterogeneity of the sample, 10 measurements were taken at random locations on the sample surface.

Microbial analysis

Microbiological tests to determine total microbial counts (TMC) were performed according to ISO 4833-2:2013. The population of *Escherichia coli*, *Enterobacteriaceae*, *Clostridium perfringens*, and lactic acid bacteria was determined according to ISO 16649-1:2018, ISO 21528-2:2017, ISO 7937:2004, and ISO 15214:1998, respectively. The results are reported as colony forming units per gram of product (CFU/g). *Listeria monocytogenes* was determined in a 25 g sample, according to ISO 11290-2:2017.

Statistical analysis

Data analysis was performed using the statistical analysis software Statistica (StatSoft, Poland). The data collected for five different carcasses of each of the three studied lamb breeds were included in the analysis. The analysis of variance with post hoc Tukey's method preceded by Levene's and Shapiro-Wilk's test was used. The statistical significance was set at the level of 0.05. Additionally, principal component analysis was performed with a single linkage over Euclidean distance for three breeds, and the results were presented in the form of dendrograms.

Results

The primary chemical composition of WRZ meat differed slightly from that of UHR and SWI meat (Table 1). The meat used in the study consisted of approximately 73% of water, 18% of protein, 8% of fat, 2.2% of collagen, and 0.26% of sodium. UHR and SWI meat had almost a similar basic chemical composition (water, protein, fat, collagen, sodium), while WRZ meat differed from them (Figure 1). A geometric (Euclidean) distance of 0.8 was observed which is not very high. WRZ meat had significantly ($P<0.05$) lower fat content and higher sodium content compared to the meat of the other two breeds.

Table 1. Proximate composition of lamb meat (mean ± standard deviation)

Parameters	WRZ	UHR	SWI
Moisture (%)	74.9±3.8	72.8±3.6	73.3±3.7
Fat (%)	7.36±0.82 a	9.46±1.05 b	9.72±1.08 b
Proteins (%)	18.1±0.5	18.7±0.5	18.1±0.5 a
Collagen (%)	2.30	2.16	2.22
Sodium (%)	0.28 a	0.24 b	0.26 b

a, b, – homogeneous ($P\leq0.05$) groups are marked with the same letters.

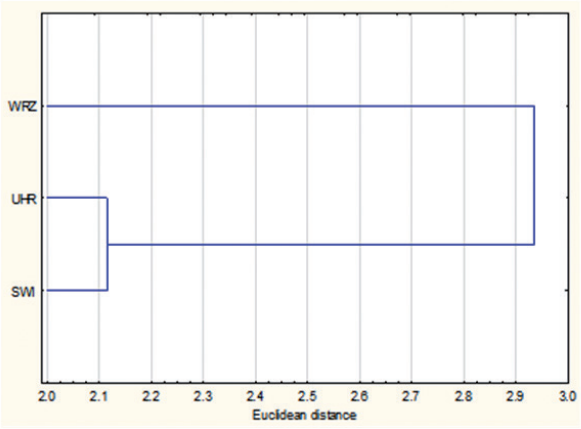


Figure 1. Similarity (PCA) of proximate chemical composition of meat of 3 breeds of lamb

The fatty acid profile analysis showed that WRZ meat had the lowest percentage of SFAs and the highest percentage of MUFAs (Tables 2 and 3). At the same time, UHR meat was characterized by the highest content of SFAs and the lowest content of MUFAs. The meat of all three analyzed lamb breeds contained approximately 3.5% PUFAs. The data on the fatty acid composition was analyzed with clusters, and it was found that the UHR and SWI meat shared more common characteristics, while WRZ meat was separated from the group by a distance of 0.43 (Figure 2). Similarly, the data on fatty acid sums were also cluster analyzed, and it was noted that UHR and SWI meat had more common characteristics, while WRZ meat was separated from the group by a distance of 1.45 (Figure 3).

The most favorable ratio of n-6 to n-3 acids was found in WRZ meat (3.66). The meat of the other two breeds was characterized by an almost similar n-6/n-3 ratio (6.13 and 5.08, respectively). The highest amounts of n-9 acids were found in SWI meat (4 g/100 g of meat), and the lowest in WRZ meat (3.22 g/100 g of meat) (Table 3). The values of lipid quality indices – DFAs, OFAs, TI, and AI – differed in the analyzed meat samples. The content of DFAs, which is the sum of unsaturated fatty acids and C18:0 (stearic acid), was higher in UHR and SWI meat fat and significantly lower ($P\leq0.05$) in WRZ

meat fat. Similarly, the content of OFAs in UHR and SWI meat fat was significantly higher (P≤0.05) than in WRZ meat fat. It should be noted that the OFA content is influenced by the content of SFAs such as C12:0 (lauric), C14:0 (myristic), and C16:0 (palmitic) acid. The AI values were significantly higher (P≤0.05) in UHR and SWI meat fat compared to WRZ meat fat. The lowest TI value (0.78) was found in WRZ meat fat, while significantly higher values (P≤0.05) were found in fat in the remaining analyzed samples. The highest h/H ratio was found in WRZ meat fat (Table 3), whereas UHR and SWI meat fat had significantly lower (P≤0.05) values.

Table 2. Fatty acid composition (more than 0.05% FAME) of meat fat of 3 breeds of lamb (mean ± standard deviation)

Fatty acid	UHR	WRZ	SWI
SFAs			
C10:0	0.30±0.03 b	0.23±0.02 c	0.37±0.04 a
C12:0	0.40±0.02 b	0.18±0.01 c	0.84±0.05 a
C14:0	4.24±0.40 b	2.36±0.23 c	7.24±0.69 a
C15:0	0.73±0.02 b	0.61±0.02 c	0.80±0.02 a
C16:0	24.51±0.38 b	20.47±0.32 c	26.02±0.40 a
C17:0	1.80±0.02 b	1.40±0.01 c	1.13±0.01 a
C18:0	21.19±0.22 b	24.08±0.25 a	15.02±0.16 c
C20:0	0.19±0.01 c	0.23±0.02 a	0.21±0.01 b
MUFAs			
C14:ln5	0.19±0.02 b	0.12±0.01 c	0.28±0.02 a
C16:ln7	1.76±0.51 b	1.77±0.51 b	2.27±0.65 a
C17:ln7	0.86±0.02 a	0.81±0.02 b	0.73±0.01 c
C18:ln9c + C18:ln9t	39.53±1.49 b	43.65± 1.65 a	41.05±1.55 ab
C20:ln9	0.13±0.02	0.11±0.01	0.12±0.02
PUFAs			
C18:2n6c	2.68±0.38	2.28±0.32	2.52±0.35
C18:3n3(alpha)	0.50±0.03 b	0.66±0.04 a	0.54±0.03 b
C20:2n6	0.09±0.02	0.11±0.03	< 0.05
C20:4n6	0.14±0.01 b	0.18±0.01 a	0.13± 0.01 b
C20:5n3	< 0.05	0.07±0.02	< 0.05

a, b, c – homogenous (P≤0.05) groups are marked with the same letters. SFA – saturated fatty acid, MUFA – monounsaturated fatty acid, PUFA – polyunsaturated fatty acid.

Table 3. The nutritional indices of meat fat of 3 breeds of lamb

Parameters	UHR	WRZ	SWI
SFA (%)	53.58 a	49.77 c	51.84 b
MUFA (%)	42.72 c	46.67 a	44.70 b
PUFA (%)	3.70 a	3.56 ab	3.46 b
PUFA n-3 (%)	0.50 b	0.72 a	0.54 b
PUFA n-6 (%)	3.04 a	2.64 b	2.72 b
PUFA n-9 (%)	39.66 b	43.76 a	41.17 b
PUFA n-6/n-3	6.13 a	3.66 c	5.08 b
DFA	6.38 a	5.46 c	6.12 b
OFA	2.76 b	1.70 c	3.31 a
AI	0.91 b	0.60 c	1.16 a
TI	0.95 a	0.78 c	0.89 b
h/H	1.47 b	2.02 a	1.29 c

a, b, c – homogenous (P≤0.05) groups are marked with the same letters. SFA – saturated fatty acid, MUFA – monounsaturated fatty acid, PUFA – polyunsaturated fatty acid, DFA – hypocholesterolemic fatty acid, OFA – hypercholesterolemic fatty acid, AI – atherogenic indices, TI – thrombogenic indices, h/H – hypocholesterolemic to hypercholesterolemic fatty acids ratio.

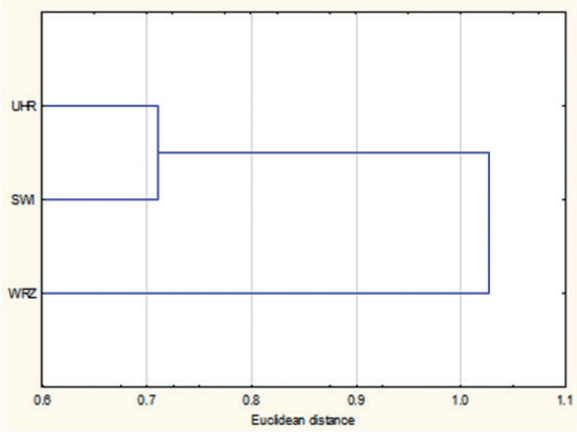


Figure 2. Similarity (PCA) of fatty acid composition of meat fat of 3 breeds of lamb

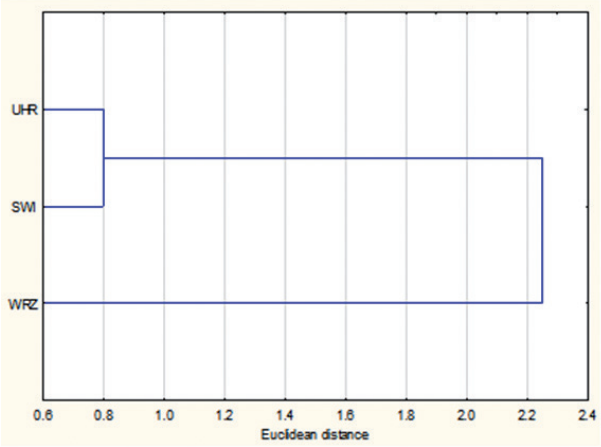


Figure 3. Similarity (PCA) of total fatty acids sum of meat fat of 3 breeds of lamb

Post hoc analysis did not indicate that the breed of lamb had a significant ($P \leq 0.05$) effect on meat pH, fat oxidation, and cooking performance. However, it indicates that the meat of lambs of different breeds differed in the ORP value. In terms of WHC, UHR and SWI meat showed a significant difference, while WRZ meat did not differ statistically significantly from them (Table 4). The results were subjected to cluster analysis based on the single binding method (the data were previously standardized to make the scale of the units comparable). WRZ and UHR meat had more features in common with SWI meat. However, the small distance (0.34) of nodes indicated minor differences between the group consisting of WRZ and UHR in relation to SWI (Figure 4).

The pH_{24} value of the tested lamb was 5.6 on average. The WHC of lamb ranged from 12.72% to 19.50%, with the highest value recorded for SWI meat. Although WHC and cooking loss are closely related parameters, no effect of breed on cooking loss was noted. In all tested trials, cooking loss was approximately 30%. No significant influence of the lamb breed was found on TBARS index, the value of which in all tests was significantly below 1 mg/kg. At the same time, it was found that meat containing less total fat had a lower MDA content.

Color is one of the most important characteristics of meat, which is considered a visual indicator by consumers to determine its quality, freshness, and acceptance. Redness (a*) and lightness (L*) are the main color parameters of lamb (Janiszewski et al., 2021), while yellowness (b*) is regarded as an indicator of fat color in meat industry. In this study, a significant difference was observed in the color parameters of the studied lamb samples ($P<0.05$). WRZ meat was significantly darker (L*=52.27), with more significant redness (a*=23.68) and lower yellowness (b*=16.60) compared to UHR and SWI meat (Table 4.).

Table 4. Acidicity, redox potential, water holding capacity, lipid oxidation, water activity, cooking loss and color parameters of meat of 3 breeds of lamb (mean ± standard deviation)

Parameters	UHR	WRZ	SWI
pH_{24}	5.62±0.05	5.56±0.06	5.64±0.04
WHC (%)	12.72±1.99 a	17.57±2.79 ab	19.50±2.42 b
CL (%)	32.41±2.46	30.68±1.82	29.00±0.47
TBARS (mg malonaldehyde/kg)	0.74±0.05	0.62±0.10	0.85±0.14
ORP (mV)	33.3±5.17 a	41.27±5.95 b	79.23±1.64 c
L*	57.48±5.08 a	52.27±2.02 b	60.04±0.39 a
a*	19.47±1.68 b	23.68±0.37 a	19.26±0.42 ab
b*	18.78±0.56 a	16.60±1.46 b	17.91±0.75 a
a_w	0.990±.003 a	0.986±.004 ab	0.982±.002 b

WHC – water holding capacity, CL – cooking loss, TBARS – lipid oxidation, ORP – redox potential, L* – lightness, a* – redness, b* – yellowness, aw – water activity.

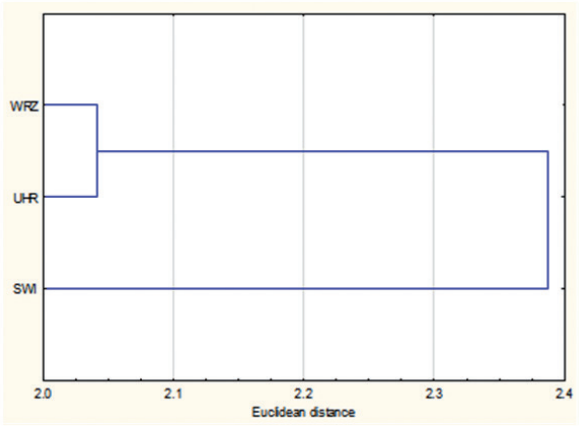


Figure 4. Similarity (PCA) of physicochemical (pH, ORP, WHC, TBARS, a_w, CL, CIE L*a*b*) parameters of meat of 3 breeds of lamb

Although the studied breeds of lambs were reared in similar conditions, they were slaughtered at the same time, in the same facility, after 72 hours (Table 5). The analysis of microbiological purity of meat stored under refrigerated conditions highlighted a considerable

variation between the trials. Water activity in the meat samples, which has a significant impact on the development of microorganisms, was high and amounted to over 0.982. The highest number of microorganisms was found in WRZ meat, with more than twice TMC as UHR and SWI meat. WRZ meat had much higher numbers of lactic acid bacteria and *Enterobacteriaceae*, but it was much less contaminated with *E. coli* compared to the meat of the other two breeds. The highest level of *E. coli* contamination was found in SWI meat. All the studied meat samples contained *L. monocytogenes*.

Discussion

Breed can affect the chemical composition of meat (Mazinani and Rude, 2020). The water content in the Polish native breeds Uhruska, Świniarka, and Wrzosówka studied by us was similar to that found by Janiszewski et al. (2021) (70–72%) and Radzik-Rant et al. (2020) (74%), and of other breeds such as Tunisian Barbarine (74%) (Yagoubi et al., 2018). The meat of native Italian Biellese and Sambucana lambs (77%) and German Texel-Merino-Blackhead-Charollais (75%) (Gonzales-Barron et al., 2021) and Brazilian Santa Ines-Dorper (72%) (de Sousa et al., 2022) hybrids contained slightly more moisture.

The meat from native Polish lamb breeds contains slightly more than 18% of protein. The present study indicated no significant effect of the breed on protein content. However, studies by other authors show a large discrepancy. Gonzales-Barron et al. (2021) found that the meat of Italian lamb breeds Biellese and Sambucana had approximately 19.6% of protein, which is most similar to that determined in our study. Cadavez et al. (2020) found 21% of protein in the meat of German Texel-Merino-Blackhead-Charollais hybrid and local Iberian breeds. The Fabian lambs (Polidori et al., 2017) and Brazilian Santa Ines × Dorper hybrids (de Sousa et al., 2022) contained about 22.5% protein. Janiszewski et al. (2021) observed the highest protein content, as much as 24–25%, in the meat of Polish native lamb breeds, including Wrzosówka, Uhruska, and Świniarka. Some authors (Blasco et al., 2019; Gonzales-Barron et al., 2021) noted a higher protein content in the meat of crossbreeds than in the meat of indigenous breeds, which would be consistent with the results of our study.

The fat content of meat varies greatly depending on the cut (carcass), with the value being the lowest in the legs and the highest in the breast (Campo et al., 2016). Additionally, some breeds have more intramuscular fat (IMF) (Arvizu et al., 2011). Janiszewski et al. (2021) found that the IMF content in the *longissimus lumborum* muscle of Polish primitive breeds, including Wrzosówka, Uhruska, Wielkopolska, Polish Merino, ranged from 2% to 4%. Similar values of the IMF content (approximately 4%) were found by Radzik-Rant et al. (2020) in the *longissimus lumborum* and *gluteus medius* muscles of Polish Merino and Polish Merino × Berrichone du Cher crossbred lambs, and by Yagoubi et al. (2018) in the *longissimus thoracis* muscle and *lumborum* muscle of Tunisian fat-tailed Barbarin lambs. Gonzales-Barron et al. (2021) observed lower IMF content in *longissimus thoracis et lumborum* muscle in Italian lamb breeds Biellese and Sambucana, and German Texel-Merino-Blackhead-Charollais hybrids, and Cadavez et al. (2020) recorded a much lower value of <2% in the meat of local Iberian lamb breeds. In our study, samples of fat were extracted from meat trimmings separately for each breed. The amount of fat in meat ranged from 7.36% (WRZ) to slightly more than 9% (UHR and SWI). The purpose of this study was to evaluate the quality of trimmed meat for stuffing preparation. Therefore, it is difficult to compare our results with those of other authors who have studied defined parts of carcasses, often without the outer fat cover (Frank et al., 2016). Nevertheless, the IMF content of red meat is widely associated with tenderness by consumers. Evidence indicates that consumers consider lamb with IMF content of >2.5% to have acceptable tenderness (Realini et al., 2021), and that the acceptance increases with increasing fat content (Pannier et al., 2014). Warner et al. (2021) highlighted that a high amount of IMF contributes to disrupting myofibrils and connective tissue structures, reducing their shear force and thus helping to improve the tenderness of red meat.

Table 5. Microbiological purity of lamb of different breeds

Microorganism		WRZ		UHR		SWI	
		mean	range	mean	range	mean	range
LAB	CFU / g	$2.0 \cdot 10^8$	$1.4–2.9 \cdot 10^8$	$1.5 \cdot 10^8$	$1.0–2.2 \cdot 10^8$	$1.1 \cdot 10^8$	$0.74–1.6 \cdot 10^8$
Cl. perfringens	CFU / g	< 10		< 10		< 10	
Enterobacteriaceae	CFU / g	$5.5 \cdot 10^7$	$3.1–9.9 \cdot 10^7$	$3.9 \cdot 10^7$	$2.1–7.1 \cdot 10^7$	$4.6 \cdot 10^7$	$2.5–8.3 \cdot 10^7$
E. coli	CFU / g	$4.8 \cdot 10^3$	$2.9–7.9 \cdot 10^3$	$8.5 \cdot 10^3$	$5.2–14.0 \cdot 10^3$	$13.0 \cdot 10^3$	$8.0–21.0 \cdot 10^3$
L. monocytogenes	in 25 g	found		found		found	
TMC	CFU / g	$4.1 \cdot 10^8$	$2.6–6.6 \cdot 10^8$	$1.5 \cdot 10^8$	$0.98–2.3 \cdot 10^8$	$1.7 \cdot 10^8$	$0.98–2.3 \cdot 10^8$

In general, the content of collagen is an indirect indicator of the content of connective tissue (Koohmaraie et al., 2002) and possibly the tenderness of red meat (Alvarenga et al., 2021). In this study, no differences in collagen content were found between meat samples from different breeds. However, other authors (Ablikim et al., 2016; Radzik-Rant et al., 2020) point to significant differences in collagen content between lamb breeds and muscle types. Hopkins et al. (2013) reported that the concentration of lamb collagen did not affect the shear force or consumer assessment of meat tenderness. Starkey et al. (2016) found that the lamb tenderness felt by consumers significantly correlated with the IMF concentration and final pH of meat, and the sex of the animals, but not with the collagen concentration.

Although the composition of fatty acids can vary in lamb based on breed, body fat (Willems et al., 2014), muscle type, and lipid content, diet is the main influencing factor of this parameter (Yagoubi et al., 2018; Prache et al., 2022; de Sousa et al., 2022). Ruminants can biohydrate the unsaturated fatty acids contained in their diet, which in turn increases the amount of SFAs in their meat (Mazinani and Rude, 2020). In this study, the most abundant FA in the tested meat samples was palmitic (C16:0) acid followed by stearic (C18:0) and oleic (C18:1) acid, which is consistent with the results of many authors (Majdoub-Mathlouthi et al., 2013; Yagoubi et al., 2018).

The most favorable ratio of n-6 to n-3 acids was found in WRZ meat (3.66). The meat of the other two breeds was characterized by a similar n-6/n-3 ratio (6.13 and 5.08, respectively). The highest amounts of n-9 acids were found in SWI meat (4 g/100 g of meat), and the lowest in WRZ meat (3.22 g/100 g of meat) (Table 3). The values of lipid quality indices — DFAs, OFAs, TI, and AI — differed in the analyzed samples. The content of DFAs, which is the sum of unsaturated fatty acids and C18:0 (stearic acid), was higher in UHR and SWI meat fat, and significantly lower ($P \leq 0.05$) in WRZ meat fat. Similarly, the content of OFAs in UHR and SWI meat fat was significantly higher ($P \leq 0.05$) than in WRZ meat fat. It should be noted that the OFA content is influenced by the content of SFAs such as C12:0 (lauric), C14:0 (myristic), and C16:0 (palmitic) acids. The AI values were significantly higher ($P \leq 0.05$) in the UHR and SWI meat fat compared to WRZ meat fat. The lowest TI value (0.78) was found in WRZ meat fat, while significantly higher values ($P \leq 0.05$) were found in fat in the remaining analyzed samples. The highest h/H ratio was found in WRZ meat fat (Table 3), while UHR and SWI meat fat had significantly lower ($P \leq 0.05$) values.

The nutritional quality of meat and fat can be assessed in terms of saturation index and the content of SFAs, MUFAs, total PUFAs, as well as n-6 and n-3 PUFAs and their ratio (Peiretti et al., 2007). The animal breed, production system, diet, age, and weight can significantly influence the fatty acid profile and lipid nutritional value of meat (Polidori et al., 2017; Cadavez et al., 2020). The indexes AI, TI, and h/H ratio are calculated to determine the nutritional quality and fatty composition of meat. AI and TI express the potential impact of single fatty acids on human health and are associated primarily with cardiovascular health. AI indicates the risk of fat buildup in the artery walls, which can cause atherosclerosis, while TI indicates the possibility of blood clot formation (Ulbricht and Southgate, 1991). The higher the values of these coefficients, the greater the risk of developing cardiovascular diseases (Ivanova and Hadzhinikolova, 2015). Our study proves that the meat of Wrzosówka breed has the highest possible potential to protect against cardiovascular problems. The hypocholesterolemic/hypercholesterolemic (h/H) ratio expresses the functional effect of fatty acids on cholesterol metabolism and associates with the functional activity of fatty acids in transport of plasma cholesterol. According to Santos-Silva et al. (2002), higher values of this ratio are more desirable.

Basically, the pH_{24} value is used to assess meat's shelf life, quality, and suitability for processing (Gonzales-Barron et al., 2021). The value of pH may usually drop from 7.0–7.2 to 5.5–5.7 in about 24 hours. According to Mullen and Troy (2005), meat with a final pH of about 5.5–5.8 has the most desirable quality characteristics and tenderness (Gonzales-Barron et al., 2021). The ultimate pH values should be in the range recommended for high-quality meat (Majdoub-Mathlouthi et al., 2013). Such desirable pH values were reported by other researchers (Malva et al., 2016; Yagoubi et al., 2018; Radzik-Rant et al., 2020; Gonzales-Barron et al., 2021; Janiszewski et al., 2021; de Sousa et al., 2022), whose results showed that lamb breed has only a slight effect on the pH level of meat. Malva et al. (2016) suggests that the most critical factors affecting the pH of meat are the preslaughter glycogen level and the stress susceptibility typical of young lambs.

WHC and cooking loss influence the consumers' perception of juiciness. Studies show a strong negative correlation between WHC and cooking loss (Ablikim et al., 2016; de Sousa et al., 2022), i.e., the higher the WHC, the better the juiciness. The WHC of meat is determined by many interacting factors such as physicochemical properties, particularly pH. Sañudo et al. (2007) pointed out that the final pH could explain 80% of the WHC variability of meat. However, in our study, the differences between the breeds were not related to pH, as it was similar in all tested meat samples.

The other determinants of the WHC of meat are the muscle structure and the extent of postslaughter changes. Different genotypes may differ in meat structure, carcass fatness, or meat composition in terms of protein and IMF content, as well as the rate and extent of postmortem proteolysis and consequently protein degradation, fragmentation, and shrinkage myofibrils of meat (Corazzin et al., 2019). An increase in protein content, which can bind to water, increases WHC of meat, whereas an increase in the IMF content reduces the water content (Frank et al., 2016). In our study, breed did not affect protein content, and thus did not influence WHC. This suggests that the

effect of breed on WHC or cooking loss or both is very much similar to that of other diverse factors (Kuchtík et al., 2011; Popova and Marinova 2013). Radzik-Rant et al. (2020) found that the meat of hybrid lambs had a lower water retention capacity than the meat of pure Merino lambs. It can therefore be concluded that WHC is mainly influenced by the structure of the muscle tissue and the strength of proteins to bind water, as observed in the case of SWI meat.

Our findings on cooking loss are consistent with those of other authors, who report that it ranges from 12% to 40 percent in the meat of small ruminants (de Sousa et al., 2022; Janiszewski et al., 2021). It is impossible to unequivocally and directly compare our results with those of others because cooking loss depends more on the method of determination than on breed (Janiszewski et al., 2021; Oswell et al., 2021; Szmańko et al., 2021).

Lipid peroxidation in red meat is determined by the concentration of thiobarbituric acid reactive substances (Holman and Hopkins, 2021). The fatty acid profile of red meat affects the concentration of TBARS, especially the susceptibility of unsaturated fatty acids to oxidation. The acceptance threshold for malondialdehyde in 1 kg of meat is 1 mg (Ripoll et al., 2011). The presence of at least 2 mg MDA/kg causes a sensory change in taste that the consumer does not accept (Arshad et al., 2018).

The ORP value of the lamb meat of different breeds was significantly different. The highest value was found in SWI meat, and the lowest in UHR meat. The higher the ORP value, the lower the oxidation capacity (Barbieri et al., 2019). In raw meat, ORP decreases during initial storage due to the oxygen consumption of meat tissues or microorganisms. Cornforth et al. (1986) reported that microbial growth decreased ORP and thus increased the reduction capacity. However, our study showed no correlation between the ORP value and the microbiological purity of meat.

Consumers will characterize red meat as high quality if its lean tissue has a light cherry red color (Corlett et al., 2021). From an analytical standpoint, this implies that fresh lamb meat should have values higher than 9.5 for a* and 34 for L* in order to be accepted by consumers, and an increase in these values up to 14.5 and 44, respectively, is accepted by 95% of consumers (Khliji et al., 2010). Janiszewski et al. (2021) also observed the effect of breed on the color parameters of the meat of primitive Polish lamb breeds. Their study confirmed that WRZ meat was characterized by a darker and redder color than the meat of other breeds, and similar to our results, a higher b* value was observed in SWI meat. Furthermore, Gonzales-Barron et al. (2021) observed a difference in the lightness (L*) and redness (a*) parameters of meat among Italian Biellese and Sambucana breeds and German Texel-Merino-Blackhead-Charollais crossbreds, which had significantly darker and redder flesh. Similarly, Kuchtík et al. (2012) found that genotype significantly affected L* and b* parameters. The meat of the Czech Romanov-Suffolk hybrid was lighter, yellower, and less reddish than the meat of the Romanov-Charollais hybrid lambs.

The factors which, in addition to the amount and chemical state of myoglobin, mainly affect the meat color of small ruminants are the pH of the meat and the characteristics of IMF (Corazzin et al., 2019). In particular, the color of the meat changes with a reduction in pH during maturation. Teixeira et al. (2011) found a significant negative correlation between the final pH and a* parameter and the final pH and b* parameter, with the most desirable color achieved in the pH range from 5.5 to 5.8. Final pH of >6.0 is associated with a dark color of the meat due to the low level of myofibril protein denaturation. As a result, the meat retains more water and reflects less light. At the same time, due to lower oxygen penetration as a result of low myofibril degradation and higher mitochondrial activity, a more reducing environment is created, which promotes the formation of deoxymyoglobin instead of oxymyoglobin, making the meat appear darker. However, in this study, the meat of all lamb breeds had a similar pH. This indicates that pH does not affect the meat color of native Polish lamb breeds.

Another critical factor affecting color is the fat content of the meat. Higher levels of IMF increase the colorimetric values of meat because fat has a greater light reflectance than protein. This may affect oxygen penetration in the meat, delaying the formation of metmyoglobin, thus allowing the meat to maintain its color for a long time. Moreover, Calnan et al. (2017) showed that an increase in IMF from 2% to 8% causes an increase in L*, a*, and b*, which consequently affects the color values of lamb. In fact, in our study, UHR and SWI meat contained more fat than WRZ meat, as well as higher L* and b* values.

Food safety is one of the major concerns of the food industry, government food safety, and consumer regulators due to the significant increase in food-borne diseases and epidemics reported worldwide in the 20th and 21st centuries. Microbiological, chemical, and physical hazards are considered important food safety issues in the food industry. Microbiological hazards mainly include contamination by food-borne pathogens (Teixeira et al., 2020). Lamb can be affected by several microorganisms, including bacteria, particularly *E. coli*, *Salmonella*, and *Campylobacter* (Prache et al., 2022), of which *E. coli* is the most significant threat (EFSA, 2013).

Conclusion

A comparative analysis of the meat of the native Polish breeds Uhruska, Świniarka, and Wrzosówka showed that these breeds are characterized by high-quality meat. The results did not indicate any influence of breed on the chemical composition of meat. However, the fatty acid composition and AI and TI of meat significantly differed between the breeds, with the meat of Wrzosówka lambs having a distinct advantage and the most significant potential to protect against cardiovascular problems. Fur-

thermore, the meat of Wrzosówka breed had color parameters that are most desired by consumers. Summing up, the assessment of technological suitability and lipid quality indicators showed that the meat of Wrzosówka breed has the best characteristics among the studied breeds. These results are also of practical importance as combining meat from different breeds of lambs can allow achieving high product quality. The meat of Wrzosówka breed can be successfully used for producing high-quality meat products and can serve as flagship meat for export to other European and global markets.

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