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## The chemical composition of wild boar (*Sus scrofa*) meat hunted in the Polish Carpathians

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### ABSTRACT

The wild boar (*Sus scrofa*) is a popular animal worldwide. Boar populations in Europe and Asia are numerous and widespread. However, these animals cause many problems: they damage agricultural crops, spread infectious diseases dangerous to pigs (African swine fever, ASF), encroach on human settlements, cause traffic accidents, and pose an increasing threat to humans. Attempts to reduce the number of feral pigs have a low success rate, since, thanks to their rapid reproduction, their herds quickly recover after periods of intensive shooting. In 2019 -2023, the annual harvest of wild boar carcasses ranged from 221,00 to 420,00. After mandatory veterinary inspection, wild boar meat can be a more environmentally friendly, low-cost alternative to pork. Previous studies show that wild boar meat is nutritionally valuable. The aim of the study was to analyze the chemical composition of wild boar meat harvested in the Polish Carpathians and to compare the results with those reported by other authors for wild boar meat from other European countries. The results indicate that the chemical composition of meat, particularly the fatty acid profile of wild boar fat harvested across different regions, varies with the feed source used by the wild boars.

**Keywords:** wild boars, meat, chemical composition, quality

### INTRODUCTION

The wild boar (*Sus scrofa*) is a highly adaptable species found in a variety of habitats (from semi-deserts to swamps and forests) and characterized by enormous reproductive potential [1]. The availability of food, the absence of natural enemies, climate warming (especially the lack of cold and snowy winters), and high reproductive potential have contributed to the rapid growth of this species' population. In Poland, wild boars are common throughout the country, from the Baltic coast to the mountainous regions. They are game animals, and although they play an important role in the forest ecosystem, their growing population and behavior can cause conflicts, especially with agriculture. Wild boars are very intelligent animals, which allows them to quickly adapt to environmental changes resulting from human activity. Wild boars are both beneficial animals and pests. They play a sanitary role in forests by eating small animals and carrion. In addition, they dig up forest litter and soil, mixing them together. They eat insects, their larvae, and pupae, which helps to control forest pests [2], [3]. The abundance of food around human settlements (plots of land, garbage dumps, and fields) and in fields has led to the formation of packs that spend most of their time outside the forest, among grain and corn fields. By venturing into farmland more often, they cause serious damage to agriculture. Irresponsible human behavior in forests and wild boars searching for easy food near human settlements have contributed to the emergence of a population of wild boars that are not afraid of humans and live near buildings and even in cities. The high mobility of these animals and their movement in search of food have made wild boars a frequent cause of road accidents. Across Europe, wild boar populations are steadily increasing [1], [4]. The population growth has accelerated since the 1990s [4], [5]. Wild boars have a significant impact on biodiversity [6]. Concerns have

been raised about the transmission of diseases that threaten public health [7] and pig farming in many European countries [8]. Between 2014 and 2020, ASFV infected wild boar populations in 11 European Union (EU) countries: Estonia, Lithuania, Latvia, Poland, the Czech Republic, Bulgaria, Belgium, Romania, Hungary, Slovakia, and Germany. This led to the spread of African swine fever to pigs, threatening to wipe out pig herds, which is why many European countries (including Poland) implemented wild boar depopulation programs. According to Polish hunting law, wild boars are not subject to seasonal protection. On August 3, 2017, the Minister of the Environment completely abolished the protection period (including for sows), allowing wild boar (both males and females) to be hunted year-round. Culling wild boars for depopulation purposes means that more wild boar meat is being harvested, which should lead to an increase in its consumption. Although Poland is one of the leading producers and exporters of game meat in Europe, its consumption in the country is very low, amounting to approximately 0.08 kg/person/year [9]. The low consumption of game meat among Poles is due to its high price, limited availability in stores, and the large supply of cheaper animal meat on the market [10]. In addition, Polish game meat is an export commodity. According to [11], game consumption varies by geographical location: residents of Southeast European countries consume more games than those in Central European countries. The European Union (EU) promotes game consumption through the program “European game meat, nature in its purest form” [12], [13]. Demonstration of the suitability of venison for processing was analysed and reported [5], [14]. The game is used to produce luxury smoked meats (ham, tenderloin), sausages (dry, semi-dry, medium, and finely minced, steamed), as well as offal cold cuts, pâtés, and preserves [15]. Promoting the consumption of wild boar meat requires information about its benefits and safety. Since wild boars live in different habitats and feed on a variety of foods in agricultural areas, the chemical composition and quality of their meat may vary.

### Scientific Hypothesis

Wild boars can be a valuable source of meat rich in nutritional factors. However, it is unclear how meat quality differs between different areas where wild boars are present

### Objectives

The aim of the study was to analyze the quality of wild boar meat obtained in the Polish Carpathians and compare the results with those of other authors regarding the composition of wild boar meat harvested in other European countries.

## MATERIAL AND METHODS

### Samples

#### Samples description:

The wild boars were obtained during depopulation hunts in the autumn-winter season of 2021-2022. Meat samples for analysis were collected at a game processing plant where the carcasses were sent after being gutted, skinned, and examined by a veterinarian

#### Samples collection:

Samples were collected and temporarily stored at 10°C until transport to the laboratory, where colour analysis was performed. After, samples were divided for further analysis, and some were analyzed immediately after preparation, and some were frozen at -20 °C until further analysis

#### Samples preparation:

Samples were defrosted, unpacked, and analysed.

#### Number of samples analysed:

We have analysed 40 samples.

### Chemicals

Chemicals were purchased from Supelco Bellafonte (PA, USA), Sigma-Aldrich Co. (St. Louis, MO, USA), and POCH (Poland) and were of analytical grade.

### Animals, Plants and Biological Materials

Not used in this study

Wild boars obtained from the depopulation procedure in the Karpatian region

Not used in this study

### Instruments

Trace GC Ultra (Thermo Electron Corporation, Milano, Italy), Dionex Ultimate 3000 (Thermo Scientific), Konica Minolta CM-600d (Minolta Co., Ltd., Tokyo, Japan)

### Laboratory Methods

#### Determination of the fatty acid profile

The fatty acid profile was determined using two analytical methods: lipid extraction from meat according to [16] and esterification according to [17]. The fatty acid methyl esters were separated by gas chromatography using a Trace GC Ultra (Thermo Electron Corporation, Milano, Italy) with a flame ionization detector (FID) using Supelcowax 10 column (30 m × 0.25 mm × 0.25 μm). The separation conditions were as follows: helium as the carrier gas, 1 mL/min; FID detector temp. 250 °C; injector temp. 220 °C; oven temp. Was held at 160 °C and increased (3 °C/min) to 210 °C (35 min); split ratio 10 mL/min. To obtain fat (around 10 mg), 0.5 mL of 0.5M KOH in methanol was added and heated at 85 °C, after which 1 mL of 12% BF<sub>3</sub> in methanol was added and reheated at 85 °C. After cooling to room temperature, 1 mL of hexane and 5 mL of saturated NaCl solution were added. 1 μL of the solution was injected into the chromatograph.

Individual fatty acid methyl esters (FAME) were identified by comparing with a standard mixture of 37 FAME components (Supelco Bellafonte PA, USA, Sigma-Aldrich Co. St. Louis, MO, USA) and CLA isomers (Sigma-Aldrich Co. St. Louis, MO, USA).

### Determination of the amino acid profile

The amino acid profile was determined by reversed-phase liquid chromatography using the ACCQ Tag analytical kit from Waters (Millford, MA, USA). Hydrolysis of approximately 30 mg of the sample was carried out with 4 mL of 6M HCl (POCH, Poland) and the addition of 15 μL of phenol (Sigma Aldrich St. Louis, MO, USA) at 110°C for 24 hours. The sample was sealed under a nitrogen atmosphere. The resulting hydrolysate was filtered through 0.45 μm syringe filters and then dried using nitrogen. The sample thus prepared, after appropriate dilution, was subjected to a derivatization procedure according to Waters' recommendations. For this purpose, 10 μL of the sample was mixed with 70 μL of borate buffer (pH in the range 8.2 to 9.0), and then 20 μL of 6-aminoquinolyl-N-hydroxysuccinimidylcarbamate (AQC) reagent at a concentration of 3 mg/mL acetonitrile was added. Standards (Waters, Millford, MA USA) were handled analogously. Chromatographic separation was performed using a liquid chromatograph from Thermo Scientific: a Dionex Ultimate 3000 equipped with an LPG - 3400 SD gradient 4-channel pump, a WPS 3000 TSL autosampler, and a FLD-3400RS 4-channel fluorescence detector. The column used for the analysis was a Nova -Pak C 18, 4 μm, (150x 3.9 mm) column from Waters. Separation temperature 37°C. Elution was carried out in a two-component gradient and a flow rate of 1 mL/min: eluent A, acetate-phosphate buffer pH=5.2, B acetonitrile/water 60:40. Gradient: 0min - 100%A, 0.5min -98%A, 15min- 93%A, 19min- 90%A, 32min-67%A, 33min-67%A, 34min- 0%A, 37min-0%A, 38min- 100%A, 64min-100%A, 65min- 0%A. Detection Excitation wavelength 250, Emission wavelength 395. Quantitative analysis was performed using 1-point calibration (using an analytical standard of 100 pmol each). Development of results using Chromeleon 7.0 software. All reagents from Waters (Millford, MA, USA) kit: Standards, borate buffer, AQC. Eluent acetate-phosphate buffer (pH 5.2). Water, Acetonitrile Sigma Aldrich (St. Louis, MO, USA).

### Meat colour

Meat colour was determined using a Konica Minolta CM-600d spectrophotometer (Minolta Co., Ltd., Tokyo, Japan) with a 50-mm diameter measuring head in the CIE L\*a\*b\* system, where the L\* parameter corresponds to the degree of lightness (L\* = 0: black, L\* = 100: white), a\* and b\* are colour components (a\* > 0 red, a\* < 0 green, b\* > 0 yellow, b\* < 0 blue). The chromametre was calibrated against a white tile (Y = 93.8, x = 0.3136, y = 0.3192) [18].

### Cooking loss

Muscle fragments weighing around 120 g were packed in aluminium foil. Thermal treatment in an electric furnace was carried out at 180±2°C until the muscle temperature reached 72±2°C. The temperature inside the muscles was measured with a digital thermometer using a probe needle. After heat treatment and cooling on ice, cooking loss was determined from meat weight loss.

### Description of the Experiment

**Study flow:** The aim of the study was to analyze the quality of meat from wild boars hunted in the Polish Carpathians - from the Bieszczady Mountains to the Silesian Foothills - between the southern border of Poland and the E40 motorway. The Polish Carpathians stretch across three provinces: Subcarpathian, Lesser Poland, and Silesian. The Polish Carpathians are characterized by a large proportion of grasslands and significant forests. The Carpathian flora includes about 500 plant species found in mountainous regions. Potatoes, oats, and barley are the main crops, with vegetables and fruit in the lower elevations, which may be eaten by wild boars. The wild boars were obtained during depopulation hunts in the autumn-winter season of 2021-2022. Meat samples for analysis were collected at a game processing plant where the carcasses were sent after being gutted, skinned, and examined by a veterinarian. Raw meat (*m. longissimus dorsi lumborum*) from 20 carcasses of subadult (yearling) wild boars (1–2 years) and 20 carcasses of adult wild boars (older than 2 years) was analyzed. The raw meat (*m. longissimus dorsi lumborum* between 13<sup>th</sup> and 14<sup>th</sup> rib) was minced, and average samples obtained were subjected to the following chemical analyses:

- Water content according to the standard PN-ISO 1442:2000 [19]).
- Fat content according to the standard PN-ISO 1444:2000 [20],
- Protein content by Kjeldahl method PN-75/A-04018 [21],
- Total ash content according to the standard PN-ISO 936:2000 [22],
- Total carbohydrates content was calculated assuming that the all total solids and water stand for 100%.
- The energy value was calculated using conversion factors, according to the Guide [23].

### Quality Assurance

**Number of repeated analyses:** 2.

**Number of experiment replication:** 2.

**Reference materials:** Standard mixture of 37 FAME components (Supelco Bellefonte PA, USA, Sigma-Aldrich Co. St. Louis, MO, USA) and CLA isomers (Sigma-Aldrich Co. St. Louis, MO, USA) for fatty acids profile. ACCQ Tag analytical kit and standards from Waters (Millford, MA, USA) for amino acids analysis

**Calibration:** The chromametre was calibrated against a white tile ( $Y = 93.8$ ,  $x = 0.3136$ ,  $y = 0.3192$ ) which was supplied by the manufacturer.

**Laboratory accreditation:** All analyses were performed in non-accredited laboratories. All laboratories were part of the University of Agriculture in Krakow.

### Data Access

Data are available on request from the corresponding author

### Statistical Analysis

The results were analyzed with ANOVA and presented as means with standard deviation. The calculations were performed with licensed software [24].

## RESULTS AND DISCUSSION

Game meat, including wild boar meat, is a rich source of nutrients. Because wild boar inhabits diverse geographic zones, both in forest and agricultural ecosystems, from lowlands to mountainous regions, and consumes a variety of foods of both plant and animal origin, this influences the chemical composition of its meat. The approximate composition of European wild boar meat shows a high protein content (21.2–25.9%) and a low fat content (0.7–2.8%) [25]. Table 1 presents the chemical composition, color parameters, and cooking loss of wild boar meat obtained in south-eastern Poland. The meat of subadult wild boars was characterised by a lower protein and fat content compared to the meat of adult wild boars. The protein content in the meat of these wild boars ranged from 22.48 to 22.66%, while the fat content was 1.65–1.95%. The highest protein content (23.3%) in the meat of 2-year-old wild boars, compared to 23.0% in 4- and 5-year-old wild boars and 22.1% (the lowest value) in the meat of 8-month-old wild boars hunted in the district of Zlaté Moravce in western Slovakia (Nitra region), in the municipality of Hostie (on the eastern side of Tribeč Mountain) [26]. Higher fat content in the meat of older wild boars was found by other authors [27], [28], [29]. Other authors [30] found that the meat of wild boars hunted in the southwest and southeast region of Šumadija, Serbia. whose body weight exceeded 144.0 kg contained 1.87% fat and 23.67% protein. Significantly higher IMF content in meat obtained from adult wild boars (34–36 months) than in younger ones (10–12 months and 22–24 months) harvested in winter was reported [31]. In the study of [32], an IMF content of 4.7% in the triceps brachii muscle of wild boars with a carcass weight of 16–51 kg was hunted in the south of Sweden. These authors [33] showed that the age class of wild boars significantly influenced the total fat content of the meat, with adult individuals having the highest fat content (7.60%) compared to subadults (4.52%). According to [34], the age of wild boars does not significantly affect IMF content, whereas the hunting season is an important factor, as wild boar carcasses contained more fat before winter than in spring. These results were compared with those of other authors who analyzed the chemical composition of wild boar meat from various European countries (Table 2). Wild boar meat is a rich source of easily digestible protein. The protein content in *m. longissimus lumborum* of wild boars ranged from 20.78% (Czech Republic) to 23.67% (Serbia). Wild boar meat is low in calories (approximately 110 kcal/100 g) and low in fat (1.95% according to our own research). In the study of [35] analyzing loin and ham of wild boars hunted from August to January in the four hunting economic years (2013/2014, 2014/2015, 2015/2016, and 2016/2017) in the following voivodeships: Lower Silesia, Opole, Silesia, Lesser Poland, Podkarpackie, and Lublin), found a higher fat content (4.03 – 4.83) and a higher caloric value (126.9 – 134.0 kcal/100g) of meat. Wild boar meat hunted in winter in Romania and Hungary was characterized by a higher fat content (6.74 – 7.60%). The mobility of wild boars and the low fat content give this meat a natural dark red, burgundy color. The  $L^*$  parameter measures the brightness of a product's color. The value of this parameter for wild boar meat slaughtered in Poland was 47.12 – 45.85, while for meat slaughtered in other countries it ranged from 32.30 (Sweden) to 42.16 (Serbia). Lower L values were obtained by [36] (41.8 - 43.1) for the meat of wild boars shot in the Northwest Poland and by [37] for the meat of wild boars shot in western Poland. The meat of

wild boars hunted in the Polish Carpathians was also characterized by a high  $a^*$  parameter value (19.47), making it the reddest among wild boar meat from other countries. The highest  $b^*$  parameter value was observed in wild boar meat from Sweden and Poland. The cooking loss values obtained in our study ranged from 35.21 to 36.72%. In this research, [36] found cooking losses of 33.32 – 33.38% for meat from young wild boars (<1 year) and 30.76% for meat from sub-adult wild boars (1–2 years) shot in Northwest Poland. Similar values for culinary losses were reported by [37] for wild boar meat shot in western Poland. Higher cooking losses - 36.74% for shoulder meat and 37.08% for leg meat were reported by [38], while in the study by [39], cooking losses ranged from 32.01 to 35.71% in the LTL muscle and from 33.53 to 36.71% in the semi-membranosus muscle. Game meat is low in cholesterol. In study of [30] 44.94 mg of cholesterol/100 g of meat in wild boar meat obtained in the Šumadija region, while our own studies found 52.08 mg of cholesterol/100 g of meat, while [40], [41], [42] found a higher cholesterol content (98.11 mg) in 100 g of wild boar meat obtained in Latvia. In contrast, the cholesterol content in meat from wild boars hunted in Portugal was reported to be 55.6 mg 100 g<sup>-1</sup> for females and 58.7 mg 100 g<sup>-1</sup> for males [43].

**Table 1** Chemical composition, color parameters ( $L^*$   $a^*$   $b^*$ ) and cooking loss of *m. longissimus lumborum* of wild boars hunted in the Polish Carpathians.

Parameter	Subadults (1–2 years)	Adults (>24 months)
<b>Chemical composition %</b>		
<b>Total solids</b>	25.57±2.68	26.14±1.78
<b>Protein</b>	22.48±2.96	22.66±1.81
<b>Fat</b>	1.65±0.51	1.95±0.37
<b>Ash</b>	1.04±0.03	1.06±0.04
<b>Carbohydrates</b>	0.40±0.10	0.47±0.19
<b>Caloric value kcal/100g</b>	106.37±11.76	110.07±12.09
<b>Color parameters:</b>		
<b>Lightness, <math>L^*</math></b>	47.12±1.21	45.85±3.79
<b>Redness, <math>a^*</math></b>	18.23±1.35	19.47±1.97
<b>Yellowness, <math>b^*</math></b>	11.06±0.95	11.73±2.19
<b>Cooking loss (%)</b>	35.21±1.23 <sup>a</sup>	36.72±1.89 <sup>b</sup>
<b>Cholesterol, mg 100g<sup>-1</sup></b>	50.35±4.12	52.08±3.75

Note: a, b – differences  $P \leq 0.05$ .

Intramuscular fat determines the juiciness, marble, and palatability of meat. Wild game meat is characterized by low fat content [48], and age-related changes in muscle IMF content cause differences in the fatty acid profile, which influences the flavor of the meat [49]. For consumers, the fatty acid profile of intramuscular fat is important, especially the content of saturated and unsaturated fatty acids [50]. Saturated acids, especially myristic acid C-14:0 and palmitic acid C-16:0, increase the total amount of cholesterol, especially its LDL lipoprotein fraction. Research by [51] indicates that myristic acid may lower the level of “good cholesterol” HDL. According to [52], the fatty acid composition in wild boars is influenced by their diet. The fatty acid profile of the muscle fat from the wild boars we analyzed was similar to that reported by [45]. Particularly noteworthy is the high content of C16:0 palmitic acid and the low content of C-18:2 n-6 linoleic acid. Similar results were found by [30] and [45]. The study by [53] did not confirm that age and gender influence the saturated fatty acid (SFA) content in wild boar fat. Age had a significant effect on the content of C15:0, C18:0, and C20:0, but not on palmitic acid (C16:0), the dominant saturated fatty acid. High C16:0 content is one of the factors contributing to higher plasma cholesterol concentrations [54], [55]. The concentration of palmitic acid was highest in subadult wild boars up to 12 months of age and lowest in the oldest individuals aged 34–36 months [31]. In one-year-old wild boars hunted in Italy (SFA levels were 40.1%), which was lower than in wild boars aged 6–8 months (44.7 %) [56]. According to [57], the content of monounsaturated fatty acids (MUFA) ranged from 38.36 to 46.75 % and was higher in wild boars older than 2 years, whose average body weight was 84 kg. According to [58], game meat has the advantage of containing fewer saturated fatty acids (SFAs) and more polyunsaturated fatty acids (PUFAs) than meat from farmed animals. Monounsaturated fatty acids (MUFAs) are used by the body as an energy source and have a more beneficial effect than SFAs, reducing LDL and protecting HDL [53], [59]. Significantly higher MUFA content in older (>1 year old) wild boars than in younger ones [1].

**Table 2** Chemical composition, color parameters (L\* a\* b\*) and cooking loss of *m. longissimus* of wild boars hunted in various European countries.

Characteristic	European countries					
	Poland [39]	Serbia [30]	Hungary [44]	Romania [33]	Slovakia [45]	Czech Republik [46]
<b>Hunting season</b>	nd	nd	winter hunting	Winter 2010-2017	08 2016 - 01 2017	nd
<b>Hunting area</b>	south-eastern Poland	Southwest and southeast Region Šumadija	Tolna county	Frasin District	Záhorská nížina	South-east of the Czech Republic
<b>Chemical composition %</b>						
<b>Total solids</b>	25.40-25.79	27.03	nd	nd	28.98	25.41
<b>Protein</b>	21.42-21.84	23.67	21.87	21.99	nd	20.78
<b>Fat</b>	1.46-2.20	1.87	6.74	7.60	2.84	1.30
<b>Ash</b>	nd	1.26	nd	1.20	nd	0.94
<b>Carbohydrates</b>	nd	nd	nd	nd	nd	nd
<b>Caloric value kcal/100g</b>	136.00-144.43	nd	nd	nd	nd	nd
<b>Color parameters:</b>						
<b>Lightness, L*</b>						
<b>Redness, a*</b>	41.13-45.41	42.16	nd	nd	nd	nd
<b>Yellowness, b*</b>	9.10-12.41	11.97	nd	nd	nd	nd
	8.81-10.60	8.94	nd	nd	nd	nd
<b>Cooking loss (%)</b>	32.01-35.71	nd	nd	nd	nd	nd
<b>Cholesterol, mg 100g<sup>-1</sup></b>	nd	44.94	nd	nd	nd	nd
Characteristic	European countries					
	Latvia [41]	Ukraine [15]	Germany [1]	Sweden (male) [32]	Portugal [43]	Italy [47]
<b>Hunting season</b>	Autumn-winter season	November 2022	June 2006-January 2009	October 2021	Autumn and Winter	October 2011 -January 2012
<b>Hunting area</b>		Sumy region	Mecklenburg- Western Pomerania	South of Sweden	Vale Feitoso and Poupa Beira Baixa province	Southern Maremma province of Viterbo
<b>Chemical composition %</b>						
<b>Total solids</b>	25.38	nd	25.70	nd	nd	25.59
<b>Protein</b>	20.88	22.98	22.50	nd	nd	21.20
<b>Fat</b>	3.45	1.84	2.10	nd	4.75	3.13
<b>Ash</b>	1.14	0.87	nd	nd	nd	1.26
<b>Carbohydrates</b>	nd	nd	nd	nd	nd	nd
<b>Caloric value kcal/100g</b>	nd	108.48	nd	nd	nd	nd
<b>Color parameters:</b>						
<b>Lightness, L*</b>						
<b>Redness, a*</b>	nd	nd	nd	32.30	nd	38.64
<b>Yellowness, b*</b>	nd	nd	nd	15.20	nd	5.52
	nd	nd	nd	19.30	nd	10.48
<b>Cooking loss (%)</b>	nd	nd	nd	nd	nd	31.77
<b>Cholesterol, mg 100g<sup>-1</sup></b>	98.11	nd	nd	nd	58.70	nd

Note: nd - no data.

MUFA concentration depends on wild boar age and is highest in animals older than 24 months [57]. Study of [1] and [57] explain the high C18:1c9 content in fat by the high content of acorns and chestnuts in the diet of wild boars feeding in forests or the high content of sunflowers and maize in the diet of wild boars feeding in fields. Studies show that wild boars living in forests were characterized by higher levels of n-3 polyunsaturated fatty acids and a more favorable n-6/n-3 fatty acid ratio than those from agricultural areas. According to [56], the season when wild boars are hunted influences the fatty acid profile of the IMF. It was reported by [60] that the ratio of n-6 to n-3 polyunsaturated fatty acids is significantly dependent on the hunting season (summer vs. winter) and not on the sex of the animals. The fatty acid profile and n-6: n-3 PUFA ratio of meat is influenced

by dietary composition, which in turn depends on the availability of food in the wild boar's habitat [33], [61]. In our studies, the n-6:n-3 PUFA ratio ranged from 11.19 to 11.97. The ratio of n-6 to n-3 acids at the level of 17.0 in the IMF meat of adult males and 15.5 in adult females [43], while in the study by [62], this ratio in the meat of two-year-old wild boars was as high as 32.0. Such an unfavorable ratio of n-6 to n-3 fatty acids in the human diet may be associated with the risk of cancer and cardiovascular disease [63], and [64]. In our study, both wild boar age groups showed a polyunsaturated fatty acid-to-saturated fatty acid (PUFA: SFA) ratio below the recommended value of 0.4, ranging from 0.086 to 0.095. Similar PUFA:SFA ratio values (0.11 for the youngest wild boars, 0.062 for the adult wild boars) were obtained by [45], analyzing the fat of the musculus semimembranosus of wild boars hunted in the southwest region of Slovakia. Such a low value of the PUFA/Sfa index is caused by the low content of C-18:2 n-6 acid in wild boar fat, both in our own studies (3.91 – 4.10) and in [45] - 2.69 – 4.42. The hunting grounds for the wild boars analyzed by [45] were in the Zahorska Lowland and the Little Carpathians. This area is mainly covered with Scots pine, while the territory of Malé Karpaty is mainly covered with oak, beech, and witch hazel. The wild boars included in our research had a similar feed base. A higher PUFA/Sfa ratio (0.50-0.61) in the fat of wild boars hunted was found in Romania, Spain, and Italy [33], [43], and [64]. In the studies by [1] and [47], the PUFA/SFA ratio was even higher, at 0.84 and 0.95, respectively. The fat of longissimus lumborum of wild boars shot in Poland (Subcarpathian, Lesser Poland, and Silesian Voivodeships) was found to contain 1.74% myristic acid and 32.99% palmitic acid (Table 3). Higher levels of these fatty acids were found only by [30], [55] in meat from wild boars hunted from the southwest and southeast parts of the Šumadija region in Serbia - Table 4. The diet of wild boars in the Sumadija region and in Poland is similar and consists of seeds of deciduous trees: moose oak, linden, chestnut, and hazel, grasses, cereals (corn, wheat, and barley), and fruits (apple, plum, and pear), and in Serbia, additionally apricot and peach. In Poland, potatoes are also a popular food for wild boars. The fat of wild boars obtained in Italy in the provinces of Viterbo and Molise was characterized by a lower content of myristic and palmitic acids (Table 4). These provinces are characterized by large areas of oak and beech forests, as well as uncultivated pastures and mountain meadows [65]. The intramuscular fat of wild boars obtained in south-eastern Poland (own research) and in the south-west and south-east region of Šumadija, Serbia [30] was characterized by a predominance of saturated fatty acids (52.05 and 58.18, respectively). In studies by other authors, wild boar fat was dominated by unsaturated acids, mainly C-18:1 n-9 and C-18:2 n-6. Among all unsaturated acids, those from the linoleic acid (n-6) and alpha-linolenic acid (n-3) families are of particular importance, as they play structural roles and perform key functions in human biochemical processes. The effects of n-6 and n-3 acids in certain mechanisms are opposite, which is why it is assumed that the ratio of n-6 to n-3 should be less than 4. The ratios of polyunsaturated to saturated fatty acids (PUFA/SFA) and polyunsaturated fatty acids from the n-6 to n-3 family have become important parameters for assessing the nutritional value and health-promoting properties of food [50], [66], and [67]. For optimal health, many nutritional organizations recommend a PUFA/SFA ratio of at least 0.4 [63]. In wild boar meat obtained in Poland, Serbia, Slovakia, and Hungary, the PUFA/SFA ratio was unfavorable for consumer health, ranging from 0.09 to 0.29. The ratio of polyunsaturated fatty acids from the n-6 to n-3 family closest to the recommended ratio (below 4) was found in the fat of wild boars obtained in Latvia (6.13), while the least favorable ratio of these acids for consumer health was found in wild boar fat obtained in Portugal (17.0) and Poland (13.20-14.85). Very unfavorable ratio of n6 polyunsaturated fatty acids to n3 polyunsaturated fatty acids of 32.03:1 in the fat of m. longissimus lumborum of wild boars hunted in the Podkarpacie region were reported by [62]. Given the low consumption of wild boar meat in Poland, the unfavorable n-6 to n-3 polyunsaturated fatty acid ratio is not a significant nutritional problem, but consumers should be advised to incorporate game meat products into their diet to increase their intake of n-3 polyunsaturated fatty acids. The meat of wild boars feeding in forest-dominated areas is characterized by a higher content of n-3 polyunsaturated fatty acids and a lower n-6/n-3 ratio compared to the meat of wild boars from agricultural habitats [25]. In the meat of wild boars hunted in winter, a lower SFA content and a higher PUFA content, as well as PUFA/SFA and n-6/n-3 PUFA ratios, were found compared to wild boar meat in summer [68]. The fat of wild boars obtained in Poland and Hungary was found to contain CLA acids (0.08-0.3%), which are characteristic of ruminant fat. According to [69], the CLA content of pork, chicken, and horse meat is usually lower than 1 mg/g lipid. CLA exerts positive effects on cancer, cardiovascular disease, diabetes, body composition, immune system, and bone health [68]. The higher proportions of CLA in wild boar meat compared to pork could be explained by the intestinal bacterial flora biosynthesis. Gender is a significant factor influencing the fatty acid content in the intramuscular fat of wild boars [26]. The high proportion of polyunsaturated fatty acids (PUFA) in game fat is considered an important factor contributing to the development of "wild", "gamey" and "grassy" flavor in meat. [25].

**Table 3** Fatty acid profile of *m. longissimus lumborum* fat of wild boars hunted in the Polish Carpathians (%).

Fatty acids	Subadults (yearlings) 1–2 years	Adults (>24 months)
<b>C-8:0</b>	0.0	0.0
<b>C-10:0</b>	0.12±0.02	0.12±0.02
<b>C-12:0</b>	0.11±0.04	0.11±0.01
<b>C-14:0</b>	1.71±0.23	1.74±0.15
<b>C-14:1</b>	0.11±0.06	0.18±0.08
<b>C-15:0</b>	0.07±0.03	0.11±0.02
<b>C-16:0</b>	32.50±4.11	32.99±2.81
<b>C-16:1<math>n</math>9</b>	0.58±0.10	0.70±0.08
<b>C-16:1<math>n</math>7</b>	2.11±0.72	2.19±0.22
<b>C-17:0</b>	0.28±0.11 <sup>a</sup>	0.39±0.07 <sup>b</sup>
<b>C-17:1</b>	0.15±0.08	0.16±0.02
<b>C-18:0</b>	16.76±1.92	16.38±0.67
<b>C-18:1 <math>n</math>-9</b>	36.08±4.12	35.95±2.76
<b>C-18:1<math>n</math>-7</b>	3.45±0.51	3.06±0.34
<b>C-18:2 <math>n</math>-6</b>	4.10±1.83	3.91±1.25
<b>C-18:3<math>n</math>-6</b>	0.04±0.02	0.04±0.01
<b>C-18:3<math>n</math>-3</b>	0.27±0.15	0.25±0.12
<b>CLA</b>	0.08±0.04	0.08±0.02
<b>C-20:0</b>	0.22±0.10	0.21±0.04
<b>C-20:1<math>n</math>-9</b>	0.79±0.31	1.08±0.44
<b>C-20:2</b>	0.19±0.06 <sup>a</sup>	0.14±0.05 <sup>b</sup>
<b>C-20:3 <math>n</math>-6</b>	0.03±0.01	0.02±0.004
<b>C-20:4<math>n</math>-6</b>	0.10±0.05	0.07±0.03
<b>C-20:4<math>n</math>-3</b>	0.05±0.02	0.03±0.02
<b>C-20:5 <math>n</math>-3</b>	0.01±0.004	0.01±0.003
<b>C-22:4 <math>n</math>-6</b>	0.03±0.01	0.03±0.01
<b>C-22:5 <math>n</math>-3</b>	0.04±0.02	0.03±0.01
<b>C-22:6 <math>n</math>-3</b>	0.02±0.008	0.02±0.003
<b>PUFA <math>n</math>-3</b>	0.38±0.05	0.34±0.03
<b>PUFA <math>n</math>-6</b>	4.30±1.90	4.07±1.27
<b><math>n</math>6/<math>n</math>3</b>	11.19±3.05	11.97±2.04
<b>PUFA</b>	4.94±1.79	4.49±1.13
<b>SFA</b>	51.84±5.85	52.05±4.12
<b>PUFA/SFA</b>	0.095±0.01 <sup>a</sup>	0.086±0.01 <sup>b</sup>

 Note: a, b – differences  $P \leq 0.05$ .

**Table 4** Fatty acid profile of *m. longissimus lumborum* fat of wild boars hunted in various European countries (%).

Fatty acids	European countries						
	Poland [28]	Poland [6]	Serbia [55]	Serbia [30]	Hungary [44]	Romania [33]	Slovakia [45]
Hunting season	December 2014 and January 2015	autumn of 2017	2018	Nd	winter hunting	winter 2010-2017	08 2016
Hunting area	The central part of Poland	south-eastern Poland	Šumadija region	Southwest and southeast Region Šumadija	Tolna county	Frasin District	Záhorská nížina
C-8:0	nd	0.02	0.78	nd	nd	nd	nd
C-10:0	nd	0.08	nd	nd	nd	nd	nd
C-12:0	nd	0.07	nd	nd	nd	nd	nd
C-14:0	1.50	1.26	0.99	3.01	0.8	0.28	1.70
C-14:1	0.78	0.02	nd	nd	nd	nd	nd
C-15:0	0.35	0.03	1.38	nd	nd	0.02	nd
C-16:0	25.95	24.77	22.4	33.20	20.8	22.13	28.49
C-16:1n9	4.92	nd	5	nd	nd	4.09	3.43
C-16:1n7	nd	2.30	2.97	0.65	0.3	nd	Nd
C-17:0	0.38	0.22	nd	nd	nd	0.23	0.46
C-17:1	0.23	0.20	0.70	nd	nd	nd	nd
C-18:0	10.75	14.04	0.44	21.97	11.1	11.39	14.26
C-18:1 n-9	32.95	45.58	16.04	36.15	39.5	35.35	38.54
C-18:1n-7	0.28	nd	40.78	nd	nd	3.53	nd
C-18:2 n-6	16.07	8.39	nd	3.29	12.3	12.85	3.63
C-18:3n-6	0.02	nd	8.30	nd	nd	0.04	nd
C-18:3n-3	1.90	0.46	nd	nd	nd	0.88	0.39
CLA	nd	nd	1.36	nd	0.3	nd	nd
C-20:0	0.04	0.24	nd	nd	0.2	0.04	0.27
C-20:1n-9	0.22	1.31	0.46	nd	nd	0.99	0.83
C-20:2	nd	0.51	0.68	nd	nd	0.04	nd
C-20:3 n-6	0.33	0.03	0.58	nd	nd	0.37	nd
C-20:4n-6	2.19	0.10	2.09	nd	2.0	1.75	0.37
C-20:4n-3	nd	0.13	nd	nd	nd	nd	nd
C-20:5 n-3	0.20	0.00	nd	nd	nd	0.24	nd
C-22:4 n-6	nd	nd	nd	nd	nd	0.37	nd
C-22:5 n-3	0.90	nd	nd	nd	nd	0.11	nd
C-22:6 n-3	0.08	nd	nd	nd	nd	0.14	nd
PUFA n-3	3.90	0.59	nd	nd	nd	1.58	nd
PUFA n-6	18.29	8.76	nd	nd	nd	15.48	nd
PUFA n6/n3	22.19	9.35	nd	nd	nd	17.12	3.73
PUFA/SFA	4.74	14.85	12.33	nd	nd	9.91	12.14
PUFA/SFA	0.57	0.25	0.29	nd	nd	0.50	0.09

Note: nd - no data.

**Table 4** Continue.

Fatty acids	European countries						
	Lithuanian males [68]	Latvia [41]	Germany [1]	Portugal males [43]	Sweden (male) [32]	Italy [47]	Italy [65]
<b>Hunting season</b>	Autumn and Winter 2010/2011	Autumn-Winter season	June 2006-January 2009	Autumn and Winter	October 2021	October 2011 - January 2012	Nd
<b>Hunting area</b>	central parts of Lithuania	nd	Mecklenburg-Western Pomerania	Vale Feitoso and Poupa - Beira Baixa province	south of Sweden	Southern Maremma - province of Viterbo	Molise - Bagnoli del Trigno and Roccavivara
<b>C-8:0</b>	nd	nd	nd	nd	nd	nd	nd
<b>C-10:0</b>	nd	nd	nd	nd	nd	nd	nd
<b>C-12:0</b>	nd	nd	nd	nd	nd	0.14	nd
<b>C-14:0</b>	0.99	nd	0.80	1.0	1.11	0.79	1.02
<b>C-14:1</b>	nd	nd	nd	Nd	nd	nd	nd
<b>C-15:0</b>	1.00	nd	nd	nd	nd	nd	nd
<b>C-16:0</b>	25.00	nd	19.20	20.7	23.1	20.66	22.64
<b>C-16:1n9</b>	nd	nd	nd	2.3	0.40	2.35	2.68
<b>C-16:1n7</b>	3.31	nd	nd	nd	2.35	nd	nd
<b>C-17:0</b>	0.51	nd	nd	0.2	0.18	0.38	nd
<b>C-17:1</b>	0.31	nd	nd	0.1	nd	0.17	0.24
<b>C-18:0</b>	11.28	nd	10.80	11.5	10.3	14.04	13.47
<b>C-18:1 n-9</b>	39.29	nd	28.00	36.1	35.0	25.83	39.66
<b>C-18:1n-7</b>	nd	nd	nd	nd	4.14	4.43	nd
<b>C-18:2 n-6</b>	11.37	nd	20.90	18.8	16.8	20.66	13.65
<b>C-18:3n-6</b>	nd	nd	nd	nd	nd	nd	nd
<b>C-18:3n-3</b>	0.46	nd	1.30	1.0	0.90	0.61	0.94
<b>C-20:0</b>	0.09	nd	nd	0.1	nd	0.17	0.46
<b>C-20:1n-9</b>	0.53	nd	nd	nd	0.58	nd	0.55
<b>C-20:2</b>	0.30	nd	nd	0.4	0.47	0.11	0.42
<b>C-20:3 n-6</b>	0.33	nd	nd	0.5	0.33	0.50	nd
<b>C-20:4n-6</b>	2.86	nd	nd	4.4	3.37	6.21	2.72
<b>C-20:4n-3</b>	nd	nd	nd	nd	nd	nd	Nd
<b>C-20:5 n-3</b>	0.42	nd	nd	0.4	0.44	0.22	0.23
<b>C-22:4 n-6</b>	0.31	nd	nd	nd	nd	0.38	nd
<b>C-22:5 n-3</b>	0.83	nd	nd	nd	0.61	1.14	0.49
<b>C-22:6 n-3</b>	0.20	nd	nd	nd	nd	0.18	0.10
<b>PUFA n-3</b>	nd	3.05	3.70	1.4	1.96	2.56	1.74
<b>PUFA n-6</b>	nd	13.63	27.20	24.0	21.0	27.97	16.79
<b>PUFA n6/n3</b>	17.39	17.00	30.90	25.4	5.66	30.53	18.53
<b>PUFA/SFA</b>	9.01	6.13	8.70	17.0	12.7	10.95	9.66
	0.45	0.40	0.95	0.60	0.24	0.84	0.48

Note: nd - no data.

Among the essential nutrients for the human body that must be supplied through food are 11 vitamins, 15 minerals, 2 fatty acids, and 9 amino acids: phenylalanine, valine, threonine, tryptophan, methionine, leucine, isoleucine, lysine, and histidine [70]. Amino acids are key components of all proteins. In total, there are 21 amino acids, 12 of which can be synthesized by humans and 9 of which must be consumed [70], and [71]. Table 5 shows the amino acid content in *m. longissimus lumborum* of wild boars shot in various European countries. Since the authors reported amino acid content in different units, we focused on discussing the ratios of nonessential-to-essential and of essential-to-nonessential. For humans, while a specific essential/nonessential amino acids ratio isn't a standard dietary guideline, a balance of both is essential for health [72]. The data presented in Table 5 show that the meat of wild boars obtained in Poland, Latvia, and Portugal was characterized by a deficiency of essential amino acids, consumers should be advised to supplement their diet with wild boar meat with products high in essential amino acids.

**Table 5** The amino acid content in *m. longissimus lumborum* of wild boars hunted in various European countries.

Amino acids	European countries				
	Poland Our own research % of AA	Poland [73] g*kg <sup>-1</sup> muscle	Latvia [58] g kg <sup>-1</sup> meat	Latvia [42] mg100g <sup>-1</sup> protein	Portugal [74] (mg g <sup>-1</sup> ) of meat
<b>Hunting season</b>	autumn-winter season of 2021- 2022	Autumn	autumn-winter 2007-2010	autumn-winter season	October to February 2018/2019 and 2019/2020
<b>Hunting area</b>	Subcarpathian, Lesser Poland and Silesian Voivodeships	Nd	Vidzeme and Latgale regions	whole regions in Latvia	continental Portugal
<b>Essential AA</b>					
<b>Lysine</b>	10.07±0.07	11.86 ± 0.45	5.03 ± 0.30	2.16 ± 0.58	16.27 ±1.13
<b>Methionine</b>	3.04±0.06	nd	2.05 ± 0.28	0.56 ± 0.06	5.97 ±0.24
<b>Isoleucine</b>	4.91±0.01	7.00 ± 0.53	2.71 ± 0.55	1.04 ± 0.12	9.67 ±0.38
<b>Leucine</b>	8.61±0.14	10.61± 0.57	5.42 ± 0.54	1.61 ± 0.11	20.20 ±0.99
<b>Phenylalanine</b>	3.96±0.29	6.89 ± 0.70	2.27 ± 0.52	0.91 ± 0.16	9.05 ±0.52
<b>Threonine</b>	4.41±0.04	8.25 ± 0.85	2.46 ± 0.19	0.52 ± 0.19	10.60 ±0.70
<b>Valine</b>	5.51±0.06	6.95 ± 0.47	3.22 ± 0.55	0.12 ± 0.03	11.54 ±0.65
<b>Tryptophan</b>	nd	nd	0.98 ± 0.15	nd	2.37 ±0.14
<b>Histidine</b>	3.03±0.05	6.16 ± 0.76	2.13 ± 0.33	1.07 ± 0.12	7.67 ±0.13
<b>Σ Essential AA</b>	43.54±0.19	50.79	26.27	7.99	93.34
<b>Endogenous AA</b>					
<b>Glutamic acids</b>	17.20±0.02	22.67 ± 1.25	12.15 ± 0.93	3.24 ± 0.61	29.88 ±1.46
<b>Glycine</b>	6.81±0.04	5.82 ± 0.84	3.59 ± 0.57	0.93 ± 0.14	9.28 ±0.26
<b>Serine</b>	4.04±0.05	7.11 ± 0.42	2.17 ± 0.18	0.79 ± 0.21	8.96 ±0.46
<b>Alanine</b>	5.90±0.02	6.28 ± 0.68	3.68 ± 0.25	1.22 ± 0.10	13.18 ±0.88
<b>Proline</b>	5.35±0.10	8.57 ± 0.65	2.38 ± 0.61	0.66 ± 0.13	9.77 ±0.81
<b>Asparagine acids</b>	7.51±0.06	15.50 ± 1.36	6.41 ± 0.89	2.09 ± 0.60	18.92 ±1.05
<b>Tyrosine</b>	2.54±0.10	5.33 ± 0.87	2.49 ± 0.63	0.74 ± 0.11	7.08 ±0.30
<b>Arginine</b>	7.12±0.01	12.40 ± 1.61	4.81 ± 0.21	2.02 ± 0.42	14.16 ±1.00
<b>Σ endogenous AA</b>	56.46±0.19	83.68	37.68	11.69	111.23
Ratio nonessential/essential	1.30±0.05	1.65	1.44	1.47	1.20
Ratio essential/nonessential	0.78±0.03	0.61	0.70	0.69	0.84

Game meat contains more trace elements than beef and pork. This is due to both genetic and environmental factors [75]. Wild boar meat has been found to contain higher levels of Ca, P, Cu, Zn, and twice as much Fe as pork, but lower levels of Na and Mg [1], and [76]. The feeding location of wild animals influences the vitamin content, particularly retinol,  $\alpha$ -, and  $\gamma$ -tocopherol in meat [1]. Studies on the meat of wild boars hunted in agricultural and forest areas showed a higher content of  $\alpha$ -tocopherol in farmland areas due to differences in vegetation and a higher content of  $\gamma$ -tocopherol in forest areas due to the presence of acorns [57].

The presented results of our own research and those of other authors show that meat composition, including the high fat and protein content, depends primarily on food availability in hunting grounds, the age of the wild boar, carcass weight, and the hunting season. Compared with young animal meat, adult animal meat is characterized by higher fat and protein content and lower water content. The meat of wild boars hunted in late autumn and winter is characterized by a higher intramuscular fat content compared to the meat of wild boars hunted in spring and summer, which is due to the greater amount of food available from autumn crops. Among the analyzed meat components, the ash content is the least susceptible to changes and ranges from 0.9 to 1.3% [25].

### Limitations

The present study has several limitations that should be considered when interpreting the results. First, the carcasses were collected from a relatively large geographical area within the Polish Carpathians, which may have introduced environmental variability related to habitat type, natural feed availability, and local agricultural conditions. Second, the study included a limited sample size ( $n = 40$ ), which may limit the generalizability of the findings. Third, all animals were harvested only during the autumn–winter season of 2021–2022; therefore, the results do not reflect possible seasonal changes in meat composition and quality. Fourth, the analyses were performed only on the *m. longissimus lumborum* muscle, so the results cannot be directly extrapolated to other muscles or edible tissues. Finally, comparisons with results reported by other authors should be interpreted cautiously, as differences in hunting season, habitat, animal age, analytical methodology, and reporting units among studies may affect comparability.

### CONCLUSION

Due to the growing wild boar population in Europe and the increasing availability of meat obtained through depopulation culling, wild boar meat may become a more important raw material for the food market. In the present study, *m. longissimus lumborum* of wild boars hunted in the Polish Carpathians was characterized by a high protein content (22.48–22.66%), low fat content (1.65–1.95%), and low energy value (106.37–110.07 kcal/100 g). Cholesterol content was also relatively low, ranging from 50.35 to 52.08 mg/100 g. The meat showed dark-red colour characteristics, with  $L^*$  values of 45.85–47.12,  $a^*$  values of 18.23–19.47, and  $b^*$  values of 11.06–11.73, while cooking loss ranged from 35.21 to 36.72%. The fatty acid profile was characterized by a high proportion of palmitic acid (32.50–32.99%) and oleic acid (35.95–36.08%), but also by an unfavourable n-6/n-3 PUFA ratio (11.19–11.97) and a low PUFA/SFA ratio (0.086–0.095). The amino acid profile showed a predominance of nonessential over essential amino acids, with a nonessential/essential ratio of 1.30 and an essential/nonessential ratio of 0.78. Overall, our results, together with literature data, indicate that the composition of wild boar meat varies depending on habitat, feed resources, hunting season, and animal age. Wild boar meat is a natural food free from antibiotics and growth promoters and represents a valuable source of protein; however, from a nutritional point of view, diets containing wild boar meat should be complemented with foods rich in n-3 fatty acids and essential amino acids. At the same time, due to sanitary risks associated with game meat, its use requires proper handling and mandatory veterinary control.

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