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PHYSICOCHEMICAL PARAMETERS OF SELECTED INTERNAL ORGANS OF FATTENING PIGS AND WILD BOARS*

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Abstract

The objective of the study was to analyse selected physical properties and chemical indicators of internal organs obtained from fattening pigs and Central European wild boars (*Sus scrofa scrofa*). Each group consisted of 12 animals. The tongue, heart, lungs, liver and kidneys were examined for physical properties, basic chemical composition, macro- and micromineral content, and fatty acid profile. The atherogenic index (AI) and the thrombogenic index (TI) were also determined. Pig offal was found to be a rich source of protein and collagen, and to contain large amounts of potassium and sodium. Liver had a high content of iron, zinc, and manganese. Pig liver and wild boar heart were characterised by favourable PUFA/SFA ratios (above 0.4%). In addition, the content of neutral and hypocholesterolemic acids (DFA) and hypercholesterolemic acids (OFA) in pig offal was comparable to that in pig meat. The results presented in this study provide an extensive evaluation of the nutritional quality of pig offal, which allows an increase in the scope of its use in the food industry, among others for production of offal products, including traditional and regional products that are increasingly demanded by consumers.

Key words: fattening pig, wild boar, offal, physicochemical properties

The anatomy and function of internal organs, in particular the heart, lungs, liver and kidneys, is essential for proper functioning of the body. Furthermore, the internal organs of farm animals are an important raw material for the food industry. Polish

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standards PN-65/A-82000 (1965) and PN-86/A-82004 (1986) define offal as edible internal organs and other parts of slaughter animals which are not part of the carcass, half-carcass or quarter carcass. Pig offal includes the brain, kidneys, spleen, and the pluck, comprising the lungs (with trachea, oesophagus, larynx, and sinewy parts of the diaphragm), heart, liver, and tongue. In the food industry, pig offal is most often used in the manufacture of offal products (liverwurst, liver sausage, black pudding, brawn) and stuffing for ready-made products (Toldrá et al., 2012). In this respect, it is important not only to monitor the proportion of basic chemical components as well as the physical parameters, but above all the parameters currently considered to be a priority with regard to dietetics, foods and human nutrition, e.g. the lipid fraction profile, the heavy metals content, etc. (Sicińska et al., 2015).

It is commonly believed that internal organs, due to their function, accumulate components that are undesirable in the raw materials used for the manufacturing of food products (Olsson et al., 2005; Tomović et al., 2011). Although their presence in the internal organs of healthy pigs should not raise concerns, there is a need for continuous post-slaughter monitoring of the organs. The analysis of offal of pigs and internal organs of wild boars is justified by the insufficient amount of available scientific information in this field (Seong et al., 2014).

The aim of the study was to analyse some physical properties and chemical indicators of the internal organs obtained from fattening pigs (hybrids of domestic and foreign breeds) and Central European boars (*Sus scrofa scrofa*) found in the same area.

Material and methods

Animals

The study was performed in the Lublin region (east-central Poland) with two groups of animals: group I – 12 fattening pigs (barrows), hybrids derived from the crossing of Polish Large White (PLW) and Polish Landrace (PL) domestic breeds, and Duroc and Pietrain international (domestically bred) breeds, using the following crossbreeding scheme: ♀(PLW × PL) and ♂(Duroc × Pietrain). Pigs were kept in an individual farm located in the Lubelskie Voivodeship. The pigs were slaughtered at a meat processing plant approx. 3 hours after transport, in compliance with the company's regulations using automatic electrical stunning (250V, 5A, 2.4 s) and exsanguination in a lying position. Body weight at slaughter ranged from 113.6 to 115.3 kg; group II – 12 male wild boars (*Sus scrofa scrofa*) obtained as part of planned game management in the Lublin region (Act of 13 October 1995 Law on Hunting, Journal of Laws 1995 no. 147 item 713 with later amendments, Journal of Laws 2015 item 2168 and 2016 item 1082). The body weight of the wild boars ranged from 51.9 to 54.3 kg.

This study included the tongue, heart, lungs, liver and kidneys, which were called offal in the case of pigs, and internal organs in the case of wild boars. The choice was dictated by the consumer acceptance of certain organs as edible offal meat from the domestic pig. The organs of wild boars provided the material for comparison.

Preparation of samples for laboratory tests

Pig offal was subjected to postmortem veterinary examination. The appropriately dissected tongue, heart, lungs, liver and kidneys (without connective and adipose tissue) were washed under running water to remove blood clots. The cleaned samples were packed into oxygen permeable containers and transported in a portable refrigerator at +4°C to a laboratory, where they were stored at +4°C. The internal organs obtained from wild boars were examined in their entirety by a veterinarian and transported in a portable refrigerator at +4°C to a laboratory, where they were prepared the same way as the pig offal.

The individual elements were weighed with an analytical balance (PM 10.4Y RADWAG, Poland) and the data obtained were used to calculate the proportion (%) of a given element in the animal's total body weight.

Physical properties

Due to the detailed characteristics of the organs obtained from wild boars, the pH of the internal organs and offal was measured 24 h postmortem using a pH Star CPU (Stone Food Machinery Ltd, Ireland) device. The apparatus was calibrated with solutions of known pH according to the manufacturer's methodology. Measurement of pH was performed after the electrode was inserted directly into the tissue of the offal. Next, the percentage of free water was determined using the method of Grau and Hamm (1952) as modified by Pohja and Niinivaara (1957). This method is based on measuring the area of the stain of a compressed sample with a mass of 300 mg and infiltration.

Chemical composition

The internal organs and offal were homogenized (homogenizer BÜCHI Mixer B-400 Flawil, Switzerland) and analysed for percentage of total fat, total protein, water, NaCl and collagen using a FoodScan (FOSS, Denmark) analyser according to standard PN-A-82109 (2010). The analyses were made by the certified Central Agro-ecological Laboratory UP in Lublin in accordance with accepted standards with calibration of the meat apparatus. The concentration of basic minerals (macroelements K, Na, Ca, Mg and microelements Zn, Fe, Mn, Cu) was determined in the certified Central Instrumental Laboratory of the University of Life Sciences in Lublin by means of atomic absorption spectrometry (AAS) with the use of a SOLAR 939 (Unicam) spectrometer. The results were expressed as mg/kg of fresh tissue. The fatty acid profile was analysed according to standards PN-EN ISO 12966-2 (2017) and PN-EN ISO 12966-1 (2015) by gas chromatography (Varian 3900, Walnut Creek, CA, USA) with a flame-ionizing detector (FID) equipped with an auto injector. The column used was a CP-Sil 88 (with a length of 50 m and diameter of 0.25 mm), the sample volume was 1 μL. The initial temperature of the column oven was 120°C, the isothermal time was 3 min and the heating rate was 2°C/min. The duration of the whole analysis was 50 min. The injector port and detector temperatures were, respectively, 270°C and 300°C. The flow rate of the carrier gas (hydrogen), air and make-up were as follows: 25 mL/min, 350 mL/min and 7 mL/min.

Neutral and hypocholesterolemic acids (DFA) and hypercholesterolomic acids (OFA) were calculated based on the formula: DFA =UFA+C18:0; OFA=SFA-C18:0.

The atherogenic index (AI) and the thrombogenic index (TI) were calculated using the formulae reported by Ulbricht and Southgate (1991):

AI= (C12:0 + 4C14:0+ C16:0)/(PUFA n-6 + PUFA n-3 +MUFA),

TI = (C14:0 + C16:0 + C18:0)/(0.5MUFA + 0.5 PUFA n-6 + 3PUFA n-3 + PUFA n-3/PUFA n-6).

Statistical analysis

The analyses were performed using the STATISTICA 6.0 software for analysis of data (StatSoft Inc. 2003, STATISTICA. Data analysis software system, version 6.0. www.statsoft.com). The normality was assessed using the Kolmogorov-Smirnov test, and the Leven's homogeneity of variance test was applied to examine the equality of variances. The general linear model (GLM) procedure for analyses of variance included the organ and animal group as well as their interaction as fixed effects. Tukey's test was applied for multiple comparison among means, considering $P<0.05$ as significant.

Results

The weight of analysed elements

The weight of analysed elements and their proportions in total body weight are presented in Table 1. Significantly the highest weight of the pig offal and of the wild boar internal organs was characteristic of liver ($P\leq0.05$), which constituted 1.41% of body weight in pigs and 2.55% in wild boars. As regards the offal of the pigs, the kidneys were characterized by the lowest weight. Of the wild boar internal organs, the tongue had the lowest weight. Analysis of the different weights of pig offal and wild boar internal organs showed that wild boars were characterized by a significantly lower tongue weight (by 65 g) and higher weight of kidneys (by 138 g). It was observed that although wild boars were almost twice as light as pigs, the weights of the liver and heart in these groups were similar, which translated into a significantly higher liver and heart percentage in total body weight of the wild boars compared to the pigs.

The physical parameters

Table 2 gives data on the basic physical parameters, which provide information about the rate of change in tissues postmortem. Among the analysed offal and internal organs, by far the highest pH_{24} values were observed for wild boar and pig lungs. At the same time, the pH_{24} of wild boar lungs was significantly higher compared to that of pig lungs. As regards the free water content of pig offal, it was significantly highest in liver out of all offal. In wild boars, the differences in the free water content of internal organs were not significant. When analysing the influence of the group effect (pig, wild boar), significant differences were found between the free water

content of heart and liver. Compared to pigs, wild boars had 3.4 percentage units more free water in the heart and 7.1 percentage units less free water in the liver.

Table 1. Weight and percentage of pig offal and wild boar internal organs in the carcass

Item	Tongue	Heart	Lungs	Liver	Kidney
	$\bar{x}$±sd	$\bar{x}$±sd	$\bar{x}$±sd	$\bar{x}$±sd	$\bar{x}$±sd
Weight (g)					
pig	295.0±40.0	422.0±60.0	881.0±20.0	1607.0±250.0	167.0±20.0
wild boar	230.0±25.9	418.9±96.0	859.3±20.5	1358.0±320.0	304.9±60.3
Significance of differences pig/wild boar	*				*
Ratio to mass body (%)					
pig	0.26±0.03	0.37±0.05	0.77 ±0.18	1.41±0.24	0.15±0.02
wild boar	0.43 ±0.04	0.79±0.18	1.62±0.38	2.55±0.62	0.57±0.12
Significance of differences pig/wild boar	*	*	*	*	*

* – means for pigs and wild boars are significantly different at P≤0.05.

Table 2. Physical properties of pig offal and wild boar internal organs

Item	Tongue	Heart	Lungs	Liver	Kidney
	$\bar{x}$±sd	$\bar{x}$±sd	$\bar{x}$±sd	$\bar{x}$±sd	$\bar{x}$±sd
pH_{24}					
pig	5.86 cd±0.31	5.79 d±0.41	6.74 a±0.18	6.13 bc±0.14	6.40 b±0.14
wild boar	6.03 b±0.17	6.16 b±0.75	7.13 a±0.31	6.25 b±0.34	6.45 b±0.57
Significance of differences pig/wild boar			*		
Free water content (%)					
pig	14.54 b±3.06	13.31 b±2.11	13.90 b±0.61	20.70 a±2.73	11.97 b±1.60
wild boar	12.71±3.96	16.69±2.75	13.70±2.85	13.57±7.33	14.75±5.34
Significance of differences pig/wild boar		*		*	

a, b, c, d – means in rows with different small letters are significantly different at P≤0.05.
* – means for pigs and wild boars are significantly different at P≤0.05.

The chemical composition

The proportion of the main chemical components in selected offal and internal organs are shown in Table 3. Among the analysed organs, in both pigs and wild boars, significantly the highest fat content was characteristic of the tongue, which contained 8.64 percentage units more fat than the heart and 11.74 percentage units more fat than the liver. Compared to pig offal, the internal organs of wild boars contained significantly less fat in the heart (by 3.4 percentage units), and significantly more fat in the lungs and liver (by 2.9 percentage units and 4.5 percentage units, respectively). In both pigs and wild boars, protein content was significantly most abundant in the liver. Comparison of both study groups showed that in terms of protein content, the heart, lungs and liver of wild boars contained significantly more protein compared to

the analogous offal of pigs by 3.1, 5.1 and 4.5 percentage units, respectively. Among the analysed elements, significantly the highest water content per 100 g of tissue was characteristic of pig lungs and kidneys, and of wild boar heart. The internal organs of wild boars, compared to the analogous offal of pigs, had a significantly higher content of water in the heart (by 2.5 percentage units) and lower content of water in the lungs and liver (by 10 percentage units and 5.2 percentage units, respectively). Pig liver had significantly the lowest content of collagen (0.9 percentage units); this value was around twice as low as in the kidneys and heart, and three times as low as in the tongue and lungs. Among the internal organs of wild boars, significantly the lowest collagen content was characteristic of the liver, but also of the kidneys and heart. Compared to pigs, wild boars contained significantly less collagen in heart samples (by 0.5 percentage units), and more collagen in liver samples (by 0.6 percentage units). Significantly the highest content of sodium chloride (NaCl), among the elements analysed in both pigs and wild boars, was found in the liver. At the same time, all the wild boar internal organs had a significantly higher NaCl content compared to pig offal.

Table 3. Chemical composition of the analysed offal and internal organs ($\bar{x} \pm SD$)

Item	Tongue	Heart	Lungs	Liver	Kidney
Fat (%)					
pig	15.04 a±2.53	6.40 b±0.95	3.77 c±1.75	3.30 c±1.19	4.87 cb± 0.97
wild boar	14.77 a±4.08	3.05 d±0.57	6.65 bc±2.16	7.82 b±0.76	4.84 cd±2.11
Significance of differences pig/wild boar		*	*	*	
Protein (%)					
pig	15.97 c±0.83	17.48 cb±0.90	20.01 b±4.47	25.33 a±1.46	16.50 c±1.55
wild boar	15.86 d±1.08	20.54 cb±4.47	25.08 b±2 41	29.86 a±0.58	20.19 cd±6.05
Significance of differences pig/wild boar		*	*	*	
Water (%)					
pig	66.24 bc±2.35	70.26 ab±1.91	76.33 a±9.69	63.3 c±1.34	73.80 a±2.86
wild boar	67.46 ab±1.91	72.73 a±2.77	66.32 b±5.74	58.1 c±1.55	70.33 ab±7.06
Significance of differences pig/wild boar		*	*	*	
Collagen (%)					
pig	2.73 a±0.24	2.17 b±0.34	2.81 a±0.39	0.90 c±0.29	1.86 b±0.16
wild boar	2.71 a±0.291	1.69 b±0.47	2.33 a±0.69	1.47 b±0.18	1.64 b±0.30
Significance of differences pig/wild boar		*		*	
NaCl (%)					
pig	0.70 c±0.10	1.27 bc±0.25	2.07 b±1.34	2.98 a±0.47	0.57 c±0.14
wild boar	0.92 c±0.146	1.58 c±0.09	3.36 b±1.20	4.93 a±0.59	1.92 c±1.39
Significance of differences pig/wild boar	*	*	*	*	*

a, b, c, d – means in rows with different small letters are significantly different at $P \leq 0.05$.
* – means for pigs and wild boars are significantly different at $P \leq 0.05$.

Table 4. Content of minerals in the analysed offal and internal organs ($\bar{x} \pm SD$)

Item	Tongue	Heart	Lungs	Liver	Kidney
Na (mg·kg^{-1})					
pig	857.9 ab±146.6	751.4b c±90.1	614.0 c±212.6	665.4 bc±153.0	1036.3 a±210.5
wild boar	829.4 bc±102.7	628.8 d±80.6	882.9 ab±71.4	737.3 cd±112.0	997.34 a±37.30
Significance of differences pig/wild boar			*	*	
K (mg·kg^{-1})					
pig	2533.9 ab±221.8	2705.7 a±298.2	2316.5 b±165.8	2357.3 b±258.3	2331.5 b±181.6
wild boar	2429.8 c±99.9	2713.4 b±128.1	2539.7 c±37.8	2900.2 a±69.6	1994.7 d±103.7
Significance of differences pig/wild boar			*	*	*
Ca (mg·kg^{-1})					
pig	117.8 ab±20.9	94.7 ab±29.9	114.3 ab±17.7	82.3 b±39.5	142.4 a±81.3
wild boar	260.1 a±73.1	48.6 d± 2.9	124.7 bc±34.2	156.3 b±16.0	85.2 cd±14.9
Significance of differences pig/wild boar	*	*		*	
Mg (mg·kg^{-1})					
pig	172.4 a±13.1	203.6 a±36.9	121.8 b±19.4	179.3 a±34.8	180.3 a±14.9
wild boar	166.3 bc±6.2	225.3 ab±8.0	147.4 c±3.5	178.6 abc±6.3	238.6 a±92.8
Significance of differences pig/wild boar			*		
Fe (mg·kg^{-1})					
pig	22.39 c±1.59	37.43 bc±2.15	72.39 b±32.53	144.8 a±51.6	46.58 bc±6.12
wild boar	25.9 c±2.04	51.12 c±6.39	68.51 c±12.66	300.2 a±55.2	137.4 b±40.9
Significance of differences pig/wild boar	*	*		*	*
Zn (mg·kg–1)					
pig	21.95 b±2.41	16.58 b±0.74	16.88 b±3.41	61.59 a±16.44	25.84 b±3.49
wild boar	23.47 b±2.56	17.46 b±0.84	18.31 b±0.55	50.08 a±12.61	22.48 b±1.92
Significance of differences pig/wild boar					*
Cu (mg·kg^{-1})					
pig	2.05 bc±0.23	3.62 b±0.08	1.27 c±1.11	7.42 a±2.89	6.36 a±1.72
wild boar	1.99 bc±0.08	10.07 a±6.47	0.83 c±0.04	3.96 bc±0.31	6.70 ab±3.72
Significance of differences pig/wild boar		*		*	
Mn (mg·kg^{-1})					
pig	0.83 c±0.80	0.31 c±0.05	0.44 c±0.32	2.47 a± 0.37	1.51 b±0.23
wild boar	0.89 b±0.29	0.46 c±0.03	0.34 c±0.02	3.01 a±0.26	1.11 b±0.16
Significance of differences pig/wild boar		*			*
Cd (mg·kg^{-1})					
pig	0.015 c±0.008	0.177 a±0.107	0.012 c±0.006	0.035 b±0.013	0.196 a±0.079
wild boar	0.039 c±0.023	0.018 c±0.009	0.020 c±0.009	0.244 b±0.093	1.022 a±0.223
Significance of differences pig/wild boar	*			*	*

a, b, c, d – means in rows with different small letters are significantly different at P≤0.05.
* – means for pigs and wild boars are significantly different at P≤0.05.

Table 5. Mean content of fatty acids (%) in fat from selected offal and internal organs ($\bar{x} \pm SD$)

	Pigs					Wild boars					Significance of differences pig/wild boar				
	tongue (J)	heart (S)	lungs (P)	liver (W)	kidneys (N)	tongue (J)	heart (S)	lungs (P)	liver (W)	kidneys (N)	J	S	P	W	N
C10:0	0.12 a±0.01	0.10 b±0.01	0.00 d±0.00	0.00 d±0.00	0.09 c±0.00	0.10 c±0.01	0.11 b±0.01	0.08 d±0.00	0.11 b±0.01	0.14 a±0.01	*	*	*	*	*
C12:0	0.10 a±0.01	0.10 a±0.01	0.00 c±0.00	0.00 c±0.00	0.08 b±0.01	0.13 c±0.01	0.22 b±0.01	0.10 d±0.01	0.21 b±0.01	0.24 a±0.01	*	*	*	*	*
C14:0	1.45 b ±0.03	1.39 c±0.03	2.33 a±0.05	0.73 e±0.01	1.23 d±0.03	1.55 b±0.06	1.13 d ±0.04	2.20 a±0.05	0.83 e±0.03	1.43 c±0.05	*	*	*	*	*
C14:1	0.00 b ±0.00	0.00 b±0.00	0.07 a±0.01	0.00 b±0.00	0.00 b±0.00	0.00 d±0.00	0.06 c ±0.00	0.00 d±0.00	0.08 b±0.00	0.13 a±0.01		*	*	*	*
C15:0	0.09 d ±0.01	0.12 c±0.01	0.24 a±0.01	0.20 b±0.01	0.09 d±0.01	0.09 d±0.01	0.39 a ±0.02	0.00 e±0.00	0.20 b±0.01	0.15 c±0.01		*	*		*
C15:1	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.06 c±0.00	0.07 b ±0.00	0.12 a±0.01	0.06 c±0.00	0.00 d±0.00	*	*	*	*	
C16:0	25.39 b±1.32	26.71 b±1.27	34.71 a±1.08	17.67 c±0.90	25.32 b±1.11	24.63 b±1.26	21.12 b±0.75	33.04 a±0.81	18.32 d±0.53	23.74 b±0.86		*	*		*
C16:1	3.32 a± 0.45	2.18 c± 0.24	2.73 b±0.43	1.60 d± 0.20	1.80 cd±0.22	3.92 a±0.16	2.13 c ±0.09	3.21 b±0.11	1.43 e±0.06	1.92 d ±0.07	*		*	*	
C17:0	0.48 d±0.00	0.60 b± 0.01	0.56 c±0.01	1.67 a±0.01	0.47 d ±0.00	0.39 c±0.02	0.51 b±0.02	0.29 d±0.01	0.98 a±0.04	0.42 c±0.02	*	*	*	*	*
C17:1	0.48 a±0.01	0.42 c±0.01	0.32 d±0.01	0.44 b±0.01	0.29 e±0.01	0.37 a±0.01	0.35 b ±0.01	0.19 d±0.01	0.27 c±0.01	0.19 d±0.01	*	*	*	*	*
C18:0	12.42 d±0.66	19.06 b±0.69	15.73 c±1.11	27.20 a±1.63	17.97 b±1.52	10.13 d±0.48	15.46 c±0.64	16.38 b±0.54	24.64 a±1.03	17.25 b±0.78	*	*		*	
C18:1n9c+ C18:1n9t	43.01 a±1.78	37.25 c±1.16	21.77 d±1.12	17.79 e±0.77	40.36 b±0.92	45.33 a±1.60	31.55 c±0.75	34.89 b±1.07	26.12 d±0.98	31.26 c±1.06	*	*	*	*	*
C18:2n6c + C18:2n6t	9.60 b±0.21	8.19 cb±0.90	8.80 b±1.04	15.06 a±1.87	6.96 c±1.00	10.60 c±0.33	15.74 a±0.74	5.11 d±0.21	16.14 a±0.50	13.14 b±0.42	*	*	*		*
C18:3n6 (gamma)	0.08 c±0.01	0.08 c±0.01	0.12 b±0.02	0.37 a±0.04	0.07 c±0.01	0.10 b±0.01	0.00 c±0.00	0.00 c±0.00	0.78 a±0.02	0.00 c±0.00	*	*	*	*	*
C18:3n3 (alpha)	0.79 a±0.08	0.51 c±0.05	0.35 d±0.04	0.72 b±0.06	0.45 c±0.04	0.58 a±0.03	0.41 b±0.01	0.24 d±0.01	0.30 c±0.01	0.31 c±0.01	*	*	*	*	*
C20:0	0.15 c±0.01	0.27 a±0.01	0.22 b±0.01	0.15 c±0.01	0.21 b±0.01	0.12 d±0.01	0.10 e±0.01	0.18 c±0.01	0.93 a±0.03	0.32 b±0.01	*	*	*	*	*
C20:1	1.18 b±0.02	1.24 a±0.02	0.66 d±0.01	0.43 e±0.01	1.00 c±0.02	1.60 b±0.03	0.52 e±0.02	0.66 d±0.03	7.56 a±0.18	0.83 c±0.02	*	*		*	*
C20:2	0.63 b±0.02	0.49 d±0.02	0.66 a±0.02	0.34 e±0.01	0.54 c±0.02	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	*	*	*	*	*
20;3n3	0.19 a±0.01	0.12 c±0.01	0.16 b±0.01	0.07 d±0.01	0.15 b±0.01	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	*	*	*	*	*
C20:3n6	0.15 d±0.02	0.14 d±0.02	0.84 a±0.07	0.50 b±0.05	0.22 c±0.02	0.19 d±0.01	7.30 b±0.24	2.93 c±0.12	0.00 d±0.00	7.95 a±0.29	*	*	*	*	*
C20:4	0.34 e±0.01	0.98 d±0.02	8.48 b±0.19	13.90 a±0.26	2.48 c±0.04	0.00 e±0.00	0.27 c±0.01	0.23 d±0.01	0.59 a±0.02	0.29 b±0.01	*	*	*	*	*

a, b, c, d – means in rows within pig/wild boar group, marked with different small letters are significantly different at $P \leq 0.05$.

* – means for pigs and wild boars are significantly different at $P \leq 0.05$.

Table 6. Content of different fatty acid groups (%) and dietary indexes in selected offal and internal organs ($\bar{x} \pm SD$)

	Pigs					Wild boars					Significance of differences pig/wild boar				
	tongue (J)	heart (S)	lungs (P)	liver (W)	kidneys (N)	tongue (J)	heart (S)	Lungs (P)	Liver (W)	Kidneys (N)	J	S	P	W	N
SFA	40.22 d±1.53	48.41 b±1.73	54.32 a±1.87	48.07 b±2.46	45.46 c±2.43	37.04 e±1.76	40.09 d±1.27	52.42 a±1.31	46.65 b±1.51	43.85 c±1.57	*	*	*		*
MUFA	48.01 a±2.25	40.66 c±0.99	26.09 d±0.74	20.37 e±0.75	43.50 b±1.73	51.27 a±1.47	36.20 c±0.73	39.06 b±1.01	34.76 cd±2.31	34.32 d±1.03	*	*	*	*	*
PUFA	11.78 c±0.22	10.51 c±0.98	19.60 b±1.27	31.56 a±2.29	11.04 c±1.09	11.59 d±0.37	25.60 a±1.11	8.52 e±0.34	18.59 c±2.36	21.81 b±0.71		*	*	*	*
PUFA *n-3*	0.79 b±0.08	0.51 c±0.05	0.54 c±0.04	1.33 a±0.06	0.54 c±0.04	0.70 a±0.03	0.41 c±0.01	0.24 e±0.01	0.35 d±0.15	0.44 b±0.02	*	*	*	*	*
PUFA *n-6*	10.02c±0.21	9.25 c±0.92	17.40 b±1.17	29.33 a±2.17	9.50 c±1.03	10.70 d±0.34	16.01 b±0.75	5.34 e±0.22	17.40 a±0.59	13.43 c±0.43	*	*	*	*	*
UFA	59.79 a±1.53	51.59 c±1.73	45.68 d±1.87	51.93 c±2.46	54.54 b±2.43	62.96 a±1.76	59.91 b±1.27	47.58 e±1.31	53.35 d±1.51	56.15 c±1.57	*	*	*		
UFA/SFA	1.49 a±0.09	1.07 c±0.08	0.84 d±0.06	1.09 bc±0.11	1.21 b±0.12	1.71 a±0.13	1.50 b±0.08	0.91 e±0.05	1.15 d±0.07	1.28 c±0.08	*	*	*		
MUFA/SFA	1.20 a±0.08	0.84 c±0.05	0.48 d±0.03	0.43 b±0.03	0.96 d±0.09	1.39 a±0.11	0.90 b±0.04	0.75 c ±0.04	0.75 c±0.06	0.78 c±0.05	*	*	*	*	*
PUFA/SFA	0.29 c±0.01	0.22 d±0.03	0.36 b±0.04	0.66 a±0.08	0.24 cd±0.04	0.31 d±0.02	0.64 a±0.04	0.16 e±0.01	0.40 c±0.06	0.50 b±0.03	*	*	*	*	*
DFA	72.21 b±1.36	70.65 c±1.31	61.41 d±1.13	79.13 a±0.93	72.50 b±1.15	73.09 c±1.33	75.37 b±0.77	63.96 d±0.86	77.98 a±0.60	73.39 c±0.91		*	*	*	
OFA	27.79 c±1.36	29.35 b±1.31	38.59 a±1.13	20.87 d±0.93	27.50 c±1.15	26.91 b±1.33	24.63 c±0.77	36.04 a±0.86	22.02 d±0.60	26.61 b±0.91		*	*	*	
AI	0.53 c±0.04	0.64 b±0.05	1.00 a±0.07	0.41 d±0.04	0.57 c±0.05	0.49 c±0.04	0.49 c±0.03	0.94 a±0.05	0.42 d±0.03	0.62 b±0.04	*	*	*		*
TI	1.25 d±0.20	1.78 b±0.13	2.26 a±0.17	1.59 c ±0.16	1.59 c±0.16	1.10 d±0.08	1.38 c±0.08	2.25 a±0.12	1.62 b±0.11	1.68 b±0.11	*	*			

SFA – saturated fatty acids; MUFA – monounsaturated fatty acids; PUFA – polyunsaturated fatty acids; UFA – unsaturated fatty acids; DFA – neutral and hypocholesterolemic acids: DFA =UFA+C18:0; OFA – hypercholesterolemic acids: OFA=SFA-C18:0; AI – atherogenic index; TI – thrombogenic index; a, b, c, d – means in rows within pig/wild boar group, marked with small letters are significantly different at $P \leq 0.05$, * – means for pigs and wild boars are significantly different at $P \leq 0.05$.

The content of minerals

Table 4 gives the content of basic macro- and microelements in the pig offal and wild boar internal organs. The offal and internal organs had a high content of sodium, which works synergistically with potassium. The highest Na content was noted in the kidneys of pigs and wild boars. Significant differences between the groups (pig/wild boar) were observed for the liver and lungs. In both cases, the wild boar organs had a higher content of sodium. The elements obtained from fattening pigs and wild boars were characterized by a high accumulation of potassium. In wild boars, its proportion ranged from 1994.7 mg·kg^{-1} (kidney) to 2900.2 mg·kg^{-1} (liver), and the differences in potassium content between the analysed organs were statistically significant. In pigs, potassium content ranged from 2316.5 mg·kg^{-1} (lungs) to 2705.7 mg·kg^{-1} (heart) with a significant difference. Analysis of the differences in potassium accumulation between the wild boar organs and pig offal demonstrated that the wild boar lungs and liver had a significantly higher content of this microelement, whereas its content in the kidney was significantly lower. For the amount of calcium, the highest differences were observed in pigs between the liver and kidney. In the liver, Ca content was significantly lower, by 60.1 mg·kg^{-1}. In wild boars, the highest significant difference (211.5 mg·kg^{-1}) was found between the heart and tongue, in which Ca was the most abundant. Magnesium content in different organs and offal remained at a similar level except for the lungs, for which the values were lowest and differed significantly in relation to the other elements. Pig lungs were also found to contain significantly more magnesium than wild boar lungs. Significantly the highest level of iron among the analysed elements was observed in the liver of pigs and wild boars, with Fe content in wild boar liver being twice as high (by 155.4 mg·kg^{-1}) as in pigs. At the same time, pig and wild boar liver, out of all the elements, had significantly the highest amounts of zinc, as well as a significantly higher proportion of manganese, which in the liver was higher by 2.16 mg·kg^{-1} and 2.66 mg·kg^{-1} compared to the lowest values obtained for pig heart and wild boar lungs, respectively. Another heavy metal analysed, which is also classified as a toxic metal, is cadmium. Among the analysed pig offal, significantly the highest accumulation of cadmium occurred in the heart and kidneys. In the internal organs of wild boars, cadmium was most abundant in the kidneys and liver, and the observed values were many times higher than those found in the analogous pig offal.

Mean content of fatty acids (%) in fat

Table 5 gives data on the proportion of fatty acids in the analysed samples from wild boars and pigs. Analysis of the fatty acid profile of offal and internal organs revealed that the analysed elements are a rich source of oleic acid (C18:1n9c) and elaidic acid (C18:1n9t). The sum of both C18:1 isomers ranged from 17.79 (pig liver) to 45.33% (wild boar tongue). Significant differences were found in the content of this acid between all pig offal and wild boar internal organs; these differences were highest (around 10 percentage units) for the lungs and liver, to the advantage of the wild boar internal organs. In the group of unsaturated fatty acids (UFA) there was a high proportion of linoleic acid (C18:2n6c) and linolelaidic acid (C18:2n6t). Their highest values among the analysed elements were found in the liver of both wild

boars (16.14%) and fattening pigs (15.06%). The content of C18:2n6c and C18:2n6t in wild boar heart and kidneys was almost twice as high as in the analogous pig offal. In the case of arachidonic acid (C20:4), which is one of the polyunsaturated fatty acids (PUFA), its content was significantly higher in pig offal compared to the same organs from wild boars. Among monounsaturated fatty acids (MUFA), a proportion higher than 1% was noted for C16:1 acid in all the elements analysed. C20:1 higher than 1% occurred in the tongue and heart of pigs and in the tongue and liver of wild boars. The content of these acids differed significantly within the different elements under analysis. Out of all saturated fatty acids found in the analysed samples, the highest percentage of palmitic acid (C16:0) was found in pig and wild boar lungs, especially when compared to the liver. The other wild boar organs and pig offal had a similar content of this acid. Among the analysed elements, liver also had the highest content of stearic acid (C18:0), i.e. 27.20% (pigs) and 24.64% (wild boars). For both groups of animals, a decreasing proportion of C18:0 acid was found for the heart, kidneys, lungs and tongue. Among the other saturated fatty acids (SFA), a higher than 1% content was noted for myristic acid (C14:0) in all the analysed elements except for the liver. The values obtained differed significantly compared to both the same offal/internal organ from different study groups and other elements analysed in the group.

The content of different fatty acid groups and dietary indexes

The other fatty acids, both saturated and unsaturated, had a proportion of less than 1%. Their percentages are given in Table 5 and discussed in the context of the presence of groups of fatty acids analysed in the study, namely SFA, UFA, MUFA, and PUFA (Table 6). Table 6 contains data concerning the content of omega-3 (PUFA *n-3*) and omega-6 acids (PUFA *n-6*), hypocholesterolemic (DFA) and hypercholesterolemic acids (OFA), as well as the dietary indexes of atherogenicity (AI) and thrombogenicity (TI). The most UFA were found in wild boar tongue (62.96%) and the least in pig lungs (45.68%). Both figures differed significantly in relation to the other analysed elements obtained from wild boars and pigs. In addition, for the tongue, heart and lungs, UFA values observed in wild boars were significantly higher compared to the analogous pig offal. The UFA to SFA ratio, for both wild boar and pig lungs was lower than 1. The greatest difference between UFA and SFA content was noted in the tongue and heart of wild boars, while the UFA/SFA ratio was 1.71 and 1.50, respectively. The proportion of MUFA in total UFA ranged from 39% (pig liver) to 82% (wild boar lungs). The PUFA found in offal are mainly omega-6 acids, and liver proved the best source of these acids among all the offal analysed. The highest MUFA/SFA and PUFA/SFA ratios were observed in wild boar tongue and pig liver, respectively. Among the analysed elements, the content of DFA, i.e. neutral and hypocholesterolemic fatty acids (UFA + C 18:0), which are believed to reduce the level of total cholesterol, was significantly the lowest in lungs (61.41% in pigs, 63.96% in wild boars). The other offal contained from 70.65% (pig heart) to 79.13% DFA (pig liver). As regards the hypercholesterolemic fatty acids (OFA), significantly the lowest content among the analysed elements was observed in the liver (20.87% in pigs, 22.02% in wild boars). Dietary indexes were determined in addition to the

content of total cholesterol regulating fatty acids. The atherogenic index (AI) ranged from 0.41 (pig liver) to 1.00 (pig lungs). The lowest value of the thrombogenic index (TI) was noted for wild boar tongue (1.10) and the highest for lungs (2.25–2.26).

Discussion

In many countries, pig offal is used in the food industry to manufacture offal products, fillings, etc. In this regard, it should meet not only the health but also the nutritional expectations of consumers (Seong et al., 2014). The results obtained for the weight of elements analysed in the study conformed with the aggregate data of the weight of pig offal published in the Encyclopedia of Meat Sciences (Devine and Dikeman, 2014), where the weight of particular types of offal was as follows: tongue: 0.3–0.4 kg; lungs: 0.40–0.85 kg; heart: 0.15–0.35 kg; liver: 1.1–2.4 kg; kidney: 0.2–0.4 kg. The heart and liver percentage in total carcass weight was similar to the figures reported by Seong et al. (2014).

The logarithm of hydrogen ion concentration is the most important parameter of meat quality, because it determines its keeping quality and technological properties (Babicz et al., 2009). Postmortem changes in the tongue and heart, due to the tissue composition, bear a resemblance to changes in the skeletal muscles of pigs (Przybylski et al., 2016). A different pattern of acidification was observed for the other organs, with pH measured 24 h postmortem in the lungs, liver and kidneys ranging from 6.12 to 7.13. The results for these types of offal agree with the findings reported for calf offal (Florek et al., 2012).

The nutritional and dietary value of offal is dependent on its chemical composition. Daily consumption of fat is important to human health because dietary fat aids in the absorption of vitamins A, D, E and K. However, high daily fat consumption is related to the prevalence of endocrinological diseases, cardiovascular diseases, and obesity (Shao et al., 2014). Comparison of fat and protein content in the analysed pig offal with the data provided by the National Nutrient Database for Standard Reference (US Department of Agriculture, 2009) showed that the data are compatible for the tongue, heart, and kidneys. For lungs and liver, the fat and protein content was about 4 percentage units higher and about 1 percentage unit lower than the values reported in the database. The highest accumulation of protein was observed for the liver, which is consistent with the findings of Seong et al. (2014). However, for the protein content of lungs, we obtained a higher value than the authors cited above.

Collagen constitutes over 11% of ostrich stomach protein (Adamczak et al., 2017). Pig offal was found to contain between 0.9% and 2.81% of collagen. It should be noted that Kim et al. (2016) reported the collagen content of loin from Berkshire pigs to be 0.89%. Even less collagen (from 0.42% to 0.5%) in the meat of Basque × Large White pigs, kept in different production systems, was reported by Lebret et al. (2015). On these grounds, it may be concluded that pig offal contains more collagen than does pig meat.

It is believed that the mineral content of wild boar internal organs and pig offal, like for valuable carcass cuts, depends on both genetic factors (such as breed,

productive type, sex, age) and environmental factors (including the diet and housing system) (Zhao et al., 2016). Balanced rations as well as rearing conditions have an effect on the availability of elements, which translates into their level in body parts. While it is possible and indeed recommended to monitor the rations for pigs, this is difficult in the case of wild boars. Human contribution to the quality of wild boar meat is minimal because the chemical composition of the meat from wild animals depends primarily on their habitat (Skobrák et al., 2011). It is particularly important to maintain the right proportions between minerals that work synergistically (e.g. calcium and magnesium) and antagonistically (e.g. zinc and copper). Sodium plays an important physiological role in animals by regulating water-electrolyte metabolism and aiding in the transport of amino acids and carbohydrates into tissues. Furthermore, it is antagonistic to potassium, and together they create a gradient on both sides of the cell membrane, which allows for transfer of nerve impulses as well as contraction and relaxation of muscle cells. The highest sodium concentration for both pigs and wild boars was observed in the kidneys (1036.3 and 997.33 $mg \cdot kg^{-1}$, respectively – Table 4). The respective potassium concentration was 2331.5 and 1994.7 $mg \cdot kg^{-1}$ (Table 4). These results are comparable to the data from the National Nutrient Database for Standard Reference (US Department of Agriculture, 2009), where kidney sodium and potassium were determined to be 1210 and 2290 $mg \cdot kg^{-1}$, respectively. The concentration of these elements in the other parts also falls within the range reported by the database cited above.

As regards calcium content, the data reported by Tomović et al. (2011) show that pig liver contains almost twice as much calcium (20.4 mg/100 g) as pig muscle tissue (11.8 mg/100 g). These same authors establish that the content of individual minerals in both muscle tissue and offal is influenced by pig breed. The calcium content values obtained in the present study (Table 4) for wild boar liver (15.63 mg/100 g) correspond with the findings of Tomović et al. (2011), but the calcium content of pig liver was lower (8.23 mg/100 g). However, the results obtained for fattening pigs are comparable to the data presented by the US Department of Agriculture (2009) – 9 mg/100 g and the European Institute of Oncology (2008) – 10 mg/100 g.

Magnesium was the element that showed the least variation in both groups under study, and also between the individual elements analysed. The values given in Table 5 were similar to the amounts of magnesium in the heart (198.73 $mg \cdot kg^{-1}$), liver (210.14 $mg \cdot kg^{-1}$) and lungs (137.14 $mg \cdot kg^{-1}$) collected from 6-month-old Landrace × Yorkshire × Duroc pigs (Seong et al., 2014).

Iron is one of the basic minerals needed for optimal blood function, and its deficiency causes anaemia, especially in pregnant women and in children (Tomović et al., 2015). The analysed elements (Table 5) were characterized by a high content of iron, comparable to the data reported by Seong et al. (2014). Pig liver proved the best source of iron out of the types of offal under analysis. As reported by Tomović et al. (2015), 100 g of liver provides 15 times as much iron as pork, 8 times as much as aged raw ham, and 4 times as much as bovine liver. Our study demonstrated that the liver obtained from wild boars contained twice as much iron as pig liver. A similar relationship in the iron content of muscle tissue for the wild boar and pig was shown by Skobrák et al. (2011). It should be borne in mind, however, that excess dietary iron

may have harmful effects, leading to diseases of the liver, lungs and heart, diabetes, hormonal abnormalities, and immune disorders (Gurzau et al., 2003).

In our study, we also found that pig liver had the highest content of zinc, copper and manganese. Another type of offal with a relatively high content of zinc and copper were the kidneys. These results are consistent with the findings of Falandysz (1993), who reported that zinc and copper concentrations were 50.0 and 8.5 $mg \cdot kg^{-1}$ in pig liver, and 30.0 and 8.4 $mg \cdot kg^{-1}$ in kidneys, respectively. The high content of zinc in the liver results from its biochemical function in the body, because this macroelement is a component or cofactor of around 300 enzymes. After ingestion, zinc is transported to the liver and then distributed throughout the body. Around 85% of zinc is found in muscles and bones, some 11% in skin, hair and liver, and the remaining 4% in the digestive tract, pancreas and other tissues (Tapiero and Tew, 2003).

Literature data suggest that cadmium content in the liver and kidneys of pigs varies considerably, from 0.019 and 0.110 $mg \cdot kg^{-1}$ (Jorhem et al., 1991) to 0.133 and 0.381 mg·kg, respectively (Tomović et al., 2012). Furthermore, Tomović et al. (2011), who analysed liver cadmium concentrations in 10 different genetic lines of pigs from the Vojvodina region (Serbia), found high variation of the results in the samples, from 0.03 to 0.27 $mg \cdot kg^{-1}$. These relationships indicate that the accumulation of heavy metals in offal is specific to a particular animal, and this also contributed to the high variation observed in our study. Amici et al. (2012) reported that the heavy metals and trace elements content of meat and internal organs from wild boars varies according to geographical origin. Our study also showed that the internal organs of wild boars, compared to pig offal had many-fold higher concentrations of cadmium ($P \leq 0.05$).

From the perspective of human dietetics, food and nutrition, a decisive role in the group of fatty acids is played by polyunsaturated fatty acids (PUFA), which include linoleic acid (LA, C18:2 *n-6*), α-linolenic acid (ALA, C18:3 *n-3*) and long-chain PUFA, which are formed in the body through enzymatic changes from LA and ALA, as well as by the acids supplied through the diet: arachidonic (AA, C20:4 *n-6*) and eicosapentaenoic and docosahexaenoic (EPA C20:5 *n-3* and DHA C22:6 *n-3*) (Majewska et al., 2016; Sicińska et al., 2015). In our study, the highest PUFA levels were found in pig liver and wild boar heart, which in the case of pigs agrees with the findings of Seong et al. (2014). As shown by analysis of the samples collected from the wild boars and pigs, UFA content was highest in the tongue and lowest in the lungs. Seong et al. (2014) also demonstrated that among the offal under analysis, pig lungs had the lowest amounts of UFA (50.51%). It should be remembered that the high proportion of unsaturated fatty acids in meat and other products of animal origin makes them more susceptible to oxidation. This process occurs mainly during culinary treatment and storage of the meat. A certain amount of polyunsaturated fatty acids (PUFA) is an essential part of a healthy diet. Omega-3 and omega-6 PUFA are not produced in the human body and therefore have to supplied by the diet. They are an important component of cell membrane phospholipids, and thus have an effect on membrane fluidity, ion transport, calcium binding, and prostaglandin synthesis (Sallis et al., 2014). According to The World Health Organization (WHO) and the Food and Agriculture Organization of the United Nations (FAO), the prescribed maxi-

mum amount of dietary fat, safe for human health, is 20–35%, including 10% SFA, 15–20% MUFA and 6–11% PUFA (Burlingame et al., 2009). Dietary recommendations for humans state that the PUFA/SFA ratio should exceed 0.4, while the PUFA *n-6*/PUFA *n-3* ratio should be 4.0 or lower (Great Britain Cardiovascular Review Group). An excessive content of *n-6* fatty acids in the diet is thought to induce cancer and cardiovascular diseases. We found beneficial PUFA/SFA values for pig liver and wild boar heart. The content of neutral and hypocholesterolemic acids (DFA) and hypercholesterolemic acids (OFA), found in pig offal and internal organs of the wild boars, proved comparable to the amounts of these acids in pork (Grześkowiak et al., 2010).

Conclusions

The physical properties of the analysed offal and internal organs, their chemical composition (including the proportion of minerals and fatty acids) were related to the study group (pig, wild boar) and offal/internal organ. Pig offal was found to be a rich source of protein and collagen, and to contain large amounts of potassium and sodium. Liver had a high content of iron, zinc, and manganese. Pig liver and wild boar heart were characterized by favourable PUFA/SFA ratios (above 0.4%). In addition, the content of neutral and hypocholesterolemic acids (DFA) and hypercholesterolemic acids (OFA) in pig offal was comparable to that in pig meat. As regards the content of toxic heavy metals, the highest accumulation of cadmium in pig offal was found in the heart and kidneys. The internal organs of wild boars, compared to pig offal, had many-fold higher amounts of cadmium ($P \leq 0.05$) except for the heart. The results presented in this study provide an extensive evaluation of the nutritional quality of pig offal, which allows for increasing the scope of its use in the food industry, among others for production of offal products, including traditional and regional products that are increasingly demanded by consumers.

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