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ANALYSIS OF PHYSICAL PARAMETERS AND CHEMICAL COMPOSITION OF OFFAL FROM PUŁAWSKA FATTENING PIGS RAISED IN DEEP LITTER AND SLATTED FLOOR HOUSING SYSTEMS*

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Abstract

The objective of this study was to comparatively analyse the physical parameters, basic chemical composition and the macro- and microelement content of offal obtained from fattening pigs raised in deep litter and slatted floor housing systems. The experiment involved a group of 80 Puławska fatteners, including 40 pigs kept in deep-litter pens (group I) and 40 pigs in slatted pens without bedding (group II). Offal (tongues, kidneys, hearts, lungs and livers) was evaluated for weight, physical characteristics (pH_{45}, pH_{24}, WHC), chemical composition (water, protein, fat) and the content of minerals: macro- (K, Na, Mg, Ca) and microelements (Zn, Fe, Mn, Cu). Based on the results obtained, associations were found between housing system and basic chemical composition of some offal, i.e. percentage of water (slatted floor<deep litter) and protein (slatted floor>deep litter) in lungs, content of protein (slatted floor>deep litter) and fat (slatted floor<deep litter) in liver, and content of fat in heart (slatted floor<deep litter). The amount of macro- and microelements was significantly differentiated by the housing system with regard to the kidneys: potassium, magnesium, calcium and manganese (slatted floor<deep litter), sodium (slatted floor>deep litter); lungs: sodium (slatted floor>deep litter), potassium (slatted floor<deep litter); and liver: iron (slatted floor>deep litter) and copper (slatted floor<deep litter). In general, the housing system of fattening pigs modified the physical parameters and chemical composition of the analysed offal.

Key words: fatteners, Puławska breed, offal, quality, housing system

Apart from the main slaughter product of meat, pigs provide considerable amounts of edible by-products such as offal, blood, natural casings, internal carcass fat (Verma et al., 2008). They form around 14% of the fattener's body weight (Ockerman and Basu, 2004). In terms of nutritive value, the most valuable slaughterhouse by-products are edible blood followed by offal (Duarte et al., 1999). The pork offal commonly used for culinary purposes includes the tongue, heart, liver, lungs and kidneys (Toldrá et al., 2012).

The high nutritive value and the relatively low price of offal are important in terms of consumer intake. Offal can be a valuable source of vitamins, macro- and microelements, and has a more favourable PUFA/SFA ratio compared to muscle tissue (Lawrie and Ledward, 2006; Seong et al., 2014; Tomović et al., 2019).

The quality of slaughter raw materials from pigs depends on genetic and environmental factors (Babicz et al., 2020), one of which may be the housing system of pigs. The two basic housing systems of pigs are deep litter and slatted floor, each having its merits and shortcomings. One advantage of the deep-litter system is that the pigs can express their natural behaviour (rooting, nest building, prevention of abnormal behaviours), which is also beneficial in terms of the ethical quality of pork and offal harvesting as seen by consumers (Ludwiczak et al., 2021). Furthermore, this type of housing helps to minimise stress factors, which may have a positive effect on the quality of the slaughter raw material from pigs (Karpiesiuk et al., 2013). It is also necessary to stress that deep-litter system is conducive to reducing the emissions of harmful gases, which is essential for sustainable animal production. In addition, it provides manure, which is a relatively cheap and at the same time highly valuable natural fertilizer (Mihułka et al., 2003). The essential benefits of the slatted floor system include less labour input for manure removal (Zhou et al., 2015).

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The advantages and disadvantages of these systems also result from their effects on animal bodies, which may translate into their productivity. These relationships have been a subject of research (Karpiesiuk et al., 2013). Patton et al. (2008) demonstrated no significant differences in carcass quality traits, i.e. dressing percentage and loin eye area, in pigs under different housing systems. In turn, Morrison et al. (2007) concluded that pigs raised on deep litter were characterised by lower pH and lighter colour of loin, relative to pigs from the slatted floor system. It should also be emphasised that the living habitat of fattening pigs, supplemented with litter, influences not only their comfort but also the time spent resting, which may translate into carcass fatness (Van de Weerd et al., 2006). The above studies focus on determining the effect of housing system (deep litter/slatted floor) on changes in growth parameters and on the quality of their meat and carcasses. There are no studies that analyse the relationships between pig housing system and offal quality.

We hypothesized that the housing system of pigs (slatted floor/deep litter) can affect the quality of pork offal.

The aim of this study was to comparatively analyse the physical parameters, basic chemical composition and the macro- and microelement content of offal obtained from fattening pigs kept in the deep litter and slatted floor systems.

Material and methods

Animals

The experiment was conducted on a farm with 80 Puławska fatteners with an initial body weight of 25 kg (±1.5 kg). Animals were assigned to two groups of 40 animals per group. Pigs from group I were kept in deep-litter pens, and those from group II in slatted floor pens, in compliance with animal welfare requirements (*OJ L 56/344, 15.2.2010*).

In the deep litter system straw from cereals (wheat, barley and oats) was used as bedding.

The straw contained 4.97% protein 2.24% fat and the following macro and microelements: K (12.6 g/kg), Na (8.76 g/kg), Ca (3.6 g/kg), Mg (1.12 g/kg), Fe (1.68 g/kg), Cu (0.003 g/kg), Mn (0.06 g/kg), Zn (0.03 g/kg).

The daily straw requirement was 0.15 kg/head for weaners and 0.3–0.5 kg/head for fatteners (Kamyczek and Tyra, 2020).

After the pigs were sold, manure was removed in accordance with the principle of biosecurity using the all-in, all-out procedure.

In line with the Act of 15 January 2015 on the protection of animals used for scientific or educational purposes (*OJ L 266 15.01.2015*), the performed study did not require approval of the Ethics Committee. In addition, the study was compatible with Directive 2010/63/EU on the protection of animals used for scientific purposes (EU, 2010).

All animals were provided unlimited access to water and feed. Single-phase feeding was applied in both groups. The feed mixture contained 15% protein, 2.2% fat, 5.5% fibre and 12.7 MJ ME. Diets were formulated according to pig feeding standards (Grela and Skomiał, 2015).

The body weight of the fatteners on the day of slaughter averaged 115.76 kg ± 3.19 (group I) and 114.86 kg ± 2.43 (group II). Slaughter age was 176 ± 5.97 days (group I) and 173 ± 6.89 days (group II).

Fatteners were transported to the Meat Processing Plant in compliance with the standards contained in Council Regulation (EC) No 1/2005 of 22 December 2004 on the protection of animals during transport and related operations (*OJ L 3, 5.1.2005*). The transport took 3 hours. The loading density was 0.7 m^2 per fattener. The pigs were transported in the same lorry, which was driven by the same driver. During the pre-slaughter period, the pigs were handled by the same personnel. Pre-slaughter conditions were identical for both groups. Animals were slaughtered around 3 h after the transport, in accordance with company standards, using automatic electrical stunning (250V, 5A, 2.4 s) and bleeding in a horizontal position.

After slaughter, in accordance with the meat plant procedure (*OJ L 131, 17.5.2019)* carcasses with offal were subjected to veterinary assessment to determine suitability of the meat and offal for consumption.

Preparation of samples for laboratory analysis

Whole tongues, kidneys, hearts, lungs and livers were sampled. The internal organs were rinsed under running water to remove blood clots and possible bone particles. Next, visible adipose and connective tissue was separated from offal. Tongues were obtained by cutting the hyoid bone and removing the larynx. Kidneys were released from the adipose capsule, after which the ureter, renal vein and artery were cut from the kidney. Hearts were trimmed to clean the atria and ventricles from blood clots and to remove residual aorta and pulmonary vein. Lungs were separated from the trachea. The liver was separated from the gallbladder, hepatic lymph nodes, hepatic artery and portal vein. Cleaned offal was placed in portable refrigerators (temperature +4°C) and transported to a laboratory, where it was kept in individual polypropylene bags under cold storage conditions (temperature +4°C) for 24 hours.

Determination of weight and offal to body weight ratio

The offal was weighed using an analytical balance. The results were compared to the animal's body weight before slaughter, thus calculating the ratio of offal weight to body weight.

Determination of physical properties

The analysis of physical properties included measuring the concentration of hydrogen ions (45 min and

24 h post-mortem) with a pH-Star CPU device (Matthäus). The pH was always measured three times at the same location of the organ. In addition, 24 hours after slaughter percentage of free water (WHC – water holding capacity) was determined by the method of Grau and Hamm (1952) modified by Pohja and Niinivaara (1957).

Determination of chemical composition of the offal

Basic chemical composition

The samples for chemical analysis were homogenised using a Büchi Mixer B-400 (Flawil, Switzerland). The percentage of basic chemical components (water, total protein, total fat) was measured with a FoodScan™ meat analyser (Foss A/S, Denmark) using near-infrared spectrometry (NIRS) with a spectral range from 850 mm to 1048 mm according to standard PN-A-82109 (2010). The basic accuracy parameters for the NIRS predictive equations i.e. R2 (coefficient of determination) and SEP (Standard Error of Prediction) for individual components were as follows: water (R^2 = 0.99; SEP = 0.72%), total protein (R^2 = 0.97; SEP = 0.62%), total fat (R^2 = 0.99; SEP = 0.78%).

Content of macro- and microelements

The content of macroelements: potassium (K), sodium (Na), magnesium (Mg), calcium (Ca) and microelements: zinc (Zn), iron (Fe), manganese (Mn), copper (Cu) was determined by the atomic absorption spectrometry with air-acetylene flame atomization using a Varian Fast Sequential Atomic Absorption Spectrometer, model AA240FS (Varian Australia Pty Ltd, Australia).

A 1 g portion of each sample was placed in CEM MARSXpress (PFA) vessels (CEM Corporation, Matthews, NC, USA), 5 ml of 65% nitric acid (Suprapur) (Merck, Germany) was added and then mineralised for 30 min using a microwave oven MarsXpress (CEM Corporation, Matthews, NC, USA). After digestion, the digestate was transferred to 25 ml volumetric flasks and supplemented with deionised water.

To eliminate interferences, the samples for determination of K, Na, Ca and Mg were diluted with Schinkel buffer (Merck, Germany) for correction (10 g L^{-1} CsCl + 100 g L^{-1} La).

The accuracy of the determinations was verified by measuring blank samples and Standard Reference Material 1577c BovineLiver (NIST, USA). The content of elements was determined at the following wavelengths: Ca 422.7 nm, Mg 202.6 nm, Na 589 nm, Fe 248.3 nm, Mn 279.5 nm, Cu 324.8 nm, Zn 213.9 nm and K 766.5 nm. All the measurements were done in triplicate.

Quantitative analysis was performed using the standard curve method, and the results were verified based on the limits of detection and determination. The limit of detection (LOD) was 0.01 mg kg^{-1} for Na; 0.04 mg·kg^{-1} for K; 0.22 mg·kg^{-1} for Ca; 0.47 mg·kg^{-1} for Mg; 0.01 mg·kg^{-1} for Zn; 0.09 mg· kg^{-1} for Fe; 0.01 mg·kg^{-1} for Mn; 0.01 mg·kg^{-1} for Cu. The results obtained were expressed in mg·kg^{-1} of wet weight.

Statistical analysis

The analyses were performed using the SAS 9.4 software for analysis of data (SAS, 2018). The normality was assessed using the Kolmogorov–Smirnov test, and the Levene's homogeneity of variance test was applied to examine the equality of variances. The general linear model (GLM) procedure for analyses of variance included effect of offal type nested within animal housing system. Tukey's test was applied for the multiple comparisons among means, considering P≤0.05 as significant. The tables illustrate the means, the standard error of the mean and the levels of significance (P-value) for the main effects.

Linear model:

$$y_{ijk} = \mu + k(o)_{ij} + e_{ijk}$$

where:

y_{ijk} – phenotypic value of a trait,

μ – population mean,

$k(o)_{ij}$ – effect of offal type nested within effect of housing system where:

k_i – effect of animal housing system (i=1, 2),

o_j – effect of offal type (j=1, 2, 3, 4, 5),

e_{ijk} – random error.

Results

The weight and percentage of offal in the body weight of fatteners are presented in Table 1. Livers from the pigs housed on a slatted floor had significantly (P≤0.05) lower body weight (1.16 kg) compared to the livers from the carcasses of the pigs kept on deep litter (1.42 kg). Table 1 also gives data on the basic physical parameters, which provide information about the rate of change in tissues post-mortem. The pH_{45} and pH_{24} values in the analysed offal ranged from 6.01 (liver – slatted floor) to 6.59 (lungs – slatted floor) and from 5.63 (tongue – slatted floor) to 6.87 (lungs – slatted floor), respectively. Statistical analysis of the physical parameters revealed no significant differences for individual offal between the experimental groups.

The proportion of the basic chemical components in the offal is presented in Table 2. The main component of offal is water, the content of which ranged from 68.61% (tongue – deep litter) to 78.26% (lungs – deep litter). The statistical analysis showed that water percentage in lungs was influenced by the housing system and the difference was statistically significant (P≤0.05) (slatted floor<deep litter). The housing system of pigs also had an effect on protein percentage in the lungs and liver. These organs, obtained from the pigs housed on a slatted floor, were characterised by a higher proportion of protein (P≤0.05), by 2.48% and 2.88% respectively, compared to the pigs kept on deep litter. The fat content of the analysed offal showed large variation and ranged from 1.97% (liver – slatted floor) to 13.39% (tongue – deep litter). It was also demonstrated that the pigs housed on a slatted floor had a lower (P≤0.05) fat percentage in the heart and liver compared to the pigs raised on deep litter.

Table 1. Weight and percentage of offal in fattener's body weight and physical parameters of the offal

Parameters	Housing system slatted floor (40 head) deep litter (40 head)	Tongue		Housing system P-value	Kidneys		Housing system P-value	Lungs		Housing system P-value	Heart		Housing system P-value	Liver		Housing system P-value
		$\bar{x}$	SE		$\bar{x}$	SE		$\bar{x}$	SE		$\bar{x}$	SE		$\bar{x}$	SE	
Weight (kg)	slatted floor	0.25	0.01	NS	0.34	0.00	NS	0.67	0.02	NS	0.39	0.02	NS	1.16	0.04	*
	deep litter	0.27	0.03		0.38	0.02		0.69	0.01		0.40	0.00		1.42	0.03	
Offal to body weight ratio (%)	slatted floor	0.23	0,01	NS	0.30	0,02	NS	0.59	0.02	NS	0.36	0,02	NS	1.03	0,03	*
	deep litter	0.25	0,02		0.34	0,03		0.62	0.03		0.35	0,01		1.27	0,03	
pH_{45}	slatted floor	6.12	0.06	NS	6.18	0.05	NS	6.59	0.06	NS	6.32	0.04	NS	6.01	0.07	NS
	deep litter	6.28	0.04		6.03	0.03		6.50	0.04		6.18	0.05		6.19	0.03	
pH_{24}	slatted floor	5.63	0.04	NS	6.59	0.05	NS	6.87	0.05	NS	6.05	0.02	NS	6.06	0.02	NS
	deep litter	5.78	0.02		6.37	0.04		6.82	0.03		5.99	0.04		6.29	0.05	
Water holding capacity (%)	slatted floor	14.37	0.27	NS	12.92	0.20	NS	14.65	0.17	NS	14.29	0.36	NS	21.02	0.45	NS
	deep litter	15.01	0.17		11.23	0.30		14.38	0.35		14.43	0.28		19.71	0.38	

*Significant differences between housing systems (P≤0.05); NS – not significant.

Table 2. Basic chemical composition (%) of the offal

Parameters	Housing system slatted floor (40 head) deep litter (40 head)	Tongue		Housing system P-value	Kidneys		Housing system P-value	Lungs		Housing system P-value	Heart		Housing system P-value	Liver		Housing system P-value
		$\bar{x}$	SE		$\bar{x}$	SE		$\bar{x}$	SE		$\bar{x}$	SE		$\bar{x}$	SE	
Water (%)	slatted floor	69.25	0.53	NS	77.37	0.41	NS	75.09	0.50	*	73.12	0.24	NS	69.86	0.28	NS
	deep litter	68.61	0.49		76.52	0.70		78.26	0.68		73.82	0.29		69.78	0.34	
Protein	slatted floor	16.98	0.21	NS	15.98	0.52	NS	19.57	0.52	*	17.14	0.19	NS	25.15	0.57	*
	deep litter	16.39	0.19		17.34	0.86		17.09	0.44		16.93	0.11		22.27	0.49	
Fat	slatted floor	12.58	0.22	NS	3.45	0.27	NS	3.27	0.10	NS	4.38	0.12	*	1.97	0.12	*
	deep litter	13.39	0.31		3.17	0.15		3.23	0.06		5.86	0.20		3.14	0.26	

*Significant differences between housing systems (P≤0.05); NS – not significant.

Table 3. Amount of macro- and microelements in the offal (mg/kg)

Parameters	Housing system	Tongue		Housing system	Kidneys		Housing system	Lungs		Housing system	Heart		Housing system	Liver		Housing system
	slatted floor (40 head) deep litter (40 head)	$\bar{x}$	SE	P-value	$\bar{x}$	SE	P-value	$\bar{x}$	SE	P-value	$\bar{x}$	SE	P-value	$\bar{x}$	SE	P-value
K	slatted floor	2716.61	28.15	NS	2462.85	60.29	*	2306.73	59.69	*	2867.42	38.54	NS	2801.64	30.27	NS
	deep litter	2528.99	34.07		2814.57	56.45		2505.54	68.38		2926.76	49.81		2896.18	37.51	
Na	slatted floor	717.42	14.90	NS	1505.95	27.198	*	1305.33	40.91	*	824.22	9.23	NS	707.75	15.31	NS
	deep litter	807.48	10.82		1322.80	57.787		1135.26	34.25		883.20	8.54		716.96	21.25	
Mg	slatted floor	169.68	2.14	NS	181.93	4.075	*	147.29	1.29	NS	230.17	1.99	NS	201.44	2.68	NS
	deep litter	186.47	3.05		164.00	5.012		140.21	1.36		223.79	2.09		196.85	3.21	
Ca	slatted floor	123.98	7.64	NS	110.73	5.82	*	80.46	2.57	NS	72.73	2.69	NS	63.55	1.93	NS
	deep litter	132.67	6.68		133.03	9.54		89.37	1.99		83.35	3.39		63.28	2.44	
Fe	slatted floor	18.25	0.29	NS	61.46	0.89	NS	76.24	1.78	NS	50.46	1.35	NS	220.76	8.10	*
	deep litter	15.61	0.15		66.13	0.65		89.63	1.27		42.83	1.09		181.40	6.57	
Zn	slatted floor	20.40	0.49	NS	26.75	0.30	NS	19.14	0.17	NS	16.18	0.26	NS	51.28	0.89	NS
	deep litter	19.92	0.23		27.17	0.19		18.99	0.24		16.72	0.12		49.28	0.62	
Cu	slatted floor	2.01	0.04	NS	6.89	0.23	NS	1.90	0.01	NS	3.80	0.05	NS	7.01	0.25	*
	deep litter	2.09	0.05		6.20	0.17		1.24	0.17		4.12	0.09		8.66	0.39	
Mn	slatted floor	0.46	0.01	NS	1.58	0.03	*	0.23	0.01	NS	0.39	0.01	NS	2.95	0.08	NS
	deep litter	0.52	0.01		1.83	0.05		0.18	0.00		0.42	0.01		3.05	0.01	

*Significant differences between housing systems (P≤0.05); NS – not significant.

The mean content of macro- and microelements in the offal of the fatteners kept in different housing systems is presented in Table 3. The amount of macroelements in the analysed offal was as follows: K>Na>Mg>Ca. Potassium content ranged from 2306.73 mg·kg^{-1} (lungs – slatted floor) to 2926.76 mg·kg^{-1} (heart – deep litter). A significant (P≤0.05) difference between the amount of this macroelement and the housing system was observed for kidneys (slatted floor<deep litter) and lungs (slatted floor<deep litter). Housing system was noted to affect also the sodium content of this offal. Kidneys and lungs obtained from the pigs kept on a slatted floor had a 183.15 mg·kg^{-1} and 170.07 mg·kg^{-1} higher sodium content compared to the analogous components of the fatteners raised on deep litter (P≤0.05). As regards the next macroelement analysed, magnesium, it was noted that in both groups magnesium content was lowest in lungs and highest in the heart. Statistically significant differences between the two groups were found only for kidneys (slatted floor>deep litter). Also for kidneys there was a significant (P≤0.05) effect of the housing system on the amount of calcium they contained (slatted floor<deep litter).

As regards the microelements, their amount in the analysed offal was as follows: Fe>Zn>Cu>Mn. In both groups the offal with the lowest iron content was the tongue (18.25 mg·kg^{-1} – slatted floor; 15.61 mg·kg^{-1} – deep litter), and liver had the highest iron content (220.76 mg·kg^{-1} – slatted floor; 181.40 mg·kg^{-1} – deep litter). Among the pork offal, liver also has the highest amounts of Zn, Cu and Mn. The statistical analysis also revealed that housing system had a significant effect on the iron (slatted floor>deep litter) and copper content of liver (slatted floor<deep litter). Manganese content in the analysed offal ranged from 0.18 mg·kg^{-1} (lungs – deep litter) to 3.05 mg·kg^{-1} (liver – deep litter). Significant differences (P≤0.05) between the groups were noted in kidneys (slatted floor<deep litter).

Discussion

Pork offal in the food industry is most often used to produce variety meat products or ready-made stuffing (Ockerman and Basu, 2004). In this respect they should not only have suitable technological properties, but also meet consumers' nutritional expectations (Seong et al., 2014).

The results obtained for the weight of analysed offal in the present experiment were similar to those reported by Kaswan et al. (2016). They also fell within the ranges given by the Encyclopedia of Meat Sciences (Devine and Dikeman, 2014). The offal percentage in the live body weight of the pigs was consistent with the data provided by Seong et al. (2014).

Offal, except for the liver, contains a very low level of carbohydrates (Ockerman and Basu, 2004; Food Data Central, 2009). That is why their pH varies between each other. Differences in post-mortem glycolysis also result from the different physiological role of internal organs, and thus from the biochemical processes therein (Loeffler and Gäbel, 2018). According to Spooncer (1993), physiological activity in offal tissues adversely affects sensory quality during storage, therefore even chilled offal has a short shelf life of 2–3 days.

Zhou et al. (2015) concluded that housing system (deep-litter system and concrete-floor system) had no influence on the physical parameters, including pH and WHC, of pork, but there are no studies relating to the effect of the housing system on offal quality.

Our study showed that housing system was not related to pH_{45}, pH_{24} and WHC values of the offal (Table 1).

Physical characteristics of offal depend on its histological structure. The pH_{45} and pH_{24} values observed in our study (Table 1) in both the tongue (striated skeletal muscle tissue) and the heart (striated cardiac muscle tissue), are similar to the changes in normal quality (reddish-pink, firm, non-exudative – RFN) meat (striated skeletal muscle tissue), i.e. a decline in pH value within 24 h of slaughter (Przybylski et al., 2016). A different trend, i.e. an increase in acidification, was noted for lungs, livers and kidneys, which contain high amounts of connective tissue. The associations obtained in our study as well as the pH_{45}, pH_{24} and WHC values of the analysed offal are consistent with those observed in the offal of Polish Landrace fatteners (Babicz et al., 2020) and ♀(Polish Large White × Polish Landrace) and ♂(Duroc × Pietrain) crossbred barrows (Babicz et al., 2018). In turn, pH measured in the offal 24 h post-mortem (Table 1) was similar to the values reported for the offal of Swallow-Belly Mangalica pigs (Tomović et al., 2016 a).

The nutritive and dietetic value of offal depends on its chemical composition. By analogy with meat, the main component of offal is water. The internal organs of pigs show considerable variation of this component. As reported by Tomović et al. (2016 a), water content of pork offal ranges from 65.5% (tongue) to 81.6% (lungs). In our study, water content in the hearts and livers from both study groups and in the lungs of the pigs kept on deep litter was comparable to the values reported by Seong et al. (2014).

Another important chemical composition found in offal is protein. The offal with the highest protein content in both study groups was liver (Table 2), which agrees with the findings of other authors (Kunachowicz et al., 2017; Seong et al., 2014; Tomović et al., 2016 a). The proportion of protein in the liver in our study proved higher than that in calf and beef livers (Florek et al., 2012) and in poultry livers (Seong et al., 2015), which gives important information to consumers in making informed choices of food products.

In the context of fat consumption, it is important to note the association observed in our study, showing that the pigs housed on a slatted floor had a lower lipid percentage in the heart and liver. The literature data indicate that the pig environment enriched in litter increases the

time spent resting, which may translate into higher fatness of the meat and offal (Van de Weerd et al., 2006).

It is important to determine the mineral content of pig offal mainly due to its nutritive and even dietetic value. It is accepted that the proportion of potassium in pig hearts falls within a wide range of 1060–3000 mg/kg (Ockerman and Basu, 2004). The highest concentration of potassium was noted in the hearts of the fatteners raised on deep litter (Table 3). Potassium was also high in the liver, as also reported by other authors (Tomović et al., 2016 a; Despotović et al., 2018 a; Ockerman and Basu, 2004). Potassium is antagonistic to sodium, which has been also observed in our study (Table 3). The significant ($P \leq 0.05$) effect of housing system on the amount of calcium (slatted floor>deep litter) and magnesium (slatted floor<deep litter) in the kidneys results from a strong antagonism between Mg and Ca ions (Cygan-Szczegielniak et al., 2012). The contents of macroelements noted in our study are comparable to the data provided in the National Nutrient Database for Standard Reference (The US Department of Agriculture, 2009) and Tomović et al. (2016 a).

In our study we observed that the amount of Fe in offal is several to several hundred times higher compared to microelements (Table 3). An analogous tendency in research on the mineral content of pig offal was reported by other authors (Seong et al., 2014; Tomović et al., 2016 a; Despotović et al., 2018 a; Babicz et al., 2018). Special consideration should be given to the fact that liver, among the analysed offals, is the richest source of the discussed microelements, which is consistent with the data presented in other studies (Seong et al., 2014; Tomović et al., 2016 a; Despotović et al., 2018 a; Babicz et al., 2018). It is also worth pointing out that the amount of Fe, Cu and Mn in offal is higher than in pork (Tomović et al., 2016 b; Despotović et al., 2018 b). Dietary reference intake (DRI) of microelements is dependent on age and sex; however, assuming that the average recommended daily intake of Fe, Zn, Cu and Mn per adult person is 13, 9, 0.9 and 2.1 mg/d, respectively (The National Academy of Sciences, 2019), an intake of 100 g pork liver satisfies around 154%, 55%, 87% and 14% of the requirement for these microelements, respectively. Importantly, iron contained in meat is haem iron, which is absorbed several times better than non-haem iron present in plant products (Nishito and Kambe, 2018).

Conclusion

Based on the results of the comparative analysis, relationships were found between the housing system and basic chemical composition of some offal, i.e. percentage of water (slatted floor<deep litter) and protein (slatted floor>deep litter) in lungs, content of protein (slatted floor>deep litter) and fat (slatted floor<deep litter) in liver, and content of protein in heart (slatted floor<deep litter). With regard to macro- and microelements, offal was found to be their rich source, which shows that pig offal is suitable for the human diet. The amount of macro- and microelements was significantly differentiated by the housing system, especially with regard to the kidneys: potassium, magnesium, calcium and manganese (slatted floor<deep litter), and sodium (slatted floor>deep litter). For the other organs, depending on the housing system, statistically significant differences were only found in the content of sodium (slatted floor>deep litter) and potassium (slatted floor<deep litter) in lungs, and in the content of iron (slatted floor>deep litter) and copper (slatted floor<deep litter) in the liver.

In general, the housing system of fattening pigs modified the physical parameters and chemical composition of the analysed offal. The results of our study may be useful in increasing the knowledge of consumers, who make well-informed food choices and value ethical quality, including the origin of foods and the housing of animals.

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