

EFFECT OF BIOCHAR IN PIG DIETS ON THE QUALITY OF PORK RAW MATERIAL AND ITS POTENTIAL USES

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Abstract

Due to the scarce information on the use of biochar as a feed additive in pig diets, a study was undertaken to evaluate its effect on the quality of two skeletal muscles of crossbred fattening pigs. A control group (K) received only standard feed, whereas three experimental groups received standard feed with an increasing proportion of the sorbent: D1 0.25%, D2 0.5%, and D3 0.75%, respectively. The proximate chemical composition, fatty acid profile of intramuscular fat, and physicochemical technological parameters (including pH, colour, water-holding capacity, shear force, and oxidative stability) were determined in muscle tissue. Despite significant differences between some of the compared animal groups, the increasing inclusion of biochar in the ration did not exert a consistent directional effect on the evaluated properties of pork. It was confirmed that the use of biochar as a feed additive at 0.25–0.75% of the diet did not adversely affect the proximate chemical composition, physicochemical properties, or fatty acid profile of the evaluated skeletal muscles. Thus, its use does not restrict the suitability of such raw material for culinary pork or for processing into meat products. A potential limitation may be the observed reduction in intramuscular fat, which could adversely affect the development of desirable sensory characteristics of meat; however, this requires verification in further studies.

Keywords: pigs, meat, biochar, quality

Introduction

High eating quality is among the most desirable attributes of animal-derived food products. Statistically, pork is the animal-derived product most frequently consumed by the average resident of the European Union (Lin-Schilstra et al., 2022), with annual consumption of approximately 41 kg (Lebret and Čandek-Potokar, 2022). This amount exceeds the combined consumption of all other meat types, i.e. poultry, beef, mutton and goat meat (Lamkaddam et al., 2021). Owing to the diversity of pork products available on the market and changing consumer expectations regarding pig production systems, the desired quality of pork is also changing (Prache et al., 2022). Continuously increasing consumer demands require pig producers to improve the quality of final products while simultaneously increasing production (Channon et al., 2018). Among the technological parameters of raw material, the chemical composition of pork is of primary importance. Monitoring physicochemical properties (pH, water-holding capacity and colour) is also essential, as it enables identification of the most common quality defects, such as PSE meat or acid meat (Ossowski et al., 2021).

It has been shown that new substances used in animal production can help maintain or even improve meat quality. Such substances include natural sorbents, including bentonite (Young-Jik et al., 2017; Yu et al., 2008), zeolite (Lee et al., 2020), and biochar (Lao and Mbega, 2020; Toth and Dou, 2016), which are most often used as feed additives. Despite the growing number of publications on the use of natural sorbents from the smectite group (Ivanov and Ivanov, 2016; Slamova et al., 2011; Young-Jik et al., 2017), biochar appears to be a less extensively studied additive.

Biochar is defined as a material obtained through pyrolysis of plant biomass (Schmidt et al., 2019). Organic matter used to produce biochar as a feed additive is exposed to high temperatures (350°C to 1100°C) under limited or no oxygen availability (Man et al., 2021). Biochar has been effectively used to remove inorganic and organic substances from water and soil, and its capacity to reduce gaseous pollutants and nutrients (Ossowski et al., 2022), adsorb toxins (Troy et al., 2013), and bind residues of drugs or hormones (Ambaye et al., 2021) has also been confirmed. Owing to its porous structure, biochar can create a specific environment in the animal gastrointestinal tract for methanogenic archaea involved in methane transformations, which may ultimately reduce release of this gas during animal production (Eger et al., 2018; Terry et al., 2020). Biochar has also been shown to improve digestion, enhance intestinal nutrient absorption, and affect production performance and meat quality (Kashef et al., 2021; Lao and Mbega, 2020).

While smectite sorbents have been shown to be highly safe when used as feed additives, the available data on biochar are very limited (Kalus et al., 2020; Man et al., 2021). Therefore, the present study was undertaken to evaluate the use of biochar as an additive to compound feeds for crossbred fattening pigs and its effect on the chemical composition and physicochemical properties of two skeletal muscles.

Material and methods

Experimental design

The experiment was conducted in accordance with the guidelines of the Helsinki Declaration and European Union law (Directive 2010/63/EU of the European Parliament and of the Council) on the protection of animals used for scientific or educational purposes. The study was also approved by the Local Ethics Committee for Animal Experiments, approval No. 72/2021.

The study included 180 commercial crossbred pigs based on DanBred sows as the maternal component and Duroc boars as the paternal component. Animals with an initial body weight of approximately 25 kg and an equal sex ratio were randomly assigned to four groups of 45 pigs each. The groups were designated as the control (K) and experimental groups (D1,

D2, D3). All fattening pigs were kept under the same environmental conditions. The animals received a standard diet appropriate to the age group, with nutritional value consistent with the recommendations of the National Research Council (NRC, 2012). The control group (K) received only the standard diet. Animals in the three experimental groups received the standard diet supplemented with different proportions of the sorbent: 0.25% (D1), 0.5% (D2), and 0.75% (D3). The sorbent inclusion levels were established on the basis of earlier laboratory simulations. Throughout the experiment, animals were fed *ad libitum* and had free access to drinking water. Monitoring of microclimatic conditions showed no exceedance of the parameters specified in the Regulation on minimum conditions for keeping animals (Journal of Laws 2019, item 1966). At the turn of June and July, six pigs from each group were randomly selected for slaughter. Both animal transport and slaughter were carried out in accordance with Council Regulation (EC) No. 1/2005 of 22 December 2004 and Council Regulation (EC) No. 1099/2009 of 24 September 2009. Pig body weight ranged from 105 to 115 kg.

The experimental material consisted of samples of two skeletal muscles, i.e. the longissimus lumborum (*musculus longissimus lumborum*, MLL) and semimembranosus (*musculus semimembranosus*, MSM), collected during technological cutting of right carcass sides after 24 h of chilling. The samples were separately vacuum-packed in high gas-barrier PA/PE bags at a vacuum level of 98%, and then transported and stored at $2 \pm 1^\circ\text{C}$ until analysis.

Physicochemical properties

The proximate chemical composition of skeletal muscle samples was determined using reference methods: water content by drying at 103°C (Memmert UF30, Schwabach, Germany) according to PN-ISO 1442:2000; ash by incineration at 550°C (Heraeus M110, Hanau, Germany) according to PN-ISO 936:2000; total protein ($\text{N} \times 6.25$) by the Kjeldahl method using a Büchi B-324 apparatus (Flawil, Switzerland) according to PN-A-04018:1975/Az3:2002; and free fat by the Soxhlet method (n-hexane as solvent) using a Büchi B-811 apparatus (Flawil, Switzerland) according to PN-ISO 1444:2000. The Feder number (W/P, water-to-protein ratio), characterising the degree of hydration of muscle proteins, was calculated from the determined water and total protein contents. Energy value in kcal per 100 g of muscle tissue was calculated using the following energy equivalents: 4 kcal per 1 g protein and 9 kcal per 1 g fat (EU 2011).

A waterproof Elmetron CP-401 pH meter (Elmetron Sp.j., Zabrze, Poland) with an ERH-12-6 combined electrode (Hydromet S.C.) was used to determine skeletal muscle pH at 24 and 48 h post mortem, while an ERPt-13 combined electrode (Hydromet S.C.) was used to measure oxidation-reduction potential (ORP, mV) (Florek et al., 2019). Lipid oxidative stability was determined according to Witte et al. (1970) using a Varian Cary 300 Bio spectrophotometer at 530 nm. TBARS (thiobarbituric acid reactive substances) were expressed as mg malondialdehyde (MDA) per kg meat. Total haem pigment content (as haematin concentration, $\mu\text{g/g}$ meat) was determined by the Hornsey method (1956) using a Varian Cary 300 Bio spectrophotometer (Varian Australia PTY, Ltd., Mulgrave, Australia) at 640 nm.

The colour of skeletal muscles was evaluated using a Konica-Minolta 600d spectrophotometer (illuminant D65, 10° standard observer; Konica Minolta Sensing, Inc., Osaka, Japan). After 30 min of blooming at 2°C on the exposed muscle cross-section, the following parameters were recorded: L^* – lightness; a^* – redness; b^* – yellowness; C^* – chroma; and h° – hue (CIE 2004). Mean values were calculated from five measurements.

Drip loss was determined from the difference in sample weight (approximately 100 g) before and after 24 h storage at 4°C . Cooking loss was calculated from the difference in muscle sample weight before and after thermal treatment in a water bath. Muscle samples weighing approximately 75 g were sealed in plastic bags and heated at 70°C for 45 min (HENDI sous-vide system GN 1/1, Rhenen, The Netherlands), then cooled under running water for 30 min and stored at 4°C . Free water (mg) was determined according to Grau and Hamm (1953), using

Whatman No. 1 filter paper, a 300 mg sample, and a constant force of 2 kg for 5 min. The surface areas (cm²) of the meat sample (M) and total exudate (T) were measured using Multi-Scan Base ver. 14 image-analysis software and expressed as $M/T \times 100$ (%). Shear test parameters were measured using a Zwick/Roell Proline B0.5 single-column testing machine (Zwick GmbH & Co, Ulm, Germany) on muscle samples previously used for cooking-loss evaluation. A Warner-Bratzler V-blade was used to measure shear force (SF, N) and shear energy (SE, mJ) according to Florek et al. (2016b), and the results were processed using TestXpert® II software.

Fatty acid (FA) composition was determined by gas chromatography after extraction of muscle lipids according to Folch et al. (1957). Fatty acid methyl esters (FAME) were separated after transmethylation of 50 mg fat samples using a mixture of H₂SO₄ (95%) and methanol (AOCS 2000). Methyl esters were identified using a Varian GC 3900 gas chromatograph (Walnut Creek, USA) equipped with a flame ionisation detector (FID) and a CP 7420 capillary column, according to the methodology and detailed process parameters reported previously by Domaradzki et al. (2019). Fatty acids were identified from their relative retention times compared with FAME standards (Supelco Inc., Bellefonte, PA, USA). Using Star GC Workstation Version 5.5 software (Varian Inc., Walnut Creek, USA), FA composition was calculated as a percentage of all identified fatty acids in accordance with PN-EN ISO 5508:1996. Analyses were performed in duplicate.

Statistical analysis

The results were analysed statistically using STATISTICA 13 (TIBCO Software Inc., Palo Alto, CA, USA) by one-way analysis of variance to assess the effect of group (K, D1, D2, D3) on proximate chemical composition, physicochemical properties, and FA composition of the individual skeletal muscles. The significance of differences between group means was determined using Tukey's HSD test.

Results

The results for the proximate chemical composition of both skeletal muscles (Table 1) did not confirm a significant effect of biochar supplementation at any of the evaluated doses on water, total protein, fat content, or energy value. Only ash content in the MLL differed significantly among pigs receiving biochar, with an intermediate value in the control group. In the MSM, a significant ($P < 0.01$) decrease in ash content was observed with increasing biochar inclusion in the diet. It is worth noting that intramuscular fat content in both muscles showed a numerical tendency to decrease in pigs receiving biochar. However, the lack of significant differences among groups was associated with the high variability of this component. An obvious consequence of the lower intramuscular fat content was a lower energy value of the meat (by approximately 10%) compared with the control group.

Table 1. Proximate chemical composition of skeletal muscles

Specification	K	D1	D2	D3	SEM	Significance
MLL						
Water (%)	73,34	74,30	74,21	74,84	0,25	ns
Protein (%)	22,85	22,54	23,71	22,77	0,29	ns
Fat (%)	2,11	1,37	0,71	1,04	0,25	ns
Ash (%)	1,63 ^{AB}	1,96 ^B	1,26 ^A	1,36 ^A	0,07	**
W/P	3,22	3,31	3,14	3,29	0,05	ns
Energy (kcal/100 g)	110,4	102,5	101,2	100,4	2,48	ns
MSM						
Water (%)	73,58	74,34	74,88	75,21	0,28	ns
Protein (%)	21,90	22,70	22,00	22,07	0,19	ns
Fat (%)	3,19	1,62	1,83	1,92	0,38	ns
Ash (%)	1,34 ^B	1,33 ^B	1,05 ^{AB}	0,86 ^A	0,05	**
W/P	3,36	3,28	3,42	3,41	0,04	ns
Energy (kcal/100 g)	116,3	105,4	104,5	105,6	3,33	ns

Note: MLL – Longissimus lumborum muscle; MSM – Semimembranosus muscle; W/P – degree of muscle protein hydration; SEM – standard error of the mean; **P<0.01. K – control group; D1, D2, D3 – experimental groups with increasing biochar inclusion (0.25%, 0.50%, and 0.75%).

The results of physicochemical measurements (Table 2) indicate a significant effect of biochar supplementation on oxidation-reduction potential and all colour parameters of both skeletal muscles, and in the case of MLL also on pH at 24 h. The MLL of fattening pigs receiving biochar had a lower pH than the control group at 24 h (by 0.22–0.30; P<0.05) and at 48 h post mortem (by 0.10–0.15). No such clear differences were noted in MSM after 24 h; however, after 48 h the pH in the experimental groups was lower than in the control group (by 0.07–0.10). Despite significant differences in oxidation-reduction potential among the compared groups, all values were negative, indicating the reducing nature of the internal muscle environment. In MLL, a tendency towards greater oxidative stability, expressed by lower TBARS values, was also observed in the experimental groups (especially D2) compared with the control group.

Increasing biochar inclusion in the ration did not exert a consistent directional effect on MLL colour parameters, primarily because the values in the control and D2 groups were similar (P>0.05). In MSM, however, biochar supplementation had a significant (P<0.01) effect on lower lightness (lower L*) and a greater red component (higher a*), and a significant (P<0.05) increase in the yellow component (higher b*), which was also reflected in greater chroma (higher C*). Thus, MSM from pigs fed biochar had a significantly (P<0.01) darker surface and a more favourable (less yellow) hue (h°) than the control group. Some of these differences may have been associated with a higher concentration of haem iron, particularly in MSM from groups D1 and D3.

Table 2. Physicochemical properties of skeletal muscles

Trait	K	D1	D2	D3	SEM	Significance
MLL						
pH 24 h	5,59 ^b	5,29 ^a	5,37 ^{ab}	5,32 ^a	0,04	*
pH 48 h	5,47	5,35	5,37	5,32	0,01	ns
ORP (mV)	-54,1 ^b	-78,1 ^a	-75,1 ^a	-90,0 ^a	3,24	*
TBARS (mg MDA/kg)	0,211	0,177	0,116	0,155	0,014	ns
Fe (hematin µg/g)	28,2	28,5	28,3	30,8	1,60	ns
CIE colour:						
L*	53,95 ^{ab}	54,07 ^{ab}	53,27 ^a	55,26 ^b	0,24	*
a*	-0,24 ^a	0,37 ^b	-0,12 ^{ab}	0,24 ^{ab}	0,08	*
b*	9,30 ^A	10,40 ^B	9,27 ^A	10,19 ^B	0,08	**
C*	9,32 ^A	10,42 ^B	9,34 ^A	10,24 ^B	0,08	**
h°	91,6 ^b	88,1 ^a	90,9 ^{ab}	88,9 ^{ab}	0,48	*
MSM						
pH 24 h	5,59	5,53	5,57	5,58	0,02	ns
pH 48 h	5,58	5,48	5,49	5,51	0,02	ns
ORP (mV)	-119,4 ^b	-151,4 ^a	-121,0 ^{ab}	-90,0 ^b	9,04	*
TBARS (mg MDA/kg)	0,346	0,373	0,270	0,336	0,019	ns
Fe (hematin µg/g)	37,7	42,5	38,2	50,2	2,77	ns
CIE colour:						
L*	56,98 ^B	53,63 ^A	51,81 ^A	51,90 ^A	0,38	**
a*	-0,16 ^A	1,73 ^B	1,31 ^B	2,19 ^B	0,14	**
b*	9,51 ^a	11,08 ^b	9,70 ^{ab}	10,35 ^b	0,12	*
C*	9,56 ^a	11,28 ^b	9,91 ^{ab}	10,68 ^b	0,13	*
h°	91,0 ^B	81,4 ^A	82,9 ^A	78,2 ^A	0,74	**

Note: MLL – Longissimus lumborum muscle; MSM – Semimembranosus muscle; SEM – standard error of the mean; *P<0.05; **P<0.01; ORP – oxidation-reduction potential; K – control group; D1, D2, D3 – experimental groups with increasing biochar inclusion (0.25%, 0.50%, and 0.75%).

No significant effect of biochar supplementation on water-holding capacity parameters of either skeletal muscle (MLL and MSM) was found (Table 3). It should be noted, however, that muscles from pigs in the experimental groups tended to have lower water-holding capacity, expressed by greater cooking losses and a lower ability to bind their own water (lower M/T ratio and more free water), which may have been associated with the lower muscle pH in these groups. A favourable effect of biochar supplementation on meat texture was observed through a reduction in shear force (P<0.01) and shear energy (P>0.05), particularly in MSM from pigs in groups D1 and D3. Likewise, the lowest shear force and shear energy values for MLL were recorded in pigs from group D3.

Table 3. Water-holding capacity parameters and shear test parameters of skeletal muscles

Trait	K	D1	D2	D3	SEM	Significance
MLL						
Drip loss (%)	3,7	3,6	3,5	3,3	0,27	ns
Cooking loss (%)	31,0	33,5	33,2	34,1	0,82	ns
M/T (%)	28,0	23,8	26,1	25,5	0,82	ns
Free water (mg)	70,6	81,4	80,9	78,7	2,24	ns
Shear force (N)	52,5 ^A	63,0 ^B	55,0 ^{AB}	47,8 ^A	1,49	**
Shear energy (mJ)	204,0	226,3	190,0	158,2	6,94	ns
MSM						
Drip loss (%)	2,6	3,2	2,5	3,5	0,23	ns
Cooking loss (%)	30,6	31,3	29,8	31,5	0,80	ns
M/T (%)	31,5	25,6	25,1	27,2	1,12	ns
Free water (mg)	64,9	76,1	74,4	81,2	2,64	ns
Shear force (N)	65,9 ^B	53,8 ^A	57,4 ^{AB}	53,3 ^A	1,38	**
Shear energy (mJ)	233,4	183,9	207,4	176,8	6,81	ns

Note: MLL – Longissimus lumborum muscle; MSM – Semimembranosus muscle; SEM – standard error of the mean; **P<0.01; K – control group; D1, D2, D3 – experimental groups with increasing biochar inclusion (0.25%, 0.50%, and 0.75%).

Although no significant effect of biochar supplementation on the proportions of individual fatty acids or the sums of the selected FA groups was found in either MLL or MSM (Table 4), clear tendencies were observed: lower proportions of saturated fatty acids (SFA) and monounsaturated fatty acids (MUFA), accompanied by an increase in polyunsaturated fatty acids (PUFA). In MLL lipids, the decrease in SFA was most pronounced in group D2 and involved both major fatty acids, C16:0 and C18:0. At the same time, this group had the lowest proportion of monounsaturated C18:1c9 and the highest proportion of polyunsaturated fatty acids, including C18:2n-6, as well as the highest sums of n-6 and n-3 fatty acids. Consequently, this group also showed the highest P/S (PUFA/SFA) ratio. The same relationships, except for C18:1c9, were observed in MSM intramuscular fat (Table 4).

Table 4. Percentage of selected fatty acids (FA)* and individual FA groups in intramuscular fat of skeletal muscles

Specification (% of total fatty acids)	K	D1	D2	D3	SEM	Significance
MLL						
C16:0	22,50	21,48	20,98	21,54	0,39	ns
C18:0	12,63	12,81	11,92	12,68	0,15	ns
SFA	36,39	35,58	33,89	35,42	0,54	ns
C16:1c9	2,78	2,49	2,69	2,56	0,09	ns
C18:1c9	35,83	32,98	31,01	33,00	1,14	ns
C18:1c11	3,66	3,51	3,55	3,50	0,04	ns
MUFA	44,01	40,70	39,34	40,97	1,19	ns
C18:3n-3	0,30 ^a	0,42 ^b	0,38 ^{ab}	0,40 ^b	0,02	*
n-3	1,05	1,19	1,46	1,21	0,08	ns
C18:2n-6	10,96	13,66	14,61	13,93	0,89	ns
C20:4n-6	3,53	3,81	5,35	3,60	0,39	ns
n-6	15,54	18,87	21,44	18,99	1,33	ns
PUFA	16,62	20,06	22,90	20,21	1,40	ns
P/S	0,48	0,57	0,68	0,57	0,05	ns
MSM						
C16:0	22,08	21,16	20,89	21,65	0,31	ns
C18:0	11,84	11,57	10,62	11,87	0,22	ns
SFA	35,35	34,07	32,79	34,93	0,52	ns
C16:1c9	2,91	2,71	2,96	2,76	0,06	ns
C18:1c9	38,44	36,04	36,03	36,25	0,72	ns
C18:1c11	3,76	3,67	3,79	3,65	0,04	ns
MUFA	46,90	44,22	44,74	44,40	0,73	ns
C18:3 n-3	0,48	0,59	0,61	0,59	0,03	ns
n-3	1,10	1,27	1,38	1,17	0,06	ns
C18:2n-6	11,02	13,75	14,01	13,32	0,66	ns
C20:4n-6	2,56	2,95	3,52	2,63	0,25	ns
n-6	14,54	17,92	18,73	17,11	0,92	ns
PUFA	15,69	19,20	20,12	18,45	0,97	ns
P/S	0,46	0,57	0,61	0,53	0,03	ns

Note: MLL – Longissimus lumborum muscle; MSM – Semimembranosus muscle; SEM – standard error of the mean; SFA – total saturated fatty acids; MUFA – total monounsaturated fatty acids; n-3 – total n-3 PUFA; n-6 – total n-6 PUFA; PUFA – total polyunsaturated fatty acids; P/S – PUFA/SFA ratio; K – control group; D1, D2, D3 – experimental groups with increasing biochar inclusion (0.25%, 0.50%, and 0.75%).

Discussion

Mineral sorbents of various origins are used worldwide in industrial pig production, mainly to improve animal health (Elliott et al., 2020; EFSA 2011) and enhance production performance (Kim et al., 2005; Schneider et al., 2017). Although results in this field are not unequivocal because they depend on the characteristics and properties of the sorbent used (Shi et al., 2007; Shurson et al., 1984; Islam et al., 2014; Ossowski et al., 2021), studies on the effect of sorbents on broadly defined pork quality, including domestic studies, remain scarce.

The proximate chemical composition of pig skeletal muscles obtained in the present study did not differ from values reported in Polish literature for commercial fattening pigs (Grela et al., 2021; Siemiński et al., 2023). Meat from pigs receiving 0.50–0.75% biochar contained significantly less ash, and an additional tendency ($P>0.05$) toward lower intramuscular fat content was observed. In poultry, biochar supplementation of various origins has been shown to reduce carcass fatness (Kutlu and Ünsal, 1998; Kim et al., 2011). In pigs, however, the effect of biochar on intramuscular fat content is not unequivocal (Ossowski et al., 2021;

Chu et al., 2013). Islam et al. (2014) observed lower ash content and simultaneously higher fat content when 0.5% zeolite was added to the diet of three-breed crossbred pigs.

Determination of muscle tissue acidity (pH) is essential for correct diagnosis of potential pork quality defects. An appropriate ultimate meat pH (5.50–5.80), resulting from undisturbed post-mortem glycogenolysis, is one of the factors responsible for desirable sensory properties and physicochemical characteristics determining the full culinary and technological usefulness of the raw material. It should be noted that, because of problems beyond the authors' control, initial pH at 45 min post mortem was not measured; therefore, the course of post-mortem glycogenolysis (acidification) cannot be fully assessed. Nevertheless, on the basis of pH values measured at 24 and 48 h post mortem, normal glycogenolysis can be assumed in MSM from all pig groups and in MLL from the control group. In contrast, MLL from pigs receiving biochar had relatively low ultimate pH values (5.29–5.37), typical of acid meat (Sieczkowska et al., 2010). However, excessive (>5%) drip losses were not found in this muscle (3.3–3.6%). The potentially unfavourable pH may have resulted from the high temperature during transport of experimental animals to the slaughterhouse in the third ten-day period of June. It was not due to the genetic background of the pigs, because all animals were free of the stress-susceptibility “n” gene and the RN– “acid meat” gene. Biochar supplementation did not have a directional effect on MLL colour parameters. In contrast, MSM in the experimental groups had a significantly darker surface (lower L* values), a greater red component (positive a* values), and a greater yellow component (higher b* values). The observed differences in physicochemical properties between the evaluated skeletal muscles (although not statistically tested) may result from their different muscle-fibre profiles (Wojtysiak and Połtowicz, 2015). In general, the diagnostic parameter values measured in skeletal muscles of fattening pigs (Tables 1 and 2) did not clearly indicate any quality defects. In summary, muscle tissue from pigs receiving biochar had lower pH, while the surface of MSM was darker than in the control group. Kim et al. (2005), in turn, showed in the LL muscle of three-breed crossbred pigs that a greater proportion of sorbent (zeolite) in the diet was accompanied by significantly higher pH and darker muscle colour.

The present study showed that, despite significant differences, muscle tissue (MLL and MSM) of pigs from all feeding groups had negative oxidation-reduction potential values. Such ORP values indicate a reducing environment, which in muscle tissue is typical of raw meat in which ageing is not yet advanced or anaerobic conditions prevail (Florek et al., 2019). The reducing nature of the muscle environment may have contributed to the good oxidative stability of muscle lipids, because TBARS values were relatively low and similar among feeding groups within the analysed skeletal muscles, and were also independent of haem pigment content, which contains iron with pro-oxidative properties (Min et al., 2008). Significantly lower TBARS values and simultaneously lower haem iron levels in MLL and MSM of pigs fed various sorbents were reported by Ossowski et al. (2021).

Analysis of meat water-holding capacity showed no significant effect of biochar supplementation on the individual parameters, whose ranges were comparable with literature data for pigs from the national population (Grela et al., 2008; 2020). In the present study, biochar at 0.25% and 0.75% significantly ($P < 0.01$) improved instrumentally measured MSM tenderness. For MLL, the effect was multidirectional. The shear force range was 47.8 N (D3) to 63.0 N (D1) for MLL and 53.3 N (D3) to 65.9 N (control group) for MSM. According to the classification of Iwańska et al. (2016), the evaluated pork can therefore be considered intermediate between tender (30–45 N/cm²) and tough (60–90 N/cm²). These values were obtained as early as 48 h post mortem, i.e. without an extended post-mortem ageing (tenderisation) period (Florek et al., 2016a). Earlier research by Domaradzki et al. (2020) showed that in some pig breeds, extending vacuum ageing of pork to 14 days can bring measurable benefits in meat quality traits (colour, tenderness), particularly with respect to culinary use.

No significant effect of biochar supplementation in pig diets was found on the profile or proportion of selected fatty acids in the intramuscular fat of the evaluated skeletal muscles. These results confirm earlier observations by Domaradzki et al. (2022), who evaluated various natural sorbents (including 0.5% biochar) and found no significant effect on FA composition in MLL, while the effect in MSM was negligible and multidirectional. Supplementing broiler chicken (Kim et al., 2011; Park and Kim, 2001) or fattening pig diets (Chu et al., 2013) with biochar of various origins decreased SFA and simultaneously increased unsaturated fatty acids (UFA), consequently increasing the UFA/SFA ratio. In the cited studies, significant differences were mainly associated with fatty acids containing 18 carbon atoms, i.e. C18:0, C18:1, C18:2 and C18:3. Similarly, in the present study a favourable tendency ($P>0.05$) was observed toward nutritionally desirable modification of the FA profile, primarily a reduction in saturated FA and an increase in polyunsaturated FA (although with predominance of n-6 PUFA), together with an increase in the P/S ratio.

Conclusions

It can be concluded that the use of biochar as an additive in pig diets at levels from 0.25 to 0.75% does not adversely affect the proximate chemical composition, physicochemical properties, or fatty acid profile of the evaluated skeletal muscles. Thus, it does not limit the suitability of such raw material for culinary meat or for processing, e.g. into a full range of meat products. A potential limitation is the observed tendency toward reduced intramuscular fat, which may adversely affect the development of sensory characteristics of meat; however, these were not evaluated in the present study. The results indicate that biochar is a safe additive in pig diets, although this line of research should be continued, including links between current production effects and climate-environmental policy challenges, as well as evaluation of final products such as culinary meat and processed meat products.

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EFFECT OF BIOCHAR IN PIG DIETS ON THE QUALITY OF PORK RAW MATERIAL AND ITS POTENTIAL USES

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SUMMARY

Due to the scarce information on the use of biochar as a feed additive in pig diets, a study was undertaken to evaluate its effect on the quality of two skeletal muscles of crossbred fattening pigs. A control group (K) received only standard feed, whereas three experimental groups received standard feed with an increasing proportion of the sorbent: D1 0.25%, D2 0.5%, and D3 0.75%, respectively. The proximate chemical composition, fatty acid profile of intramuscular fat, and physicochemical technological parameters (including pH, colour, water-holding capacity, shear force, and oxidative stability) were determined in muscle tissue. Despite significant differences between some of the compared animal groups, the increasing inclusion of biochar in the ration did not exert a consistent directional effect on the evaluated properties of pork. It was confirmed that the use of biochar as a feed additive at 0.25–0.75% of the diet did not adversely affect the proximate chemical composition, physicochemical properties, or fatty acid profile of the evaluated skeletal muscles. Thus, its use does not restrict the suitability of such raw material for culinary pork or for processing into meat products. A potential limitation may be the observed reduction in intramuscular fat, which could adversely affect the development of desirable sensory characteristics of meat; however, this requires verification in further studies.

Keywords: pigs, meat, biochar, quality