Natural Sorbents in Fattening Pigs' Diet

Subjects: Agriculture, Dairy & Animal Science
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The effect of three natural sorbents added to the diet of pigs on the composition and physicochemical properties of two skeletal muscles—the *musculus Longissimus lumborum* (MLL) and *musculus semimembranosus* (MSM) of crossbred pigs were evaluated.

Keywords: natural sorbent ; pig ; meat ; quality

1. Introduction

According to data from the United States Department of Agriculture (USDA), the world leaders in pig farming and pork production are China and the European Union (EU), [1]. To ensure high product quality, the meat industry and livestock farmers must implement systems guaranteeing the quality and repeatability of the raw meat used in production [2][3][4]. Pig farmers focus primarily on optimal feeding, which is the most important factor determining the economic profitability of production. The quality and safety of feed play an important role in animal production because they determine the magnitude of losses incurred and the health safety of the food product. This necessitates the search for and implementation of methods to improve animal health and productivity. One means of meeting these requirements is feed supplementation with clay minerals, i.e., natural adsorbents, such as zeolite or montmorillonite, which have the capacity to bind and/or adsorb mycotoxins [3][5][6].

The production of animals for meat generates emissions of gaseous pollutants, including greenhouse gases. Livestock farmers are required to implement clean safe techniques (best available techniques—BAT) that reduce pressure on the environment. It is estimated that about 80% of emissions of ammonia (NH_3) from European agriculture are from animal waste on farms. There is enormous variation between individual countries in the level of NH_3 emissions from various sectors of production [7]. The EU climate policy is aimed at reducing the impact of farms on the environment. Many authors suggest the need for measures aimed at maintaining a balance between farms and the state of the natural environment. For this purpose, farmers use natural sorbents added to feed and litter that both increase feed safety and reduce the impact of the farms on the environment. Among sorbents of natural origin, the most common are silicates: sodium bentonite, zeolite, halloysite, perlite, or vermiculite. They have a high sorption capacity and are not harmful to animals. Their presence in feces contributes to the reduction in gaseous emissions [8][9][10][11][12][13][14]. Mineral sorbents (zeolites and bentonites) are used in pig farming mainly as feed additives for animals in various age groups: zeolites in the amount of 0.5% to 8% [15] and from 0.5% to 2% in the case of bentonites [16].

In terms of technological quality, the most important characteristics of pork include its chemical composition (including the proportion of intramuscular fat), pH, color, and water-holding capacity (WHC). Instrumental measurement of physicochemical properties makes it possible to identify the direction of changes taking place in meat after slaughter, to diagnose quality defects—most commonly pale soft exudative (PSE) and acid meat and determine an appropriate type of processing [17].

2. Effect of Natural Sorbents in the Diet of Fattening Pigs on Meat Quality and Suitability for Processing

Mineral sorbents (zeolites and bentonites) are used in pig farming mainly as feed additives for animals in various age groups: zeolites in the amount of 0.5% to 8% [18] and bentonites from 0.5% to 2% [19]. The use of sorbents (including zeolite and montmorillonite) in the diet of fattening pigs has been confirmed to have beneficial effects, improving daily weight gains, utilization of feed, and the feed conversion ratio in Duroc × Landrace × Yorkshire crossbreds [20][21]. Synthetic zeolite in the amount of 0.5% in the diet of fattening pigs (Landrace × Yorkshire × Duroc) did not affect weight gain or carcass quality [22]. In the present study as well, the addition of various sorbents in the two experiments did not significantly influence the carcass value parameters of the pigs. The positive effects on production parameters in animals, therefore, depend on the type of sorbent used (natural or synthetic), [23], its purity, and above all its structure and physicochemical properties, and the level of supplementation in the diet [24]. There are few papers, however, presenting research on the effect of sorbents on the physicochemical properties of pork.

The average chemical composition of the two skeletal muscles of the pigs from experiments 1 and 2 was similar to the values reported for the Polish population of pigs in commodity production [25][26]. Islam et al. [22] found that the addition of 0.5% zeolite to feed for crossbred pigs (Landrace × Yorkshire × Duroc) had no significant effect on the proximate chemical composition of the *longissimus* muscle (the loin). In comparison with the present study (MLL, **Table 1**), the authors report lower content of moisture (70.23%) and ash (1.16%), but higher content of protein (26.06%) and fat (2.55%).

Table 1. Physicochemical properties of the *musculus longissimus lumborum* (MLL) and *musculus semimembranosus* (MSM), (mean ± SD).

	MLL			MSM		
December	**C2** (***n*** **= 6)**	**Sorbent A** (***n*** **= 6)**	**Sorbent B** (***n*** **= 6)**	**K2/C2** (***n*** **= 6)**	**Sorbent A** (***n*** **= 6)**	**Sorbent B** (***n*** **= 6)**
pH_1	6.65 ± 0.05	6.47 ± 0.48	6.48 ± 0.05	6.58 ± 0.06	6.71 ± 0.36	6.47 ± 0.12
pH_{24}	5.79 ± 0.01	5.69 ± 0.21	5.54 ± 0.05	6.02 ^{c} ± 0.06	5.70 ^{b} ± 0.26	5.55 ^{a} ± 0.03
pH_{48}	5.64 ± 0.04	5.44 ± 0.03	5.46 ± 0.02	5.79 ^{B} ± 0.04	5.48 ^{A} ± 0.04	5.49 ^{A} ± 0.02
a_W	0.947 ± 0.002	0.953 ± 0.006	0.953 ± 0.005	0.949 ± 0.002	0.957 ± 0.007	0.953 ± 0.003
L*	50.58 ^{a} ± 1.15	54.05 ^{b} ± 2.37	53.79 ^{b} ± 1.36	44.56 ^{a} ± 0.75	50.44 ^{c} ± 3.79	48.63 ^{b} ± 2.53
a*	17.51 ± 0.93	18.17 ± 0.93	18.03 ± 0.83	20.56 ± 0.84	19.75 ± 0.86	20.38 ± 0.98
b*	4.21 ± 1.28	5.60 ± 1.84	5.51 ± 1.28	4.09 ± 1.06	5.98 ± 1.57	5.80 ± 1.28
Pigments (µg/g)	53.70 ^{C} ± 1.76	41.80 ^{A} ± 1.26	46.70 ^{B} ± 3.95	64.30 ^{B} ± 3.42	43.70 ^{A} ± 3.82	44.90 ^{A} ± 0.94
TBARS (mg MDA/kg)	0.314 ^{b} ± 0.018	0.238 ^{a} ± 0.019	0.280 ^{ab} ± 0.013	0.444 ^{C} ± 0.036	0.280 ^{A} ± 0.012	0.375 ^{B} ± 0.012
W-B SF (N)	47.60 ± 8.80	55.10 ± 21.40	48.30 ± 9.20	65.50 ± 8.70	71.50 ± 21.10	72.60 ± 20.60
W-B SE (mJ)	164.00 ± 28.50	182.00 ± 81.10	155.70 ± 41.80	289.30 ± 41.10	286.20 ± 103.50	285.90 ± 95.30

Hardness (N)	88.90 ± 14.85	96.40 ± 12.86	75.22 ± 12.24	89.15 ± 12.37	89.05 ± 16.15	90.95 ± 33.60
Springiness	0.59 ± 0.05	0.59 ± 0.03	0.60 ± 0.02	0.58 ± 0.03	0.58 ± 0.04	0.56 ± 0.03
Gumminess	34.17 ± 5.83	36.98 ± 2.70	28.90 ± 5.37	37.12 ± 2.64	34.86 ± 5.72	37.21 ± 8.16
Chewiness	20.09 ± 3.32	21.75 ± 0.99	17.38 ± 3.09	21.37 ± 0.52	19.97 ± 2.39	21.11 ± 8.09
DL (%)	3.37 ^{b} ± 0.58	2.25 ^{a} ± 0.13	2.78 ^{ab} ± 0.12	3.78 ± 0.92	3.67 ± 0.44	3.52 ± 0.11
CL (%)	27.04 ± 1.05	29.26 ± 1.61	27.06 ± 1.73	25.67 ± 1.08	26.84 ± 1.32	26.83 ± 2.20
M/T×100	37.34 ± 1.12	38.15 ± 6.59	36.95 ± 2.06	40.58 ± 4.51	45.08 ± 5.62	36.45 ± 4.34
G-H (mg)	50.45 ± 1.59	56.53 ± 4.27	55.91 ± 1.07	57.57 ± 2.52	54.89 ± 9.11	60.82 ± 5.98
Moisture (%)	75.25 ± 0.13	73.68 ± 0.53	74.42 ± 0.10	75.17 ± 0.20	73.41 ± 0.78	74.25 ± 0.19
Protein (%)	21.48 ± 0.57	21.76 ± 1.19	22.22 ± 0.72	21.17 ± 1.46	22.09 ± 1.43	22.12 ± 0.99
Fat (%)	1.08 ± 0.16	1.47 ± 0.42	1.30 ± 0.22	1.81 ± 0.04	2.24 ± 0.32	2.00 ± 0.58
Ash (%)	1.21 ± 0.04	1.25 ± 0.03	1.24 ± 0.03	1.24 ± 0.04	1.17 ± 0.10	1.24 ± 0.08
M:P	3.50 ± 0.09	3.39 ± 0.17	3.35 ± 0.11	3.56 ± 0.26	3.34 ± 0.29	3.36 ± 0.15
Energy (kcal)	95.60 ± 2.78	100.30 ± 3.42	100.60 ± 4.14	101.00 ± 6.21	108.50 ± 3.11	106.50 ± 8.06

MLL—*m. longissimus lumborum*; MSM—*m. semimembranosus*; SD—standard deviation; Groups: C2—control; A and B—groups receiving feed with 1.5% of mixtures (in different proportions) of bentonite–montmorillonite and zeolite–clinoptilolite defined in the patent application; ^{a,b} —Values in rows marked with different letters differ significantly at $p \leq 0.05$; ^{A,B}—Values in rows marked with different letters differ significantly at $p \leq 0.01$; M:P—moisture to protein ratio; CIE color parameters: L*—lightness; a*—red; b*—yellow; TBARS—thiobarbituric acid reactive substance; MDA—malondialdehyde; a_W—water activity; W–B SF—Warner–Bratzler shear force; W–B SE—Warner–Bratzler shear energy; DL—drip loss; CL—cooking loss; M/T—meat sample/total loss × 100; G–H—free water by the Grau–Hamm method [[27]].

By measuring the pH of muscle tissue, it is possible to diagnose potential quality defects in pork. An appropriate pH resulting from post-mortem glycogenolysis ensures favorable sensory and technological properties, including an attractive color, tenderness, palatability, and WHC [28]. Case-ready pork should have a final pH (24 and 48 h post-mortem) ranging from 5.50 to 5.80 [25]. In characterizing the parameters of the technological quality of the meat, it should be stressed that the low initial pH of the muscle tissue of the pigs in experiment 1, in both the control and experimental groups (MLL 5.92–6.01 and MSM 6.03–6.09), was associated with unfavorable atmospheric conditions (high ambient temperature) during transport of the experimental animals to the slaughterhouse (in June) and was not genetically determined. At 24 and 48 post-mortem, the pH of the MLL was about 5.45 and that of the pH was ≥5.5. It should be emphasized, however, that in no case was the final pH of the meat below 5.4, the typical level for acid meat [25]. Nevertheless, based on the values at 24 h post-mortem for pH (<5.5), L* (>50), and DL (>5.0%), [29], the MLL can be considered to show symptoms of the PSE defect, irrespective of the feeding group [30]. Moreover, the greater L* of the MLL may also have been influenced by the degradation of muscle proteins, which depends directly on low final pH, causing increased light dispersion [31]. These unfavorable changes were not observed in the MSM, most likely due to differences in the composition of muscle fibers in the two muscles [32]. The values of the parameters tested in the skeletal muscles of the pigs in all groups in experiment 2 (**Table 1**) also do not indicate any quality defects in the meat.

Kim et al. [20] reported increasing pH values (5.62, 5.65, and 5.82; $p < 0.05$) for the loin muscle of Landrace × Yorkshire × Duroc fattening pigs with increasing shares of zeolite in their feed (1%, 2% and 4%, respectively), while the pH in the control group was 5.58. In the case of instrumental color parameters, the authors obtained significantly lower L* values (48.81, 47.67, and 47.38) in pigs receiving a higher zeolite supplement (1%, 2%, and 4%, respectively) than in the control group (51.31), i.e., the surface of the meat became darker. This is in contrast to the results of the present study. The values for the other color parameters (redness and yellowness) were not significantly different, although a downward trend was observed—from 9.21 to 7.25 for a* and from 6.12 to 5.33 for b*. For these parameters, the values in the experimental groups (A and B) were higher than in the control group (C2).

Among the other physicochemical properties, the WHC of the MLL was more favorable in the experimental pigs in experiment 2 (**Table 2**), whose muscles had lower DL. Despite the differences observed, the TBARS value was relatively low, as aroma defects in pork are detectable within a range from 0.5 to 1.0 mg MDA/kg of meat [33]. The higher oxidative stability (lower TBARS) noted in both muscles of the pigs fed with either the addition of biochar (experiment 1) or sorbents A and B (experiment 2) may have been linked to the lower concentration of haem proteins, containing Fe and exhibiting pro-oxidant activity [34]. Shurson et al. [24] observed a linear decrease in iron retention ($p < 0.05$) in pigs fed with increasing amounts of zeolite A (0%, 1%, 2%, and 3%). The authors explain that zeolite A can partially impair the absorption of amino acids, and these in turn form ligands with iron, which are chelating factors in the transport of Fe through the cells of the mucosa for absorption. In this way, Fe absorption is impaired as well, and thus its retention in the body is reduced. This effect was not observed in the case of administration of clinoptilolite in the amount of 2.5%, 5%, and 7.5%.

Table 2. Nutrient content in 1 kg grower feed 40-70 kg and finisher feed >70 kg body weight (BW); experiments 1 and 2.

Nutrient	**Content**		**Requirement**		**% Met**	
	Grower	**Finisher**	**Grower**	**Finisher**	**Grower**	**Finisher**
Dry matter, g	762	765	–	–	–	–
Metabolizable energy, MJ	13.2	13.0	13.2	13.0	100	100
Lysine, g	10.3	9.48	10.1	9.00	103	105
Methionine, g	2.80	2.67	3.02	2.70	93	99

Methionine + cystine, g	5.92	5.74	6.03	5.40	98	106
Tryptophan, g	1.97	1.86	1.91	1.70	103	109
Threonine, g	6.49	6.04	6.53	5.85	99	103
Crude protein, g	168	157	168	155	100	101
Calcium, g	8.10	8.32	8.12	8.00	100	104
Total phosphorus, g	5.81	5.79	4.87	4.50	119	129
Digestible phosphorus, g	1.47	1.45	2.64	2.00	56	72
Sodium, g	1.79	1.78	1.73	1.70	104	105
Fiber, g	43.8	46.8	43.1	43.0	102	109
Magnesium, g	1.68	1.40	64.0	65.0	3	2
Manganese, mg	98.6	98.1	40.0	40.0	246	245
Iodine, mg	2.46	2.44	0.200	0.200	1232	1 220
Copper, mg	23.5	23.3	17.5	17.5	134	133
Iron, mg	172	169	80.0	80.0	215	211
Zinc, mg	101	101	100	100	101	101
Selenium, mg	0.520	0.505	0.100	0.100	520	505
Vitamin A, IU	6 500	6 500	6 500	6 500	100	100
Vitamin D_3, IU	2 000	2 000	1 250	1 250	160	160
Vitamin E, mg	90.1	91.2	80.0	80.0	113	114

Vitamin K_3, mg	2.33	2.33	1.25	1.25	186	186
Vitamin B_1, mg	6.34	6.37	1.00	1.00	634	637
Vitamin B_2, mg	7.73	7.51	4.00	4.00	193	188
Vitamin B_6, mg	8.40	8.14	2.25	2.25	373	362
Vitamin B_{12}, mcg	0.391	0.031	20.0	20.0	2	–
Biotin, mg	0.232	0.231	–	–	–	–
Folic acid, mg	1.43	1.47	0.75	0.75	190	196
Nicotinic acid, mg	77.4	76.7	25.0	25.0	310	307
Pantothenic acid, mg	24.1	23.6	14.0	14.0	172	168
Choline, mg	1 466	1 355	150	150	977	903
Linoleic acid, mg	2 663	3 260	–	–	–	–
Sugar, g	33.9	33.3	–	–	–	–

The tenderness of the meat (from both skeletal muscles), expressed as shear force in the W–B test, was significantly varied in experiment 1; for the MLL it ranged from 27.42 to 37.93 N and for the MSM from 37.33 to 57.47 N. In experiment 2, the shear force did not differ significantly between the experimental groups in the skeletal muscles, ranging from 47.62 to 55.13 N for MLL and from 65.50 to 77.64 N for MSM. Iwańska et al. [35], taking into account different tenderization processes, proposed the following classification for pork tenderness in terms of W-B shear force (in N/cm^2): very tender <30, tender 30–45 N, tough 60–90 N, and very tough >90 N. Adopting this classification, the meat in the present study can be classified as tender for both skeletal muscles in experiment 1, while in experiment 2 the MLL was classified as intermediate and the MSM as tough. It should be noted that this level had been reached by 48 h post-mortem and did not include the aging process.

3. Conclusions

It can be concluded from the results of the study that the use of natural sorbents as feed additives for pigs has no negative effects on the physicochemical properties of the muscle tissue or its potential suitability for use as case-ready meat or the production of processed meat products. The results indicate that the sorbents used are a safe ingredient in the diet of pigs, as indicated by meat parameters such as optimum pH and water activity and high oxidative stability (TBARS). At the same time, there is a need to continue this line of research, taking into account the meat aging process, packaging, storage time at various temperatures, the quality of processed meat products, and the relationships linking the future production goals of pig farming and processing potential in the meat industry with current climate policy.

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