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EFFECT OF THE INCLUSION OF EXTRUDED FLAXSEED IN THE DIET OF FATTENING PIGS ON PERFORMANCE PARAMETERS AND BLOOD PARAMETERS*

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Abstract

The aim of the study was to determine the effect of the inclusion of 2%, 4% and 6% extruded flaxseed in the diet of fattening pigs on their growth performance parameters, carcass parameters, and selected blood parameters. The experiment was conducted on 160 weaners (from about 30 kg to about 110 kg BW) assigned to four experimental groups of 40 animals each (5 replicates with 8 individuals each). The animals in control group received a diet in which the source of fat was soybean oil. The other groups received extruded flaxseed (FE) in place of soybean meal in the amount of 2% (group 2FE); 4% (group 4FE) and 6% (group 6FE). Soybean oil was added to the diets in the experimental treatments to obtain equal amounts of fat. The inclusion of 2% and 4% extruded flaxseed in the diet of fatteners in place of soybean meal significantly improved the digestibility of basic nutrients, i.e. ether extract (by about 5%) and dietary fibre (by more than 20%) and led to better growth performance (higher BW by about 11%; higher ADG by about 20% and lower FCR by about 12%) vs group C. In the groups with 2% and 4% extruded flaxseed there was also an increase in the lean meat content of the carcasses (by about 6%) and the thickness of the backfat (by about 6.5%) vs group C. The inclusion of extruded flaxseed did not affect the animals' condition, as indicated by the haematological and biochemical parameters of the blood, which were within reference ranges. The results for production, nutrient digestibility and carcass analysis between groups 2FE and 4FE were similar, and at this stage of research indicate that the use of 2% extruded flaxseed is economically more justified.

Key words: extruded flaxseed, pigs, performance parameters, blood parameters

Recently, there is a great deal of interest in flaxseed and other flax products as a source of n-3 PUFA in animal diets (Czech et al., 2017, 2018; Leikus et al., 2018; Bartkovský et al., 2022). Among plant sources of these acids, flaxseed has the highest content of alpha-linolenic acid (ALA, C18:3 n-3) – up to 59% (Silska and Walkowiak, 2019). ALA is converted to a limited degree to a very-long-chain n-3 PUFA, i.e EPA (eicosapentaenoic acid) and DHA (docosahexaenoic acid) (Schmitz and Ecker, 2008). Besides their valuable lipid profile, flaxseeds contain numerous health-promoting substances, e.g. lignans with oestrogenic and antioxidant properties, tocopherols, bioactive peptides, and minerals (Goyal et al., 2014). Flaxseed is also a valuable source of insoluble (mainly cellulose and lignin) and soluble fiber, which includes pectins and mucilage gums (Qian et al., 2012). Thanks to the rich and diverse composition of biologically active substances, flaxseed exerts multidirectional effects on the body. It has been documented, among others, that it has a beneficial influence on inflammatory reactions, glycemic control, and blood lipid profile (Bernacchia et al., 2014).

Unfortunately, the use of unprocessed seeds, especially in the diet of monogastric animals, is limited by the presence of anti-nutritional factors (ANFs), especially cyanogenic glycosides (linustatin, neolinustatin and linamarin) (Park et al., 2005).

The toxicity of cyanogenic glycosides is due to their ability to release hydrogen cyanide via hydrolysis. Hydrogen cyanide is a potent inhibitor of cellular respiration because it inhibits cytochrome oxidase activity. It also inhibits the activity of many other heavy metal-containing enzymes (Zuk et al., 2020). The flaxseeds also contain phytic acid, which limits the absorption of minerals, mainly phosphorus, calcium and zinc, linatine (a vitamin B_6 antagonist), and tannins (Mukhopadhyay et al., 2007). It is assumed that tannins reduce iron bioavailability by forming insoluble complexes with this metal (Delimont et al., 2017).

One effective means of eliminating ANFs from flaxseeds is extrusion, which can significantly reduce their quantity, especially that of cyanogenic glycosides (Imran et al., 2013). Studies indicate that the introduction of ex-

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truded or unprocessed flaxseeds to the diet of pigs can increase the level of n-3 PUFA in the muscles without significantly affecting growth performance and carcass parameters (Corino et al., 2008; Guillevic et al., 2009; Bečková and Václavková, 2010; Václavková et al., 2016; De Tonnac et al., 2017). Other studies indicate that using flaxseeds (Song et al., 2020, Zhan et al., 2009) or flaxseed oil (Duan et al., 2014) as a source of n-3 PUFA in swine diet can improve performance parameters. However, high intake of these fatty acids entails a certain risk, as they are highly susceptible to oxidation (Lyberg et al., 2005).

Therefore it is crucial to use the optimal proportion of flaxseed, as an excessive amount can not only adversely affect meat quality, but also disturb the redox balance in the body, which may negatively affect fattening results and the health condition of pigs. Therefore the aim of the study was to determine the effect of 2%, 4% and 6% extruded flaxseed in the diet of fattening pigs on their growth performance, carcass parameters, and selected blood parameters.

Material and methods

Animals and diets

The material for the experiment was weaners (Polish Large White × Neckar) from about 30 kg BW (about 84 days of age) until slaughter (about 110 kg BW – 168 days of age). The animals were individually tagged, weighed, and assigned to four feeding groups with equal numbers of males and females. Each group comprised 40 animals, which were kept in 5 pens with 8 animals each. Variation in body weight within and between each pen replicate and group was minimized to the extent practically possible. The pigs were kept in pens on straw.

The experimental procedures used throughout this study were approved by the II Local Ethics Committee on Animal Experimentation of the University of Life Sciences in Lublin, Poland (Resolution No. 64/2011 from 18.10.2011).

Dietary treatments

The animals were fed complete grower and finisher diets *ad libitum* (Table 1). The content of nutrients, amino acids, phosphorus and calcium in all groups satisfied NCR nutritional recommendations for pigs (2012).

The experimental factor was the type of fat added. The animals in group C received a diet in which the source of fat was soybean oil. The other groups received extruded flaxseed in place of soybean meal in the amount of 2% (group 2FE), 4% (group 4FE) and 6% (group 6FE). Soybean oil was added to the diets in the experimental treatments to obtain even amounts of fat. Pigs were provided with feed and water *ad libitum* throughout the study.

Table 1. Composition (g/kg) and nutritive value of grower and finisher pig diets

Ingredient	Extruded flaxseed	Grower (25–70 kg BW)				Finisher (71–115 kg BW)			
		C	2FE	4FE	6FE	C	2FE	4FE	6FE
Wheat	200	280	265	230	260	110	120	100	110
Rapeseed meal	0	80	80	80	80	100	80	80	80
Soybean meal	0	130	120	110	100	50	40	30	20
Barley	0	448	458	483	448	705.1	481.1	496	481
Flax	800	0	0	0	0	0	0	0	0
Extruded flax	0	0	25	50	75	0	25	50	75
Wheat bran	0	0	0	0	0	0	200	200	200
Soybean oil	0	35	25	20	10	10	30	20	10
Dicalcium phosphate	0	3	3	3	3	2	0	0	0
Limestone	0	3	3	3	3	6	7	7	7
L-lysine chloride	0	1	1	1	1	1.9	1.9	2	2
Mineral-vitamin premix[1]	0	20	20	20	20	15	15	15	15
Total	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
Analysed (g/kg)									
dry matter	900.6	890.3	893.1	893.5	893.9	889.5	893.3	893.8	894.2
crude protein	213.6	170.6	170.7	170.4	170.2	150.7	150.2	150.1	150.4
ether extract	364	54.8	52.9	51.8	56.9	30.4	61.5	60.4	60.7
crude fibre	89.1	46.9	48.6	47.3	50.1	51.3	59.7	61.4	59.9
total lysine	7.22	10.3	10.4	10.4	10.2	9.01	9.03	9.04	9.06
methionine + cysteine	8.01	6.44	6.49	6.44	6.39	5.84	5.42	5.79	5.82
total phosphorus	4.91	5.48	5.52	5.43	5.39	5.11	5.56	5.45	5.44
calcium	1.98	7.02	7.13	7.14	7.12	6.59	6.65	6.61	6.56
ME (MJ)[2]	20.06	13.07	13.03	13.06	13.04	12.50	12.49	12.46	12.48

[1]1 kg of mineral-vitamin premix contained: vitamin A 600,000 IU, D_3 60,000 IU, E 3,000 mg, K_3 120 mg, B_1 120 mg, B_2 240 mg, B_6 240 mg, nicotinic acid 1,600 mg, pantothenic acid 800 mg, folic acid 160 mg, biotin 10 mg, B_{12} 1.6 mg, choline chloride 12 g, Mg 0.8 g, Fe 6 g, Zn 5.6 g, Mn 2.4 g, Cu 6.4 g, I 40 mg, Se 16 mg, Co 16 mg.

[2]Metabolizable energy was calculated according to the equation proposed by Kirchgessner and Roth (1983).

Experimental procedures

Crude protein, crude fibre and crude fat in the diets were determined by methods 954.01, 920.39 and 978.10, respectively (AOAC, 2016). Feed samples were analysed for content of basic nutrients and concentrations of P and Ca using standard AOAC methods (2016) (Table 1). Total phosphorus was determined colorimetrically (method 965.17), and Ca content by AOAC (method 968.08) (2016). Total lysine, methionine and cysteine were determined according to AOAC methods (2016).

Growth performance measurement

The pigs were weighed at the start of the experiment (about 30 kg BW), at transition to the finisher diet (about 70 kg BW), and at the end of the experiment (about 110 kg BW), and average daily gains were calculated (ADG). Feed intake (FI) was recorded for the pen, and the feed conversion ratio (FCR) was calculated as the average for the pen for each period. When the pigs reached the average target weight for the pen (about 110 kg BW), they were sent to slaughter. Carcass analysis involved determination of dressing percentage (%); meat percentage in the ham (%); loin area (cm^2); lean meat content; backfat thickness (BT) at the shoulder (cm); BT at midback; average BT from 5 measurement points (BT 5); and the weight of the kidney, liver and heart. Samples of the digesta were also collected for digestibility analysis.

Digestibility analysis

At the end of the fattening period (finisher: 100–110 kg BW), 3 g of chromium oxide (Cr_2O_3) per kg of diet was added to the feed of all groups as a digestibility marker, prior to pelleting (Brestenský et al., 2017). Digesta samples were collected during slaughter from the ileum, labelled, and stored at −20°C until analysis.

The content of chromium oxide in the diets and digesta samples was determined according to Suzuki and Early (1991). After being thawed and homogenized, digesta samples were analysed for content of dry matter, protein, fibre, crude ash and fat by standard AOAC methods (2016). The apparent digestibility coefficients (ADC) of the nutrients were calculated according to the following formula:

$$ADC\ (\%) = 100(1-(Ni \cdot Md)/(Nd \cdot Mi))$$

where *Nd* is the concentration of a given nutrient in the diet, *Ni* is the concentration of the nutrient in the faeces, *Md* is the concentration of the marker (chromium oxide) in the diet, and *Mi* is the concentration of the marker in the faeces (all values expressed in g/kg DW) (Brestenský et al., 2017).

At a body weight of about 70 and 100 kg, blood for analysis was sampled from 6 barrows from each group. Pigs with similar body weight were selected for the analysis. The animals had no access to feed for 12 h before blood sampling. Blood was collected by a veterinarian from the jugular vein into 10 ml heparinized tubes.

Measurement of blood parameters

An ABACUS-Vet analyser was used to determine (in whole blood) the haematocrit (Ht), haemoglobin content (Hb), red blood cell count (RBC), white blood cell count (WBC), and differential leukocyte count, i.e the percentages of granulocytes (GRA), lymphocytes (LYM) and MID (sum of eosinophils + basophils + monocytes).

Cormay tests were used for spectrophotometric determination of selected biochemical parameters in the blood plasma: glucose (GLU), crude protein (TP), bilirubin (BIL), urea (UREA), and creatinine (CREAT). The activity of alkaline phosphatase (ALP), alanine aminotransferase (ALT), aspartate aminotransferase (AST), and lactate dehydrogenase (LDH) was determined as well.

Statistical analysis

All data are expressed as means and SEM (standard error of the mean). Data were analysed by ANOVA with treatment as the fixed effect and pen (Fi, ADG, FCR, and ADC analysis) or pig (digestibility, carcass analysis, and blood analysis) as the experimental unit. The normality of the data distribution was tested using the Shapiro–Wilk test, and equality of variance was tested by Levene's test. Treatment means were compared using Tukey's HSD (honest significant difference) test in Statistica 13 (Dell Software Inc., USA). Orthogonal polynomial contrasts were performed on the three P-deficient treatments (2FE, 4FE and 6FE) to test the linear and quadratic effects of the flaxseed level on selected response variables. For all tests, a criterion α level of $P<0.05$ was used to determine statistical significance.

Results

Both linear and quadratic relationships were found between the proportion of extruded flaxseed in the diets and performance parameters (BW and FI) in both the grower and finisher periods (Table 2). The body weight of the fatteners (BW), their average daily gains (ADG) and feed intake (FI) for the entire experiment (mean) were significantly higher in the fatteners receiving a diet with 2% or 4% extruded flaxseed (groups 2FE and 4FE) than in the other groups (control and 6FE). This corresponded with a reduced FCR in fatteners from groups 2FE and 4FE in the finisher period and the mean for both periods vs the control (C) ($P<0.001$). It should be noted that in the groups of animals receiving a diet with extruded flaxseed, body weight (BW) and daily weight gains (ADG) were significantly higher and FCR was significantly lower than in the control ($P<0.001$).

Table 2. Production and rearing parameters of fatteners

Treatment[1]	BW	BW grower	BW finisher	ADG grower	ADG finisher	ADG mean	FI grower	FI finisher	FI mean	FCR grower	FCR finisher	FCR mean
	kg			kg/day			kg			kg/kg		
C	30.16	71.19 c	101.16 c	0.804 c	0.769 c	0.789 c	2.08 b	2.99 a	2.41 b	2.58 ab	3.90 a	3.06 a
2FE	30.31	79.22 a	115.22 a	0.959 a	0.923 ab	0.943 a	2.55 a	2.59 b	2.56 a	2.66 a	2.81 c	2.72 bc
4FE	30.13	78.89 a	115.73 a	0.956 a	0.945 a	0.951 a	2.51 a	2.56 b	2.52 a	2.62 ab	2.71 c	2.65 c
6FE	30.29	73.59 b	109.07 b	0.849 b	0.910 b	0.875 b	2.16 b	2.87 a	2.42 b	2.54 b	3.16 b	2.76 b
SEM[2]	0.089	0.554	0.955	0.011	0.012	0.011	0.033	0.032	0.013	0.012	0.076	0.027
P-value												
diet[3]	0.949	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.005	<0.001	<0.001
linear FE[4]	0.944	<0.001	<0.001	<0.001	0.093	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.074
quadratic FE[4]	0.575	<0.001	<0.001	<0.001	<0.001	<0.001	0.041	0.003	0.112	0.359	<0.001	0.001

[1]There were 4 dietary treatments. The first diet (control; C) without extruded flaxseed. Diets 2–4 contained 2% (2FE), 4% (4FE) and 6% (6FE) extruded flaxseed.

FI = feed intake; ADG = average daily gain; FCR = feed conversion ratio.

a–c – means with the same letters are statistically the same across all 4 treatments (P>0.05) based on Tukey's post hoc test.

[2]SEM – standard error of the mean.

[3]P-value for overall effect of dietary treatment (diets 1–4).

[4]Orthogonal polynomial (linear FE and quadratic FE) contrasts were performed to test the effect of the extruded flaxseed level in the diets.

Table 3. Apparent ileal digestibility of nutrients in the diet of fatteners (%)

Treatment[1]	CP	EE	Fibre	NfE
C	71.46 b	62.14 b	21.03 b	88.38 b
2FE	73.34 a	65.09 a	25.19 a	90.70 a
4FE	73.95 a	65.29 a	25.90 a	91.15 a
6FE	72.04 b	65.54 a	25.63 a	91.11 a
SEM[2]	0.221	0.260	0.315	0.211
P-value				
diet[3]	0.002	<0.001	<0.001	<0.001
linear FE[4]	0.572	0.499	0.289	0.341
quadratic FE[4]	0.041	0.965	0.171	0.514

[1-4]see Table 2.

CP – crude protein; EE – ether extract; Fibre – dietary fibre; NfE – nitrogen-free extract

Table 4. Dressing percentage and organ weight of pig carcasses

Treatment[1]	Dressing percentage	Meat in ham	Loin area	Lean meat content	BT at shoulder	BT at mid-back	BT 5	Kidney weight	Liver weight	Heart weight
	%	%	cm^2	%	cm	cm	cm	g	kg	g
C	79.19 a	78.85	52.30 b	58.80 b	4.05	2.61	2.60 a	169.3 b	1.72 b	333.5 b
2FE	78.84 ab	79.03	52.64 ab	62.30 a	4.05	2.47	2.47 b	190.8 a	2.06 a	413.6 a
4FE	78.23 b	79.93	53.33 a	62.01 a	3.90	2.40	2.39 b	188.4 a	2.07 a	409.1 a
6FE	78.48 ab	79.34	52.84 ab	61.78 a	3.89	2.46	2.45 b	192.5 a	1.81 b	326.3 b
SEM[2]	0.111	0.129	0.117	0.270	0.025	0.026	0.015	1.569	0.027	6.566
P-value										
diet[3]	0.042	0.057	0.030	<0.001	0.112	0.051	<0.001	<0.001	<0.001	<0.001
linear FE[4]	0.300	0.445	0.569	0.605	0.066	0.959	0.338	<0.001	<0.001	<0.001
quadratic FE[4]	0.159	0.044	0.063	0.311	0.274	0.311	0.003	<0.001	<0.001	<0.001

[1-4]see Table 2.

The inclusion of extruded flaxseed (all proportions) in the diets for fatteners significantly increased the apparent digestibility of EE (P<0.001), but also crude fibre (P<0.001) and NfE (P<0.001) (Table 3). The apparent digestibility of CP (P = 0.002) was significantly higher in groups 2FE and 4FE vs groups C and 6FE (P = 0.002).

Fatteners from the group receiving 4% extruded flaxseed (group 4FE) had a statistically lower dress-

ing percentage (P = 0.042) compared to the control, but a statistically larger loin area (P = 0.030); Table 4). Statistically higher lean meat content was obtained in fatteners from the groups receiving extruded flaxseed (2FE, 4FE and 6FE) vs group C (P<0.001). Backfat thickness based on five measurements was statistically higher in group C than in the other experimental groups (P<0.001). The weights of the liver and heart were statistically higher in fatteners from the groups receiving a diet with 2% and 4% FE vs the remaining groups (P<0.001). The inclusion of extruded flaxseed in the diet (2FE, 4FE and 6FE) increased the weight of the kidneys compared to the control (P<0.001).

A 2% share of FE in the diet led to a significant increase in RBC count in the final stage of fattening compared to group 6FE (P = 0.015) (Table 5). Finisher pigs from group 6FE not only had a statistically lower RBC count, but also lower haemoglobin content (P<0.001) and HCT (P = 0.004) vs the remaining groups. Grower pigs receiving FE (group 2FE, 4FE and 6FE) had a statistically lower WBC count (P = 0.003) than the pigs in group C. Grower pigs from group 2FE had a lower percentage of GRA and a higher percentage of LYM than the group with 4% EF, and the differences were statistically significant (P = 0.015 and P = 0.011, respectively).

The inclusion of extruded flaxseed in the diets caused significant changes in UREA and GLU content in the blood of finisher pigs (Table 6). Finisher pigs receiving a diet with 2% FE had a significantly increased plasma glucose level compared to the other groups (P<0.001). A significant increase in UREA was noted in groups 2FE and 6FE vs groups C and 4FE (P = 0.003).

ALP activity in the plasma of grower pigs from groups C and 4FE was statistically lower than in the other experimental groups (P<0.001). In the case of fatteners in the final fattening period, statistically lower ALP activity was noted in the group of animals receiving 6% extruded flaxseed vs the remaining groups (P<0.001) (Table 7). The inclusion of FE in the diets for finisher pigs (groups 2FE, 4FE and 6FE) caused a reduction in AST and ALT in the plasma during the finisher period compared to group C (P<0.001).

Table 5. Haematological parameters of the blood of fatteners

Treatment[1]	RBC grower	RBC finisher	HGB grower	HGB finisher	HCT grower	HCT finisher	WBC grower	WBC finisher	GRA grower	GRA finisher	LYM grower	LYM finisher	MID grower	MID finisher
	10^{12}/l		mmol/l		l/l		10^9/l		%		%		%	
C	6.61	6.23 ab	6.91	7.70 a	0.338 b	0.342 a	17.10 a	17.19	45.01 ab	41.08	51.97 ab	57.09	3.02	6.61
2FE	7.02	6.73 a	7.16	8.10 a	0.348 b	0.353 a	15.25 b	18.55	39.34 b	45.22	57.68 a	53.05	2.81	7.02
4FE	6.60	6.25 ab	7.27	7.76 a	0.345 b	0.351 a	15.39 b	18.02	51.27 a	47.13	46.95 b	51.10	1.78	6.60
6FE	6.98	5.58 b	7.38	6.51 b	0.392 a	0.303 b	15.75 b	16.22	41.80 ab	41.85	55.97 ab	56.32	2.23	6.98
SEM[2]	0.083	0.112	0.067	0.113	0.005	0.005	0.181	0.389	1.25	0.914	1.13	0.888	0.207	0.129
P-value														
diet[3]	0.196	0.015	0.144	<0.001	0.007	0.004	0.003	0.409	0.015	0.185	0.011	0.173	0.284	0.999
linear FE[4]	0.214	0.227	0.295	0.067	0.925	0.823	0.046	0.760	0.010	0.297	0.008	0.299	0.217	0.963
quadratic FE[4]	0.843	0.001	0.294	<0.001	0.004	0.008	0.211	0.089	0.455	0.323	0.545	0.304	0.401	0.833

[1-4]see Table 2.

RBC – red blood cells; HGB – haemoglobin; HCT – haematocrit; WBC – while blood cells; GRA – granulocytes; LYM – lymphocytes; MID – sum monocytes + eosinophils + basophils.

Table 6. Biochemical parameters of the blood of fatteners

Treatment[1]	GLU grower	GLU finisher	TP grower	TP finisher	BIL grower	BIL finisher	UREA grower	UREA finisher	CREAT grower	CREAT finisher
	mmol/l		g/l		µmol/l		mmol/l		µmol/l	
C	4.76	5.34 a	67.46	62.95	4.22	3.13	4.21	5.14 b	138.1	159.5
2FE	4.67	4.23 b	70.14	58.90	3.98	2.71	5.13	5.77 a	138.7	121.1
4FE	4.37	5.22 a	69.21	57.50	4.24	2.75	4.49	4.81 c	141.5	142.7
6FE	4.66	5.44 a	71.73	57.51	4.40	3.11	4.72	6.05 a	145.4	147.8
SEM[2]	0.106	0.113	0.653	0.924	0.130	0.063	0.121	0.129	3.16	4.86
P-value										
diet[3]	0.797	<0.001	0.351	0.069	0.842	0.072	0.085	0.003	0.679	0.051
linear FE[4]	0.966	<0.001	0.359	0.614	0.268	0.039	0.254	0.419	0.543	0.096
quadratic FE[4]	0.252	0.103	0.254	0.769	0.877	0.298	0.419	0.002	0.956	0.538

GLU – glucose; TP – total protein; BIL – bilirubin; UREA – urea; CREAT – creatinine.

[1-4]see Table 2.

Table 7. Enzyme activity (U/l) in the blood plasma of fatteners

Treatment [1]	ALP grower	ALP finisher	ALT grower	ALT finisher	AST grower	AST finisher	LDH grower	LDH finisher
C	130.6 c	127.9 b	38.23	29.83 a	24.43	43.52 a	1095.8	1223.6
2FE	177.7 a	117.9 c	33.44	23.44 b	28.35	26.71 c	1023.5	1249.3
4FE	129.4 c	139.5 a	32.78	21.54 b	24.34	26.20 c	1003.0	1321.2
6FE	161.0 b	136.5 a	30.39	24.42 b	27.02	34.21 b	1103.3	1296.3
SEM[2]	4.43	1.73	1.01	0.819	0.678	1.544	9.89	13.57
P-value								
diet[3]	<0.001	<0.001	0.117	<0.001	0.206	<0.001	0.099	0.145
linear FE[4]	0.067	0.049	0.166	0.503	0.362	0.047	0.199	0.312
quadratic FE[5]	0.001	<0.001	0.322	0.001	0.607	0.111	0.213	0.244

ALP – alkaline phosphatase; ALT – alanine aminotransferase; AST– aspartate aminotransferase; LDH – lactate dehydrogenase.
[1-4]see Table 2.

Discussion

Many studies using extruded or non-extruded flaxseed in swine diet showed no major effect on growth performance; the main effect observed was a beneficial modification of the fatty acid composition of tissues (Corino et al., 2008; Guillevic et al., 2009; Okrouhlá et al., 2013; Václavková et al., 2016; De Tonnac et al., 2017; Tarricone et al., 2019). Some studies, however, have shown an improvement in the growth performance of pigs when flaxseed or flaxseed oil was included in their diet (Zhan et al., 2009; Duan et al., 2014; Song et al., 2020). According to Zhan et al. (2009), growth-promoting effect may not be manifested when flaxseed is used for a short time (less than 60 days) or in amounts of less than 5%, which is in conflict with the results of our experiment. Our results indicate that the inclusion of 2% or 4% extruded flaxseed in the diet of pigs increased ADG throughout the experiment (in both the grower and finisher periods), and improved the FCR. The 6% addition of flaxseed, however, was less effective, although the results were still better than in the control. The improvement in fattening parameters in the groups receiving extruded flaxseed, i.e. higher weight gains and better feed conversion, may be due to its specific chemical composition, i.e. high content of ALA and the presence of lignans. Song et al. (2020) found that reducing the n-6 to n-3 PUFA ratio in the diet of pigs (to 2:1) by including 3% flaxseed significantly increased ADG and to some extent increased feed intake. This suggests that the flaxseed addition improved the palatability of the feed, so that it was more readily consumed by the animals. Duan et al. (2014) showed that increasing the proportion of n-3 PUFAs in the diet of pigs by using 0.75% flaxseed oil can improve ADG and FCR. In that experiment there was a suppression in the expression level of pro-inflammatory cytokines, which may have translated to an improvement in growth performance. Inflammation can suppress the growth of animals, because nutrients are used to synthesize inflammatory mediators instead of as building material and a source of energy. Moreover, pro-inflammatory cytokines down-regulate biosynthesis of muscle proteins while stimulating their catabolism (Costamagna et al., 2015). The study by Zhan et al. (2009), cited above, showed that the inclusion of 10% flaxseed in the diet of barrows as a source of n-3 PUFA stimulated their growth, which the authors link partially to its modulatory effect on the production of pro-inflammatory cytokines (by activation of transcription factor PPARγ). Besides the anti-inflammatory effect of n-3 PUFAs, a reduction in inflammatory reactions by flaxseed may also be due to the presence of lignans. These compounds, in addition to their antioxidant and anti-inflammatory activities, also exhibit oestrogenic activity (Hallund et al., 2008). In rats, an increase in body weight was observed when lignan extract was added to their diet (Haran et al., 2017), which the authors explain as the effect of their oestrogenic activity. A study by Kour et al. (2021) showed that extrusion significantly decreases the content of lignans in seeds. However, given that flax is the richest source of these compounds (Touré and Xueming, 2010), their content in the extrudate may be significant and induce a biological effect. Another contributor to the improved growth performance of fatteners receiving extruded flaxseed may have been mucous substances, which are part of the soluble fibre fraction. These substances can positively affect the gut microbiota (a prebiotic effect) (Lin et al., 2011) and intestinal health, reducing the frequency of diarrhoea and in consequence stimulating weight gain. It should be noted, however, that an excessive amount of the mucous substances contained in flaxseed can also have adverse effects associated with their high water-holding capacity and swelling in the digestive tract, which can reduce nutrient absorption (Rodriguez et al., 2001). This may explain the less beneficial effect of the highest (6%) proportion of flaxseed on the performance of pigs. The poorer fattening effects in pigs receiving 6% flaxseed may also be linked to the higher content of other anti-nutritional factors (e.g. cyanogenic

glycosides), which were not completely eliminated during extrusion and can adversely affect the health and productivity of pigs. In a study by Juárez et al. (2010) using flaxseed co-extruded with field pea, even a higher level of flaxseed in the diet (15%) did not reduce growth performance, provided it was not used for longer than 8 weeks. When used for a longer period (12 weeks), irrespective of the proportion (5–15%), it caused a decrease in ADG. Soni-Guillermo et al. (2017), who used five different levels of flaxseed (from 2% to 10%) in the diet of fatteners, found that in pigs with a body weight of 75–100 kg the diet modification did not affect growth performance. However, in pigs with BW of 50–75 kg, levels of just 4% flaxseed and higher adversely influenced ADG and FCR, while 2% flaxseed was more beneficial.

The results of the present study indicate that the improved body weight gain, lower feed intake, and especially lower FCR in fatteners receiving a diet with 2% or 4% extruded flaxseed corresponded to a significant increase in the apparent faecal digestibility coefficients of basic nutrients, i.e. protein, ether extract, and fibre, relative to the control. Improved apparent digestibility of nutrients, except protein, was also noted in fatteners receiving 6% extruded flaxseed.

The beneficial effects observed in fatteners receiving flaxseed included an increase in the lean meat content of the carcass and a decrease in backfat content. This effect was not dependent on the percentage of extruded flaxseed in the diet. In addition, in the group receiving 4% flaxseed in the diet there was a significant increase in the area of the loin, accompanied by the lowest dressing percentage. Most studies in which flaxseeds were used, indicate that they do not statistically influence the carcass parameters of fattening pigs (Corino et al., 2008; Guillevic et al., 2009; Václavková et al., 2016; De Tonnac et al., 2017). Tarricone et al. (2019), however, reported that 3% extruded linseed in the diet of Nero Lucano pigs led to an increase in dressing percentage. Juárez et al. (2011) observed an increase in lean yield and total lean content in pigs following co-extruded flaxseed dietary addition. In turn, flaxseed diet contributed to a decrease in total dissectible fat and inermuscular fat contents. Huang et al. (2008), who used 10% non-extruded flaxseed for growing-finishing barrows, found that the experimental diet caused hypertrophy of some muscles, including the *longissimus dorsi*. This was correlated with an increase in intramuscular fat deposition, which is a beneficial effect, as this fat determines the eating quality of meat. In contrast to the results of our experiment, a flax diet did not affect the average backfat thickness. It has been documented that dietary n-3 PUFA inhibit the process of lipogenesis and stimulate fatty acid oxidation, which may affect body fat deposition (Ukropec et al., 2003). In our study, apart from that the effect on backfat thickness and lean meat content, diets containing extruded flaxseed increased the weight of the kidneys (all levels of flaxseed) and that of the liver and heart (2% and 4% FE). These findings are difficult to interpret and not discussed in the literature, which suggests that this effect of flax has not been observed. Flaxseed is known to be a source of cyanogenic glycosides, which are not entirely eliminated despite the extrusion process. Hydrogen cyanide released during their hydrolysis can exert hepatotoxic and nephrotoxic effects. Flaxseed also contains other anti-nutritional factors, which can put a strain on these organs. The results of the blood analyses (no increase in enzymes AST and ALT or creatinine) do not indicate any functional anomalies or damage in the liver or kidneys. As these are highly metabolically active organs, their enlargement may indicate an increase in the rate of processes taking place in them, e.g. those associated with protein metabolism. Schoknecht and Pond (1993) showed that a high-protein diet may contribute to hypertrophy of the liver and kidneys and is an adaptive mechanism to excessive protein intake. The digestibility analyses showed that the inclusion of extruded flaxseed in place of soybean meal increased the digestibility of protein in the feed, so that it was more efficiently utilized by the animals. It may be that the level of protein exceeded the body's demand, as there was an increase in the urea concentration in the blood of pigs receiving flaxseed (2% and 6%). This parameter is a recognized marker of protein utilization by animals, and thus an increase in its level may indicate excessive protein in the diet. Analysis of the effect of the experimental diet on the values of other blood parameters showed only a decrease in the glucose level. This may be due to the hypoglycaemic effect of lignans which are able to reduce insulin resistance probably thanks to their antioxidant activity (Rhee and Brunt, 2011). However, this effect was observed only in pigs receiving 2% flaxseed in the diet, and only in the finisher period.

In addition to the biochemical parameters, haematological indicators providing valuable information on the physiological condition of animals and their responses to diet modifications were analysed as well. This is particularly important if the diet may contain substances affecting the hematopoietic system. A study in rabbits which analysed the potential effect of flaxseed lignans (40 mg/kg BW) on blood parameters showed that even when ingested for a long time (2 months) they caused no adverse changes in either erythrocyte or leukocyte parameters (Prasad, 2005). Króliczewska et al. (2017), using a diet with flaxseed (10%) for 42 days in experimental rabbits, noted an increase in RBC number and HCT value. It is known that dietary n-3 PUFA may be incorporated into the phospholipids of erythrocyte membranes and thus influence their structure and functions (Barceló-Coblijn et al., 2008). The results of the present study showed no substantial differences in RBC parameters, although in the group receiving the highest level of extruded flaxseed (6%) the RBC count was slightly lower than in the control, and the haematocrit value and Hb content were statistically lower than in the remaining groups. However, the values of all haematological parameters were within normal physiological limits (Friendship and Henry, 1996). Similarly, WBC parameters were normal, but

during the growing period there was a decrease in the WBC count in all groups receiving extruded flaxseed (irrespective of the proportion). This was probably due to the anti-inflammatory effect of such a diet, as WBC count is a recognised biomarker of inflammation and pro-inflammatory diet is accompanied by an increase in WBC counts (Wirth et al., 2018).

Conclusions

The use of either 2% or 4% extruded flaxseed in the diet of fatteners improved the digestibility of basic nutrients (EE and NfE) and performance parameters, and also increased the lean meat content and reduced backfat thickness in the carcass. The inclusion of extruded flaxseed did not affect the animals' condition, as indicated by the values of haematological and biochemical parameters of the blood, which were within the range of reference values. At this stage of research the similar growth performance, nutrient digestibility, and carcass parameters between pigs in groups 2FE and 4FE suggest that a 2% addition of extruded flaxseed is economically the most justified.

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