Polish Journal of Veterinary Sciences Vol. 21, No. 1 (2018), 157–165

DOI 10.24425/119034

Original article

The effect of feeding system and sex on the performance and selected gastrointestinal features of fattening pigs

E.R. Grela[1], A. Czech[2], G. Kusior[2], A. Szczotka-Bochniarz[3], R. Klebaniuk[1]

[1] Institute of Animal Nutrition and Bromatology, University of Life Sciences in Lublin, 20-950 Lublin, Akademicka 13, Poland
[2] Department of Biochemistry and Toxicology, University of Life Sciences in Lublin, 20-950 Lublin, Akademicka 13, Poland
[3] Department of Pig Diseases, National Veterinary Research Institute, 20-100 Puławy, Aleja Partyzantów 57, Poland

Abstract

The aim of the study was to evaluate the efficiency of two feeding systems for fattening pigs (wet and dry), taking into account their sex, on performance, nutrient digestibility, and some histological and microbiological parameters of the gut.

The study was conducted on 450 fattening pigs, divided into 6 groups (n = 75) and housed in pens with 15 pigs per pen. The first three groups, divided according to sex, i.e. gilts, barrows and boars subjected to immunocastration (B-I), received complete dry feed, while the next three, divided in the same manner according to sex, were fed a fermented liquid diet. The nutritional value of the feeds, calculated on a dry weight basis, was similar for the two feeding systems in both stages of the fattening period. The best weight gains were observed in the group B-I pigs which received the liquid diet, and the poorest in the gilts fed the dry feeds. The best feed conversion ratio (FCR) was observed in the boars treated with Improvac®, especially those receiving the liquid diet. The feeding system significantly influenced the digestibility of nutrients, with higher apparent digestibility coefficients for crude protein, fat and fibre noted in the animals fed in the wet system. The liquid feeding system caused an increase in crypt depth in the colon in all groups of pigs, as well as an increase in the width of the muscular layer. A significant decrease in the total bacterial count was observed in the calcium, especially in the animals fed in the wet system.

Key words: feeding system, gender, immunocastration, performance, digestibility, gut microbiology

Correspondence to: E.R. Grela, e-mail: eugeniusz.grela@up.lublin.pl

Introduction

The efficiency of pig fattening, in addition to genetic factors, is mainly determined by diet and housing conditions in accordance with welfare requirements. The choice of a suitable feeding system for pigs depends on numerous factors, such as the farm's size and facilities, and the availability of fodder, including the distance from agro-food processing plants in possession of by-products (e.g. whey). These factors also determine the quality of the pork produced, while consumers and animal rights advocate also expect the animals to be raised by humanitarian methods (Lagerkvist et al. 2006, Fredriksen et al. 2011). This mainly concerns the development of alternative methods to the common practice of surgical castration of young male pigs, performed in order to eliminate the unpleasant odour caused by the androstenone and skatole present in pork meat and fat (Brennan et al. 1986, Dunshea et al. 2001, Font et al. 2008). One such procedure is immunocastration of young boars (Cronin et al. 2003, Zamaratskaia et al. 2008, Grela et al. 2013). The development of the immunocastration method for pigs is an unquestionable breakthrough in animal welfare (Lagerkvist et al. 2006).

The efficiency of pig rearing is also determined by the feeding system (wet vs dry), which significantly influences the health of the animals, growth performance, and pork quality (Brooks et al. 2001, Brooks et al. 2003, Hong et al. 2009). Feeding systems for swine involve feed type and form, as well as how it is supplied to the pigs. The main type of feed for swine is in dry form, where the cereal grain (wheat and barley) has been ground and mixed with other dry ingredients to form a complete feed. Another way to pigs feeding is by wet feeding, which consists of mixing the feed with water or whey or fermenting the feed components. Feeding a liquid diet to pigs has been shown to affect the gastrointestinal tract (GIT), resulting in a decrease in pH and an increase in concentrations of lactic acid and volatile fatty acids (VFA) in the gastric digesta. Both the feeding system and the animals' sex, as well as the interaction of these factors, may differentiate the gut microbiome of pigs, the digestibility of feed nutrients, and growth performance.

The aim of the present study was to evaluate the efficiency of two feeding systems for fattening pigs (wet and dry), taking into account their sex (gilts and boars castrated surgically or immunologically), on growth performance, nutrient digestibility, and histological and microbiological parameters of the gut.

Materials and Methods

The study was conducted on 450 fattening pigs of the Pig Improvement Company (PIC) crossbred line, divided into 6 groups (n = 75) and housed in pens with 15 pigs per pen (5 replications). The first three groups, divided according to sex, i.e. gilts (G), barrows (B-C) and boars subjected to immunocastration (B-I), received complete compound dry feed rations, while the next three, divided in the same manner according to sex, were fed fermented liquid feed. The barrows (B-C) were surgically castrated at the age of 5 days, while the B-I pigs received two 2-ml doses (at days 74 and 141 of age) of Improvac® (Pfizer Ltd.), containing 200 µg GnRH/ml, subcutaneously below the base of the right ear. The fattening period was divided into two feeding stages: initial (30-70 kg body weight (BW)) and final (71-115 kg BW). The composition and nutritional value of the feeds given to the animals during the two stages are presented in Table 1. Content of crude fibre, amino acids, acid detergent fibre (ADF), neutral detergent fibre (NDF) and minerals (Ca, P, Na) in the feed was determined according to AOAC (2012) procedures. The dry feed was provided *ad libitum* with continual access to drinking water, and the liquid feed was given 3 times a day in troughs in each pen. Production of the liquid feed consisted of three stages: first the whey, maize silage and other feed components were placed in the fermenter; then they were heated, mixed and fermented (about 4 hours); and finally the feed was transported to the troughs. The dry matter content of the feed given to the pigs was 24-26%. Daily feed intake was recorded and body weight was monitored by weighing the animals at the start of the experiment, when the feed was changed (about 70 kg BW) and before slaughter. The digestibility of the feed nutrients was determined in metabolic cages in 5 pigs from each group, at body weights of 45-50 kg and 90-95 kg. The adaptation period of the digestibility testing lasted 6 days, after which faeces were collected for 4 consecutive days.

At the completion of the fattening period, 50 g of intestinal contents was collected from the jejunum and caecum of 8 animals in each group for microbiological testing, and samples of the ileum, caecum and colon were taken for morphometric analyses.

The intestinal contents were thoroughly mixed and then 1 g was inoculated into 9 ml of saline and vortexed. Then 1 ml of the mixture was inoculated into 9 ml of saline according to the decimal dilution method. Eight dilutions were performed for each sample of intestinal contents. The 3rd, 4th, 5th, 6th, 7th and 8th dilutions were plated on solid media. A volume of 100 µl of each mixture was cultured on

Table 1. Composition and nutritive value of growing (30-70 kg BW) and finishing (71-115 kg BW) pig diets.

Feeding system	Dry		Wet	
Fattening period	30-70 kg	71-115 kg	30-70 kg	71-115 kg
Ingredients, % of air (88.0%) DM:				
Wheat	4.15	4.80	–	–
Corn	15.0	15.0	–	–
Triticale	30.0	35.0	–	–
Barley	11.62	5.0	–	–
Oat	10.0	11.0	10.0	12.92
Bran of wheat	7.0	10.0	8.0	10.0
Soybean meal	18.41	15.33	20.32	15.5
Corn silage	–	–	40.0	40.0
Whey	–	–	20.0	20.0
Soya oil	1.0	1.0	–	–
Limestone	1.05	1.35	0.94	1.04
Monocalcium phosphate	0.41	0.37	0.02	0.04
Salt	0.44	0.47	0.05	0.03
L-lysine	0.27	0.21	0.09	0.05
L-threonine	0.06	0.01	–	–
DL-methionine	0.05	0.02	0.04	0.03
Mineral and vitamin premix[1]	0.5	0.4	0.50	0.35
Enzyme supplement[2]	0.04	0.04	0.04	0.04
Total	100.00	100.00	100.00	100.00
Content in 1 kg of DM:				
Metabolizable energy[3], MJ	13.25	13.11	13.21	13.11
Crude protein, g	168.7	156.5	172.8	158.7
NDF, g	256.4	278.2	221.3	228.5
ADF, g	84.2	93.4	72.5	73.2
Lysine, g	10.34	8.94	10.33	8.99
Methionine + cysteine, g	6.34	5.95	6.34	5.91
Threonine	7.02	6.48	7.13	6.51
Tryptophan	2.00	1.85	2.10	1.91
Calcium, g	7.52	7.34	8.02	7.69
Total phosphorus, g	5.23	4.95	4.93	4.70
Sodium, g	1.98	1.82	1.99	1.87

[1] Mineral-vitamin premix (in 1 kg): vitamin A 2,000,000 IU, D_3 400,000 IU, E 6,000 mg, K_3 273 mg, B_1 200 mg, B_2 936 mg, niacin 4,000 mg, B_6 200 mg, B_{12} 4 mg, biotin 12 mg, chloride choline 33.75 g, folic acid 133 mg, iron 16.9 g, manganese 9.0 g, copper 5.0 g, zinc 17.0 g, iodine 242 mg, cobalt 115 mg, selenium 60 mg.
[2] Enzyme supplement – 1,4-β-D-xylanase and endo-1,3(4)-β-D-glucanase (1:1)
[3] Metabolizable energy was calculated according to the equation of Kirchgessner and Roth (1983).

solid media in order to determine the number of the following:

– aerobic and facultative aerobic bacteria – the material was plated on tryptone soya agar (TSA) and incubated for 24 h in a thermostat (37°C ± 2°C, CO_2 8% (±2%)).

– bacteria similar to *Escherichia coli* (coliform bacteria) – the material was plated on MacConkey agar and incubated for 24 h in a thermostat (37°C ± 2°C, CO_2 8% (± 2%)). Only red colonies were counted.

– bacteria of the species *Escherichia coli* – the

Table 2. Effect of feeding system and sex on performance.

Item	Feeding groups						SEM	P values				
	Dry			Wet				F	S	FxS		
	G	B-C	B-I	G	B-C	B-I				FxG	Fx B-C	FxB-I
Body weight, kg												
at start – 74 days of age	25.52	25.31	27.04	25.56	25.30	26.98	1.43	ns	ns	ns	ns	ns
130 days of age	71.68^{b}	74.17^{b}	77.53^{ab}	74.81^{ab}	76.34^{ab}	81.41^{a}	0.33	*	*	ns	ns	ns
168 days of age	105.9^{b}	110.5^{a}	114.9^{ab}	109.6^{a}	114.3^{ab}	120.2^{a}	1.04	*	*	ns	ns	ns
Average daily gain, kg d^{-1}												
74-130 days	0.824^{b}	0.873^{ab}	0.902^{ab}	0.879^{ab}	0.911^{ab}	0.972^{a}	0.112	*	*	ns	ns	ns
130-168 days	0.901^{b}	0.956^{ab}	0.983^{ab}	0.916^{b}	0.999^{a}	1.021^{a}	0.121	*	*	ns	ns	ns
74-168 days	0.855^{b}	0.906^{ab}	0.935^{b}	0.894^{ab}	0.947^{ab}	0.992^{a}	0.431	*	*	ns	ns	ns
Feed intake, kg DM d^{-1}												
74-130 days	2.06	2.05	2.06	2.08	2.07	2.11	0.154	ns	ns	ns	ns	ns
130-168 days	3.04	3.04	3.05	3.10	3.11	3.14	0.122	ns	ns	ns	ns	ns
74-168 days	2.46	2.46	2.47	2.49	2.49	2.53	0.232	ns	ns	ns	ns	ns
Feed conversion ratio, kg DM kg^{-1}												
74-130 days	2.50^{a}	2.35^{ab}	2.29^{b}	2.36^{ab}	2.27^{b}	2.17^{b}	0.542	*	*	ns	ns	ns
130-168 days	3.38^{a}	3.18^{ab}	3.10^{b}	3.39^{a}	3.11^{b}	3.08^{b}	0.347	*	*	ns	ns	ns
74-168 days	2.88^{a}	2.71^{ab}	2.64^{b}	2.79^{ab}	2.63^{b}	2.55^{b}	0.299	*	*	ns	ns	ns

Legend:
G – gilts; B-C – barrows (surgically castrated boars); B-I – boars subjected to immunocastration; F – feeding system – dry vs liquid; S – sex – G vs B-C vs B-I
$^{a, b}$ – $p \leq 0.05$; ns – no statistically significant difference ($p \geq 0.05$); * $p \leq 0.05$; ** $p \leq 0.01$

material was plated on MBA (Methylene Blue Agar) and incubated for 24 h in a thermostat (37°C ± 2°C, CO_2 8% (±2%)). Only colonies with a green metallic sheen were counted (a typical characteristic of *E. coli* on MBA).

– bacteria of the species *Clostridium perfringens* – the material was plated on Columbia agar and incubated for 24 h in an anaerostat in anaerobic conditions, obtained using the GasPak Plus system for creating gaseous environments (Anaerobic System Envelopes with Palladium Catalyst, BD BBL) at 41°C (± 1°C). Only colonies with a double zone of haemolysis were counted (a typical characteristic of *Clostridium perfringens*).

The cultures on solid media were performed in three replications. The number of bacteria was determined on the basis of the lowest dilution of intestinal contents whose growth on the solid medium could be counted. The result for a single animal was expressed as the average from three replications of the number of colony-forming units (CFU) per ml (ileum) or per gram (colon) of contents.

The samples of the intestines for morphometric analysis were fixed in 10% buffered formalin, processed in a tissue processor (TP 1020, Leica Biosystems, Nussloch, Germany) and embedded in paraffin. Sections 3 µm thick were prepared from the paraffin blocks and subjected to standard H&E (haematoxylin and eosin) staining. Morphometric analysis of the slides was then performed using the NIS Elements BR 2.20 image processing and analysis system (Nikon Corporation, Tokyo, Japan), according to previously described methods (Pluske et al. 1996, Hedemann et al. 2006). The measurements were made under 40 × magnification in 6 randomly selected fields of view. In the ileum the length of the villi and their width at the base were measured, as well as the depth and width of the crypts. The width of the muscular layer was determined as well. In the caecum and colon analogous measurements were made of the crypts and muscular layer.

All parameters were processed statistically, and the significance of differences between means in groups was determined by two-way analysis of variance for orthogonal data using Tukey's test, with significance levels of 0.05 and 0.01. A two-way analysis was carried out in order to assess the significance of sex and feeding system, and was performed using the general lineal model (GLM) procedure of StatSoft software (version Statistica 12.5). The model of analysis was as follows:

$$Y_{ijk} = \mu + F_i + S_j + (F \times S)_{ij} + e_{ijk}$$

where F_i is the feeding system (i = 1,2), Sj is the sex (j = 1,2,3), $(F \times S)_{ij}$ is the interaction between feeding system and sex effects, and eijk is the residual error.

Table 3. Average total tract digestibility coefficients (%) in growing and finishing pigs.

Item	Fattening period	Feeding groups						SEM	P values				
		Dry			Wet				F	S	FxS		
		G	B-C	B-I	G	B-C	B-I				FxG	Fx B-C	FxB-I
CP	Grower	76.34^{b}	74.66^{b}	80.08^{b}	87.70^{a}	86.69^{a}	89.27^{a}	1.05	*	ns	*	*	*
	Finisher	78.35^{b}	77.63^{b}	81.12^{b}	85.48^{a}	86.15^{a}	88.24^{a}	0.876	*	ns	*	*	*
	Mean	77.35^{b}	76.15^{b}	80.60^{b}	86.59^{a}	86.42^{a}	88.76^{a}	0.578	*	ns	*	*	*
EE	Grower	60.54^{bc}	56.54^{c}	64.82^{b}	85.34^{a}	80.91^{a}	83.09^{a}	1.87	**	ns	**	**	*
	Finisher	69.23^{b}	70.11^{b}	72.31^{b}	88.32^{a}	86.17^{a}	87.48^{a}	2.01	*	ns	**	*	*
	Mean	64.89^{b}	63.33^{b}	68.57^{b}	86.83^{a}	83.54^{a}	85.29^{a}	1.04	**	ns	**	**	*
CF	Grower	18.08^{B}	15.64^{B}	17.04^{B}	41.78^{A}	45.24^{A}	46.60^{A}	2.65	**	ns	**	**	**
	Finisher	45.23^{b}	46.12^{b}	45.87^{b}	55.47^{a}	58.16^{a}	58.72^{a}	2.66	**	ns	**	*	*
	Mean	31.66^{b}	30.88^{b}	31.46^{b}	48.63^{a}	51.70^{a}	52.66^{a}	0.999	**	ns	**	**	**
NfE	Grower	87.23	85.96	89.82	92.33	93.93	93.25	4.78	ns	ns	ns	ns	ns
	Finisher	90.17	89.12	91.45	92.67	92.93	93.26	3.65	ns	ns	ns	ns	ns
	Mean	88.70	87.54	90.64	92.50	93.43	93.26	5.11	ns	ns	ns	ns	ns

Legend: see Table 2
CP – crude protein, EE – ether extract, CF – crude fibre, NfE – nitrogen-free extract

Table 4. Villus height, crypt depth and muscularis externa width in the ileum, caecum and colon of fatteners.

Item		Feeding groups						SEM	P values				
		Dry			Wet				F	S	FxS		
		G	B-C	B-I	G	B-C	B-I				FxG	Fx B-C	FxB-I
Ileum													
Villus, µm	height	302.4^{b}	346.9^{ab}	354.3^{ab}	342.7^{ab}	336.1^{ab}	393.6^{a}	5.662	ns	*	ns	ns	ns
	width	158.2^{ab}	143.3^{b}	142.1^{b}	176.7^{a}	162.5^{ab}	169.2^{ab}	3.418	**	*	ns	ns	ns
Crypt, µm	depth	414.3^{a}	428.2^{a}	423.1^{a}	368.9^{b}	398.4^{ab}	369.5^{b}	5.499	**	ns	**	ns	*
	width	49.74^{b}	54.93^{ab}	55.11^{ab}	54.45^{ab}	59.51^{a}	58.49^{a}	1.030	**	ns	ns	ns	ns
Muscularis externa, µm		251.7^{c}	303.3^{b}	318.1^{b}	376.6^{a}	379.8^{a}	398.8^{a}	6.884	**	*	**	ns	*
Caecum													
Crypt, µm	depth	483.3^{b}	526.2^{a}	519.7^{a}	471.4^{b}	479.4^{b}	476.1^{b}	4.633	**	ns	ns	*	*
	width	77.88^{a}	67.90^{b}	72.16^{ab}	69.56^{b}	76.38^{a}	76.99^{a}	0.891	ns	ns	*	*	ns
Muscularis externa, µm		219.9^{a}	202.2^{ab}	208.5^{ab}	195.3^{b}	198.8^{b}	199.5^{b}	4.697	*	ns	*	*	ns
Colon													
Crypt, µm	depth	488.6^{ab}	514.4^{a}	507.0^{a}	449.1^{b}	478.2^{ab}	492.1^{a}	4.347	*	ns	ns	ns	ns
	width	55.77	60.35	58.74	59.52	57.99	62.50	0.772	ns	ns	ns	ns	ns
Muscularis externa, µm		227.6^{a}	224.7^{a}	220.8^{a}	188.5^{b}	185.6^{b}	207.8^{ab}	3.805	**	ns	**	**	ns

Legend: see Table 2

The experiment was approved by the local Ethics Committee for Animal Experimentation in Lublin.

Results

The nutritional value of the compound feeds, calculated on a dry weight basis, was similar for the two feeding systems in both stages of the fattening period (Table 1). Only the NDF and ADF content were lower in the liquid diet, by 13-18% and 14-21%, respectively. The best weight gains were observed in the group B-I pigs which received the liquid diet, and the poorest in the gilts (G) fed the dry feeds (Table 2). Daily weight gains were 45 g (4.8%) higher in the animals fed in the wet system, and the differences in comparison with the dry feed were confirmed statistically. The highest body weight at 168 days of age was

Table 5. Microbial analysis in selected segments of the digestive tract in fatteners.

Item	Intestine part	Feeding groups						P values				
		Dry			Wet			F	S	FxS		
		G	B-C	B-I	G	B-C	B-I			FxG	Fx B-C	FxB-I
TSA (CFU/g)	Ileum	5.3×10^7	3.0×10^6	6.1×10^6	6.3×10^7	6.9×10^6	8.9×10^6	ns	*	ns	ns	ns
	Caecum	3.0×10^7	1.0×10^7	1.7×10^7	3.1×10^6	4.3×10^6	4.5×10^6	*	ns	ns	ns	ns
MacConkey (CFU/g)	Ileum	1.9×10^7	2.1×10^6	2.1×10^6	2.2×10^7	2.0×10^6	2.5×10^6	ns	ns	ns	ns	ns
	Caecum	3.7×10^6	1.0×10^5	3.5×10^5	1.5×10^5	2.8×10^4	4.6×10^4	*	*	ns	ns	ns
MBA (CFU/g)	Ileum	3.7×10^5	2.1×10^5	2.4×10^5	8.4×10^5	8.1×10^5	7.7×10^5	ns	ns	ns	ns	ns
	Caecum	5.2×10^4	5.8×10^4	7.6×10^4	5.1×10^5	2.4×10^5	2.8×10^5	*	ns	ns	ns	ns
Columbia (CFU/g)	Ileum	1.6×10^5	1.2×10^5	2.3×10^5	5.2×10^5	4.4×10^5	4.6×10^5	ns	ns	ns	ns	ns
	Caecum	1.1×10^4	1.8×10^4	1.4×10^4	2.6×10^4	3.2×10^4	3.6×10^4	ns	ns	ns	ns	ns

Legend: see Table 2
MBA – Methylene Blue Agar; TSA – Tryptone Soya Agar; Columbia Agar; MacConkey Agar

attained by the boars treated with Improvac®, and the lowest by the gilts. The difference in daily weight gains between these groups for the entire fattening period was 9.2%. Daily intake of dry weight of feed by the animals of different sexes was similar, at 2.06-2.11 kg in the first stage of fattening and 3.04-3.14 in the final stage (Table 2), with slightly higher intake noted in the pigs receiving the liquid diet (1.6%). Significant differences were observed for feed conversion in favour of the liquid feed (2.66 vs. 2.74 kg). The best feed conversion ratio (FCR) (on average 2.6 kg) was noted in the boars treated with Improvac®, especially in those receiving the liquid diet (2.55 kg).

The feeding system significantly influenced the digestibility of nutrients, with higher apparent digestibility coefficients for crude protein, fat and fibre in the animals fed in the wet system (Table 3). The differences in favour of the liquid diet were more significant in the first period of fattening, mainly in the case of digestibility coefficients for crude fibre (Table 3). The highest nutrient digestibility was noted in the boars treated with Improvac in the liquid feed system, and the poorest in the barrows fed dry feeds.

In the ileum of the pigs fed a liquid diet, the villi were longer (in the gilts and immunocastrated boars) and wider (in all groups) than in the pigs fed dry feed. The wet feeding system also reduced crypt depth in this part of the intestine in all groups and increased the width of the crypts. An increase in the width of the muscular layer was also observed in all groups of pigs fed in this system (Table 4).

In the caecum of the pigs fed in the wet system, the depth of the crypts was reduced in all groups and their width was increased in both the barrows and the boars subjected to immunocastration. The width of the muscular layer was reduced in all groups fed in the wet system.

The liquid feeding system caused an increase in crypt depth in the colon in all groups of pigs, as well as an increase in the width of the muscular layer (Table 4).

No significant differences were observed in the total bacterial count (CFU/g) in the ileum depending on the feeding system. An elevated total bacterial count was noted only in the gilts (fed in both the wet and dry systems) as compared to both groups of males (Table 5). In contrast, a significant decrease in the total bacterial count was observed in the calcium, especially in the animals fed in the wet system. This reduction pertained to the number of bacteria of the family *Enterobacteriacea* (MacConkey agar). Only in the gilts, irrespective of the feeding system, the number of these bacteria was higher than in the barrows (B-C) and the boars subjected to immunocastration (B-I). In the calcium of the animals fed the liquid feed an increase was observed in the total number of *Escherichia* (MBA). Despite the lack of statistical significance, the number of anaerobic *Clostridium perfringens* in the ileum was markedly higher in the animals fed the liquid diet. No significant differences were observed in the calcium between the animals fed liquid and dry feed (Table 5)

Discussion

The chemical analysis of nutrients in the diets showed significantly higher NDF and ADF content in the dry feeds than in the wet diet. This was mainly due to the components of the diets (barley and triticale in the dry feeds) and fermentation processes (maize silage in the wet diet), and preparation of the feed before feeding. Fermentation of liquid feeds reduces pH, increases the number of lactic acid bacteria, and

leads to the production of certain enzymes and vitamins (Brooks et al. 2001, Canibe and Jensen 2012), thereby improving nutrient digestibility and growth performance (Hong et al. 2009). The pigs fed a fermented liquid diet had higher daily weight gains (particularly in the group of boars subjected to immunocastration) and a better feed conversion ratio. Similar results have been obtained in studies on piglets and fattening pigs by Canibe and Jensen (2003). According to Brooks et al. (2003), a decrease in pH of feed to 4.0-4.5 stimulates the development of beneficial gut microflora, which significantly improves absorption of nutrients.

The type of diet used has been shown to influence the morphology of the gastrointestinal tract, particularly in the small intestine (Ruckebusch and Bueno 1976, Pluske et al. 1996). Many studies indicate that the improved growth performance in pigs fed liquid diets is closely linked to good intestinal integrity and an increase in the absorptive surface of the intestines, mainly due to increased villi length (Scholten et al. 2002, Thu et al. 2011). A study by Pluske et al. (1997) has revealed that the height of the villi and depth of the crypts correspond to body weight gains and dry matter consumption, and that a decrease in the ratio of villi height to crypt depth has an adverse effect on digestion and nutrient absorption. In our study, the liquid feeding system was a factor contributing to an increase in the length and width of the villi in the ileum and to shallower crypts, as well as to a wider muscular layer in the gilts and immunocastrated boars fed in this system. The liquid feeding system also significantly improved the width of the crypts in the caecum.

An increase in the size of the intestinal villi causes an increase in the absorptive surface of the intestine, which in turn has a positive effect on production parameters. Longer intestinal villi are linked to better feed intake and thus increase body weight gains (Pluske 1996, Scholten et al. 2002, Hedemann et al. 2006, Thu et al. 2011). This correlation was confirmed by the results of the present study.

The intestinal crypts are the site of intense cell proliferation. An increase in their depth in the small intestine, as observed in our experiment, suggests activation of regeneration and intense production of enterocytes (Pluske et al. 1996). An increase in crypt depth in the colon, observed in the group of pigs fed the liquid diet, may indicate increased nutrient availability in this system (Święch et al. 2010).

The thickness of the muscular layer of the intestine is an indicator of the body's nutritional status and availability of energy (Hedemann et al. 2007, Lima et al. 2012). The results of our study indicate that the liquid feeding system had a positive effect on this parameter in the ileum and colon.

The improvement in the morphology of the intestines may have been linked to the presence of lactic acid in the fermented feed, which according to Scholten et al. (2002) contributes to the growth of villi, improvement in their shape, and a higher ratio of villus height to crypt depth. In a study by Hong et al. (2009), piglets fed liquid fermented feed had higher content of acetic and lactic acids in the stomach, ileum and colon than piglets fed dry feed. An improved villus/crypt ratio in pigs fed fermented feed has also been reported by other authors (Scholten et al. 2002, Canibe and Jensen 2003).

From their first days of life piglets are subjected to various procedures which generate stress responses, e.g. tail docking, disinfection of the umbilical cord, grinding of needle teeth, and injections. In addition, five days after birth male piglets are surgically castrated. The pain arising from these procedures (particularly castration) may reduce the desire to eat, resulting in poorer fattening outcomes (Rault et al. 2011). The barrows had significantly lower daily weight gains than the boars treated with Improvac, as well as a poorer feed conversion ratio ($p \leq 0.05$). The differences obtained indicate poorer utilization of nutrients by this group of animals. Similar observations have been made by Grela et al. (2013) and Rault et al. (2011).

Fattening of pigs is conducted mainly on gilts and barrows, but on young boars as well. The meat of boars slaughtered at a body weight above 90 kg usually has an unpleasant odour, due to the accumulation of androstenone, the male sex hormone produced by the testes of adult individuals, in the backfat and intramuscular fat (Moya et al. 2008). Barrows are subjected to physical castration, which is associated with considerable distress, especially if the procedure is performed later. In some countries young boars undergo immunocastration, which makes it possible to obtain better growth performance and significantly reduce the unpleasant odour of the pork. In the present study, the B-I boars had significantly higher daily weight gains, as well as a better feed conversion index. This was linked to the presence of male sex hormones, which contribute to better utilization of nutrients for muscle tissue growth (Dunshea et al. 2001, Cronin et al. 2003). Furthermore, no aggressive behaviour typical of maturing boars was observed.

No correlation was found between sex and the feeding system as regards performance parameters, despite the fact the digestibility of basic nutrients, except for NfE, was significantly dependent on these two factors. The gilts, barrows and immunocastrated boars fed in the liquid system had higher total tract digestibility values for protein, fat, and crude fibre. The highest daily weight gains from the start of the

fattening period were observed in the boars subjected to immunocastration and fed in the liquid system, while the lowest weight gains were noted in the gilts fed in the dry system.

It cannot be conclusively stated to what extent sex or immunocastration affected the morphology of the gastrointestinal tract. The correct functioning of the digestive system is considered to depend largely on maintenance of the proper balance of gut flora (Laycock et al. 2012). Rapid growth of intestinal bacteria with pathogenic potential can interfere with digestive function and lead to diarrhoea, low weight gain and even death. Diet has a significant effect on intestinal function, including proliferation of pathogenic bacteria, and may be a source of both beneficial and harmful microbes. According to Canibe and Jensen (2003), a diet of fermented liquid feed for pigs improves digestive tract function as compared to animals receiving dry feed. This is due in part to a reduction in pH and an increase in the amount of lactic acid and other volatile fatty acids (VFA) in the intestinal contents, as well as a decrease in the number of *Enterobacteriacea* (Scholten et al. 2002, Canibe and Jansen 2003). In the present study, the total number of bacteria (*Staphylococcus* on TSA) colonizing the ileum did not differ significantly depending on the type of diet; only in the barrows fed dry feed a decrease in the total bacterial count was observed. In contrast, in the colon there was a significant decrease in the total bacterial count in the animals fed in the liquid system. The reduction observed in the number of microbes in this part of the gut pertained to bacteria of the family *Enterobacteriacea* (MacConkey agar). The decrease in the bacterial count, particularly in the colon of animals fed a liquid diet, was caused by an increase in the number of *E. coli* (MBA).

Well-functioning gut microflora, which was primarily observed in the pigs fed a fermented liquid diet, is responsible for proper immune status and the growth and development of the intestinal villi (this was confirmed in our experiment). It is estimated that even 60-70% of the body's immune cells are produced in the intestinal mucosa, which is a very important factor reducing the incidence of colibacillosis in young animals, particularly when their feed is changed from liquid to solid.

It is advisable to adopt a liquid feeding system for young boars subjected to immunocastration.

References

AOAC (**2012**) Official methods of analysis of the AOAC International. 19th Ed. Horwitz W, Latimer Jr GW (ed) Gaithersburg, Maryland, USA.

Brennan JJ, Shand PJ, Fenton M, Nicholls LL, Aherne FX (**1986**) Androstenone, androstenol and odor intensity in backfat of 100- and 130-kg boars and gilts. Can J Anim Sci 66: 615-624.

Brooks PH, Beal JD, Niven S (**2001**) Liquid feeding of pigs: potential for reducing environmental impact and for improving productivity and food safety. Recent Adv Anim Nutr Aust 13: 49-63.

Brooks PH, Beal JD, Niven SJ (**2003**) Liquid feeding of pigs. II. Potential for improving pig health and food safety. Anim Sci Pap Rep 21 (Suppl 1): 23-29.

Canibe N, Jensen BB (**2003**) Fermented and nonfermented liquid feed to growing pigs: Effect on aspects of gastrointestinl ecology and growth performance. J. Anim Sci 81: 2019-2031.

Canibe N, Jensen BB (**2012**) Fermented liquid feed-Microbial and nutritional aspects and impact on enteric diseases in pigs. Anim Feed Sci Tech 173: 17-40.

Cronin GM, Dunshea FR, Butler KL, McCauley L, Barnet JL, Hemsworth PH (**2003**) The effects of immuno- and surgical- castration on the behaviour and consequently growth of group-housed male finisher pigs. Appl Anim Behav Sci 81: 111-126.

Dunshea FR, Colantoni C, Howard K, McCauley I, Jackson P, Long KA, Lopaticki S, Nugent EA, Simons JA, Walker J, Hennessy DP (**2001**) Vaccination of boars with a GnRH vaccine (Improvac) eliminates boar taint and increases growth performance. J Anim Sci 79: 2524-2535.

Fredriksen B, Johnsen AM, Skuterud E (**2011**) Consumer attitudes towards castration of piglets and alternatives to surgical castration. Res Vet Sci 90: 352-357.

Font I, Furnols M, Gispert M, Guerrero L, Velarde A, Tibau J, Soler J, Hortos M, Garcia-Regueiro JA, Perez J, Suarez P, Oliver MA (**2008**) Consumers' sensory acceptability of pork from immunocastrated male pigs. Meat Sci 80: 1013-1018.

Grela ER, Kowalczuk-Vasilev E, Klebaniuk R (**2013**) Performance, pork quality and fatty acid composition of entire males, surgically castrated or immunocastrated males, and female pigs reared under organic system. Pol J Vet Sci 16: 107-114,

Hedemann MS, Dybkjbr L, Jensen BB (**2007**) Pre-weaning eating activity and morphological parameters in the small and large intestine of piglets. Livest Sci 108: 128-131.

Hedemann MS, Eskildsen M, Lbrke HN, Pedersen C, Lindberg JE, Laurinen P, Bach Knudsen KE (**2006**) Intestinal morphology and enzymatic activity in newly weaned pigs fed contrasting fiber concentrations and fiber properties. J Anim Sci 84: 1375-1386.

Hong TT, Thuy TT, Passoth V, Lindberg JE (**2009**) Gut ecology, feed digestion and performance in weaned piglets fed liquid diets. Livest Sci 125: 232-237.

Kirchgessner M, Roth FX (**1983**). Equation for prediction of the energy value in mixed feeds for pigs. J Anim Physiol Anim Nutr 50: 270-275.

Lagerkvist CJ, Carlsson F, Viske D (**2006**) Swedish consumer preferences for animal welfare and biotech: a choice experiment. AgBioForum 9: 51-58.

Laycock G, Sait L, Inman C, Lewis M, Smidt H, van Diemen P, Jorgensen F, Stevens M, Bailey M (**2012**) A defined intestinal colonization microbiota for gnotobiotic pigs. Vet Immunol Immunopathol 149: 216-224.

Lima DP, Azevedo JF, Hermes-Uliana C, Alves G, Sant'ana DM, Araújo EJA (**2012**) Probiotics prevent growth deficit of colon wall strata of malnourished rats post-lactation. An Acad Bras Cienc 84: 727-736.

Moya SL, Boyle LA, Lynch PB, Arkins S (**2008**) Effect of surgical castration on the behavioural and acute phase responses of 5-day-old piglets. Appl Anim Behav Sci 111: 133-145.

Pluske JR, Hampson DJ, Williams IH (**1997**) Factors influencing the structure and function of the small intestine in the weaned pig: a review. Livest Prod Sci 51: 215-236.

Pluske JR, Thompson MJ, Atwood CS, Bird PH, Williams IH, Kartmann PE (**1996**) Maintenance of villus height and crypt depth, and enhancement of disaccharide digestion and monosaccharide absorption, in piglets fed on cows' whole milk after weaning. Br J Nutr 76: 409-422.

Rault JL, Lay Jr. DC, Marchant-Forde JN (**2011**) Castration induced pain in pigs and other livestock. Appl Anim Behav Sci 135: 214-225.

Ruckebusch Y, Bueno L (**1976**) The effect of feeding on the motility of the stomach and small intestine in the pig. Br J Nutr 35: 397-405.

Scholten RH, van der Peet-Schwering CM, den Hartog LA, Balk M, Schrama JW, Verstegen WM (**2002**) Fermented wheat in liquid diets: effects on gastrointestinal characteristics in weanling piglets. J Anim Sci 80: 1179-1186.

Święch E, Tuśnio A, Taciak M, Ceregrzyn M, Korczyński W (**2010**) Effect of dietary fibre and protein sources on contractility and morphometry of pig colon. Livest Sci 134: 172-175.

Thu TV, Loh TC, Foo HL, Yaakub H, Bejo MH (**2011**) Effects of liquid metabolite combinations produced by *Lactobacillus plantarum* on growth performance, feaces characteristics, intestinal morphology and diarrhoea incidence in postweaning piglets. Trop Anim Health Prod 43: 69-75.

Zamaratskaia G, Rydhmer L, Andersson HK, Chen G, Lowagie S, Andersson K, Lundstrom K (**2008**) Long-term effect of vaccination against gonadotropin-releasing hormone, using Improvac, on hormonal profile and behaviour of male pigs. Anim Reprod Sci 108: 37-48.