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Choice feeding in fattening pigs: Effect of diets differing in nutrient density on feeding behaviour and fattening performance

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Abstract: The aim of this study was to determine the proportion of feed consumed by pigs when they had the choice to meet their nutrient requirements offering a low (LND) or a high (HND) nutrient dense diet on animal performance and feeding behaviour. In total 120 barrows and gilts were allotted to three dietary treatments (LND, HND and a feed choice group, FC). Diets were calculated to keep a constant ratio of megajoule net energy (MJ NE) to nutrient standardised ileal digestible (SID) lysine, SID methionine and cysteine, SID threonine, SID tryptophan, Ca, available P and Na. Pigs of the feed choice treatment that could choose between LND and HND chose an energy content between 13.3 and 13.6 MJ ME or rather 10.1 and 10.4 MJ NE. The ratio between LND and HND changed during the growing period to a higher percentage of HND (26.2% : 73.8% in the starter, 22.0% : 78.0% in the grower and 20.0% : 80.0% in the finisher phase). No differences between barrows and gilts were detected regarding the selected diet. As a result, similar zootechnical performance data were observed for HND and FC, whereas LND led to a declined ($P < 0.05$) performance. Regarding the feeding behaviour no differences in the parameters meal size and daily feeder visits between LND and HND ($P > 0.1$) were observed. However, within the FC treatment more and greater meals were consumed ($P < 0.05$) at the HND feeder compared to the LND feeder. Pigs of modern genetics still have the ability to cover their nutrient requirements choosing between diets differing in nutrient density without impairing performance. Furthermore, the results give no indication for the necessity of different energy levels in diets for sexed pigs.

Keywords: dietary fibre; energy demand; nutrient self-supply

Diets covering the nutrient requirements of fattening pigs can be considered as an important factor regarding animal welfare. The requirement for nutrients depends on several factors like physiological status (e.g. age, body weight), sex, environment (e.g. temperature), feed to energy or feed to protein content, feed form or palatability (Nyachoti et al. 2004; Kallabis and Kaufmann 2012). Compared to wild pigs that have to combine plenty of nutrient sources to cover their nutrient requirements, housed pigs are normally fed similar diet ingredients throughout the fattening period (Henry 1985). Rose and Kyriazakis (1991) supposed that despite the genetic selection for higher production performance in the last decades, the ability for an adequate nutrient self-supply is still given. This argument was confirmed by a number of studies when pigs in choice feeding trials proved their skills to cover a specific nutrient requirement (Kyriazakis et al. 1990; Ferguson et al. 1999; Ettle and Roth 2009).

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Pigs in nature spend most of the day on foraging. During the foraging phase the feed consumption is steady and the diet also contains high amounts of plants rich in dietary fibre (Graves 1984). Stolba and Wood-Gush (1989) confirmed that the foraging effect to cover nutrient requirements has not been lost by domestic pigs. Nevertheless, modern housing systems do not offer the possibility to satisfy this demand and can lead to misbehaviours (Blokhuis et al. 2007). Several studies documented the positive effect of diets high in dietary fibre (DF) and their effect to prolong chewing activity, increase satiety, as well as reduce aggression and stereotypes (Ramonet et al. 1999). Wenk (2001) reviewed that a certain amount of DF seems necessary to avoid gastric ulcers and stereotypes leading to an improved overall animal welfare. Nevertheless, protein and fat can be locked within the cell wall resulting in inhibition of their digestion in the small intestine (Bach Knudsen et al. 1993). As a result, a reduction of energy and nutrient digestibility can be observed (Noblet and Le Goff 2001). This nutrient dilution has to be compensated in the diet calculations to avoid negative effects on performance (Schedle 2016). Due to the bulking effect of some DF sources, animals' feed intake decreases as their gut fill is limited. The average daily feed intake (ADFI) is associated with many factors like daily energy intake, daily nutrient intake or taste. Moreover, ADFI has a major impact on the performance of the pig. Given a short adaptation phase, pigs can compensate the lack of nutrients by higher ADFI up to a certain amount of DF in the diet (Kyriazakis and Emmans 1995; Nyachoti et al. 2004). According to the review of Henry (1985), the body fat content of pigs increases due to overeating when given *ad libitum* access to a diet high in energy and therefore not reaching the physical saturation. It is hypothesized that pigs having the opportunity to choose their diet may select a higher proportion of the diet with high energy density, completing their daily meal with energy poor diets to fulfil a certain amount of DF.

In contrast to previous studies, the present investigation kept the ratio between energy and limiting nutrients constant and varied mainly the degree of dilution through dietary fibre. In addition, the influence on the zootechnical performance and the feeding behaviour in growing-finishing pigs was determined.

MATERIAL AND METHODS

Animals and experiments

The study was conducted at the Austrian pig testing facility (Streitdorf, Austria) under compliance with the 1st regulation of animal keeping (BGBl. II No. 485/2004). It employed a total of 120 pigs (two equally distributed trial replicates with 60 animals each, a mix of barrows and gilts in each pen; initial body weight 32.9 ± 0.3 kg; OEHYB: [(Large White × Landrace) × Piétrain)].

The pigs were allotted to experimental units [two treatments without possibility of choice: low nutrient density (LND) and high nutrient density (HND)] which had 5 animals per pen and 6 pens per treatment. The feed choice group (FC) contained 10 animals per pen, resulting in 6 replicates each, considering litter, sex and body weight. Each pen offered afully slatted concrete floor and was equipped with an automatic dry-feeding system and a nipple drinker. The automatic dry-feeding system recorded every feed intake, the time and duration of the feed intake and also the amount of feed with an individual transponder chip. In the feed choice group two pens were combined by removing the partition panel to offer two dry-feeding stations with space for 10 animals. To avoid a habituation of the diet type (low/high nutrient density) in the dry-feeding station, diets in the two feeders were changed weekly. Individual body weight was determined weekly.

The fattening period was split in three phases according to the body weights of pigs: starter (32.9 ± 0.3 kg – 55.5 ± 0.4 kg), grower (55.6 ± 0.4 kg – 90.0 ± 0.5 kg) and finisher diet (90.0 ± 0.5 kg – 117.7 ± 0.2 kg). LND was based on barley and rapeseed meal, whereas HND was based on maize and soybean meal. Cereals were ground with a hammer mill (3 000 rpm) through a 6mm sieve (Gruber, Austria). Ground feed and water were provided *ad libitum*.

The complete composition of the experimental diets is shown in Table 1. Both diets were calculated to meet or exceed the nutritional requirements of the German Society of Nutrition Physiology (GfE 2006) and to keep a constant ratio of net energy (NE) to standardized ileal digestible (SID) lysine (Lys), SID methionine (Met), SID threonine (Thr), SID tryptophan (Trp), calcium (Ca), digestible phosphorus (P) and sodium (Na). The

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Table 1. Composition of the experimental diets

Feeding phase	Starter		Grower		Finisher	
Nutrient density	low	high	low	high	low	high
Maize (%)	5.00	63.50	5.00	67.76	–	77.37
Barley (%)	61.53	5.00	61.35	5.00	74.38	5.00
Rape seed meal (%)	20.91	5.00	21.60	5.00	13.60	5.00
Soybean meal without hulls (%)	5.00	20.10	5.00	17.16	–	9.32
Pectin mixture (%)	–	–	2.50	–	5.00	–
Lignocellulose (%)	5.00	–	2.50	–	–	–
Sunflower oil (%)	–	2.37	–	1.43	–	–
Wheat bran (%)	–	–	–		5.00	–
Limestone (%)	0.74	1.10	0.67	1.02	0.74	0.98
Monocalcium phosphate (%)	0.59	1.24	0.40	1.04	0.25	0.85
Sodium chloride (%)	0.22	0.27	0.19	0.22	0.17	0.22
Vitamin and trace element premix[1] (%)	0.50	0.50	0.50	0.50	0.50	0.50
L-lysine HCl (%)	0.36	0.51	0.22	0.44	0.27	0.42
L-threonine (%)	0.13	0.26	0.06	0.21	0.09	0.18
DL-methionine (%)	0.01	0.21	–	0.16	–	0.10
L-tryptophan (%)	0.02	0.06	–	0.05	–	0.06
L-valine (%)	–	0.03	–	–	–	–
Choline chloride (%)	0.05	0.05	0.05	0.05	0.05	0.05
Phytase (%)	0.015	0.015	0.015	0.015	0.015	0.015

[1]Vitamin and trace element premix consisting of: vitamin A 1 200 000 IU/kg; vitamin D3 391 200 IU/kg; vitamin E as all-rac-alpha-tocopherol acetate 4 000 mg/kg; vitamin K3 840 mg/kg; vitamin B1 480 mg/kg; vitamin B2 1 200 mg/kg; vitamin B6 840 mg/kg; vitamin B12 as cyanocobalamin 8.4 mg/kg; niacin amide 7 200 mg/kg; Ca-D-pantothenate 3 000 mg/kg; folic acid 120 mg/kg; biotin 18 mg/kg; Fe as iron-(II)-sulphate-monohydrate 12 400 mg/kg; Zn as zinc oxide 14 200 mg/kg; Mn as manganese-(II)-oxide 7 822 mg; Cu as copper-(II)-sulphate pentahydrate 2 200 mg/kg; I as calcium iodate 260 mg/kg; Se as sodium selenite 60 mg/kg; Ca-carbonate as carrier 87.7% (i.e. 33.3% Ca)

analysed nutrient concentrations of the diets are shown in Table 2.

The nutrient levels analysed were consistent with the calculated ones for the diets. However, the energy content in the LND of the finisher phase was higher than calculated, leading to an unbalanced energy to nutrient ratio in this feeding phase. The energy content provided by SDF cannot be determined analytically as crude fibre, acid detergent fibre or neutral detergent fibre according to VDLUFA (2012).

Thus, the energy content rose in LND when adding a pectin mixture. However, pectin, which is high in soluble fibre (31.1% SDF; Slama et al. 2019), was assumed to contain no energy when calculating the diets. This was the reason for the differences regarding energy content between LND and HND diet in finisher phase.

Analyses

Samples of the diets were analysed for dry matter (DM), crude protein (CP), crude fibre (CF), ether extract (EE), crude ash (CA), starch and sugar according to standard procedures of VDLUFA (2012). Total dietary fibre (TDF), soluble dietary fibre (SDF) and insoluble dietary fibre (IDF) were determined with the ANKOM TDF Fibre Analyzer (method No. AOAC 991.43). Diets were additionally analysed for water binding capacity (WBC) and swelling property (SwP) according to Slama et al. (2019). The particle size distribution was examined according to Rohe et al. (2014).

The metabolizable energy (ME) content was estimated using the equation of the German Society of Nutrition Physiology for compound feed (GfE 2008). For the net energy (NE) content the equation

https://doi.org/10.17221/111/2020-CJAS

Table 2. Average (trial 1 and 2) analysed nutrient content and particle size distribution of the diets (per kg, based on 880 g/kg dry matter)

Feeding phase	Starter		Grower		Finisher	
Nutrient density	low	high	low	high	low	high
Dry matter (g/kg)	889	888	886	887	880	881
Predicted ME (MJ)	11.92	14.05	12.13	14.01	12.31	13.76
Predicted NE (MJ)	8.66	10.66	8.85	10.66	9.10	10.58
Crude ash (g)	48.0	49.9	46.4	45.3	40.8	40.2
Crude protein (g)	164.0	167.4	162.2	158.6	140.4	129.3
Ether extract (g)	18.7	46.3	19.7	40.6	20.8	29.0
Sugar (g)	39.5	36.5	42.3	34.1	43.5	30.7
Starch (g)	387.8	474.1	391.5	498.3	407.4	557.7
Crude fibre (g)	65.5	22.7	60.2	22.7	54.6	23.2
TDF (g)	221.5	110.2	216.1	107.2	234.9	97.4
SDF (g)	25.4	4.8	30.4	4.0	42.7	3.8
IDF (g)	196.1	105.4	185.8	103.2	192.2	93.7
SID lysine (g)	8.75	10.55	7.60	9.40	5.65	7.65
SID methionine + cysteine (g)	5.25	6.20	5.15	5.75	4.25	4.60
SID threonine (g)	5.70	7.15	5.20	6.55	4.30	5.25
SID valine (g)	6.35	6.30	6.30	6.00	5.40	4.85
Ca (g)	5.95	6.95	5.45	6.35	4.60	5.70
Na (g)	1.30	1.70	1.35	1.25	1.30	1.25
P (g)	6.10	6.60	6.05	5.85	5.20	5.25
Digestible P (g)	3.65	3.95	3.65	3.50	3.10	3.15
SID Lys/MJ NE	1.01	0.99	0.86	0.89	0.63	0.72
WBC (ml/g DM)	5.13	3.86	5.95	3.59	5.93	3.69
SwP (%)	201	101	211	80	189	103
Sieving analyses						
> 1 mm (%)	35.3	21.8	27.4	16.4	27.6	16.3
≥ 0.5 – ≤ 1 mm (%)	37.9	45.4	42.4	46.1	42.5	44.5
< 0.5 mm (%)	26.8	32.8	30.2	37.5	29.9	39.2
dMean (mm)	1.18	0.94	1.04	0.84	1.07	0.81

dMean = mean particle size; IDF = insoluble dietary fibre; ME = metabolizable energy (GfE 2008); NE = net energy (Noblet et al. 1994); SDF = soluble dietary fibre; SID = standardized ileal digestible; SID Lys/MJ NE = gram SID lysine per MJ NE; SwP = swelling property; TDF = total dietary fibre; WBC = water binding capacity

published by Noblet et al. (1994) was applied. Amino acids were analysed following the Commission Regulation (EC) No. 152/2009 and the standard ileal digestibility was calculated according to the digestibility values of Sauvant et al. (2004).

Data processing

The individual performance parameters were calculated for each feeding phase and over the whole fattening period. Additionally, besides the common performance parameters daily energy intake (EI) and energy conversion (EC) were calculated. The EI was defined as the total individual energy intake based on the energy content per kg of the applied compound feed and the ADFI. The EC was defined as the weight gain in grams based on one MJ energy intake. The individual feeding duration, feeding frequency and feed intake were calculated for each visit, day and feeding phase. Regarding the feeding behaviour, visits with 10 g or less were

https://doi.org/10.17221/111/2020-CJAS

defined as gambling and were removed from the dataset. According to the interpretation of the "meal duration" in this study it is discussed below using the term "visit" from other studies.

All data were processed in Excel and outliers were removed. Outliers were defined as the values twice higher or lower than the standard deviation of the mean. Further statistical analyses were done by the GLM procedure (general linear model, Statistical Analysis Software v9.4; SAS Institute Inc., NC, USA, 2013). The experimental factors were diet and sex as well as the diet*sex interaction. The factor recapitulation (two trials) acted as co-variable. Using the Tukey-Kramer method the multiple comparisons of least square means were performed. Differences between diets or sex were considered statistically significant at $P < 0.05$ and $P < 0.1$ was considered as trend.

RESULTS

During the entire study no health problems occurred, only 5 animals (LND: 1; FC: 2; HND: 2) without any references to the diet had to be removed from the trial.

In general, the animals selected diets with similar nutrient contents between trial replicates. The ratio between LND and HND in the feed choice group changed from the starter to finisher phase to a higher percentage of HND. The animals chose the ratios between LND and HND diets of 26.2% : 73.8% in the starter, 22.0% : 78.0% in the grower and 20.0% : 80.0% (LND : HND) in the finisher phase, which led to the nutrient contents per kg of selected diet shown in Table 3. There were no differences ($P > 0.1$) in the selected diet compositions (data not shown) between barrows and gilts.

Table 4 presents the zootechnical performance data of the three feeding phases and the whole fattening period. FC and HND improved performance (average daily gain (ADG); gain : feed (G : F) compared to the LND over the whole fattening period ($P < 0.05$).

In the starter phase FC and HND increased ADG, G : F and energy conversion ($EC_{g/MJ\ ME}$) whereas HND had lower $EC_{g/MJ\ NE}$ compared to FC. ADFI was not affected; nevertheless, the energy intake (EI) was enhanced in both FC and HND treatments. In contrast to the starter phase, no differences between treatments were observed for the parameters

Table 3. Calculated nutrient content of the free choice diets (per kg, based on 880 g/kg dry matter)

Nutrient density	Trial 1			Trial 2		
Feeding phase	starter	grower	finisher	starter	grower	finisher
Predicted ME (MJ)	13.5 ± 0.20	13.6 ± 0.16	13.6 ± 0.08	13.5 ± 0.23	13.6 ± 0.15	13.3 ± 0.13
Predicted NE (MJ)	10.1 ± 0.19	10.3 ± 0.15	10.4 ± 0.08	10.1 ± 0.21	10.2 ± 0.14	10.2 ± 0.13
Crude ash (g)	49.7 ± 0.01	45.3 ± 0.00	40.0 ± 0.13	48.9 ± 0.45	45.7 ± 0.18	40.5 ± 0.10
Crude protein (g)	166.7 ± 0.15	158.3 ± 0.47	132.8 ± 0.85	166.2 ± 0.58	160.5 ± 0.11	130.3 ± 0.63
Ether extract (g)	39.2 ± 2.41	36.0 ± 1.77	26.7 ± 0.55	38.1 ± 3.16	36.0 ± 1.62	27.8 ± 0.60
Sugar (g)	39.4 ± 0.02	35.9 ± 0.48	31.8 ± 0.66	35.3 ± 0.66	35.9 ± 0.84	35.0 ± 1.24
Starch (g)	447.1 ± 8.59	476.1 ± 8.82	533.5 ± 8.88	453.8 ± 8.60	473.6 ± 8.49	518.8 ± 12.77
Crude fibre (g)	34.8 ± 4.02	30.0 ± 3.14	27.6 ± 1.62	34.2 ± 4.55	32.2 ± 3.86	32.3 ± 3.04
TDF (g)	145.1 ± 10.26	135.2 ± 8.87	122.4 ± 7.77	137.1 ± 12.64	126.5 ± 8.75	131.6 ± 12.53
SDF (g)	10.3 ± 2.05	9.9 ± 2.12	11.1 ± 2.12	11.0 ± 2.58	9.4 ± 2.10	13.9 ± 3.59
IDF (g)	134.8 ± 8.22	125.3 ± 6.75	111.3 ± 5.47	126.1 ± 10.06	117.1 ± 6.65	117.7 ± 8.94
SID lysine (g)	10.0 ± 0.13	9.1 ± 0.15	7.6 ± 0.11	10.1 ± 0.24	9.0 ± 0.14	6.8 ± 0.17
SID methionine + cysteine (g)	5.6 ± 0.05	5.5 ± 0.04	4.7 ± 0.03	6.1 ± 0.16	5.8 ± 0.06	4.3 ± 0.02
SID threonine (g)	6.8 ± 0.12	6.2 ± 0.10	5.1 ± 0.07	6.7 ± 0.19	6.3 ± 0.12	4.9 ± 0.06
SID valine (g)	6.1 ± 0.03	6.0 ± 0.02	5.0 ± 0.04	6.6 ± 0.03	6.2 ± 0.02	4.9 ± 0.04
SID Lys/MJ NE	0.99 ± 0.01	0.88 ± 0.00	0.74 ± 0.01	1.00 ± 0.01	0.88 ± 0.00	0.67 ± 0.01

IDF = insoluble dietary fibre; ME = metabolizable energy (GfE 2008); NE = net energy (Noble et al. 1994); SDF = soluble dietary fibre; SID = standardized ileal digestible; SID Lys/MJ NE = gram SID lysine per MJ NE; TDF = total dietary fibre

https://doi.org/10.17221/111/2020-CJAS

ADG and $EI_{MJ\ ME/day}$ in the grower phase. However, pigs receiving the LND showed decreased $EI_{MJ\ NE/day}$ compared to HND and FC as well as increased ADFI ($P < 0.05$), leading to declined G : F and increased $EC_{g/MJ\ NE}$ ($P < 0.05$).

In the finisher phase, pigs consuming the high energy diets (FC and HND) showed increased ADG, $EI_{MJ\ NE/day}$ and improved G : F as well as $EC_{g/MJ\ ME}$ ($P < 0.05$).

Sexual dimorphism developed in the grower phase (Table 4) and resulted in increased ADG, ADFI as well as EI and decreased G : F for barrows compared to gilts ($P < 0.05$).

This observation persisted during the finisher phase and was also detected when calculating the whole fattening phase. In the finisher phase an interaction between diet and sex for the parameters EI, G : F and EC was observed ($P < 0.05$). Barrows fed the HND and FC diet showed increased EI compared to gilts. However, only barrows receiving the HND declined G : F and EC (data not shown).

Table 4. Effect of the nutrient density and sex on zootechnical performance

	Diet			Sex		SEM	*P*-value		
	LND	FC	HND	♂	♀		diet	sex	diet*sex
Starter									
ADG (g)	790[b]	966[a]	946[a]	913	888	13.2	< 0.000 1	0.317 1	0.777 9
ADFI (g)	1 587	1 593	1 637	1639	1 572	26.0	0.754 9	0.240 8	0.867 5
EI (MJ ME/day)	19.00[b]	21.34[a]	22.57[a]	21.31	20.63	0.36	0.001 8	0.358 9	0.534 4
EI (MJ NE/day)	13.81[b]	16.03[a]	17.12[a]	15.89	15.41	0.28	< 0.000 1	0.381 5	0.548 0
G : F (g/kg)	489[b]	596[a]	588[a]	552	556	5.5	< 0.000 1	0.899 9	0.849 8
EC (g/MJ ME)	41.0[b]	44.7[a]	41.9[a]	42.6	42.4	0.40	0.002 2	0.841 4	0.950 6
EC (g/MJ NE)	56.5[ab]	59.5[a]	55.19[b]	57.1	56.9	0.54	0.009 8	0.821 2	0.953 2
Grower									
ADG (g)	910	914	921	945	885	9.2	0.902 2	0.001 9	0.878 4
ADFI (g)	2 523[a]	2 390[ab]	2 295[b]	2 588	2 217	32.0	0.017 4	< 0.000 1	0.408 8
EI (MJ ME/day)	30.58	32.44	32.13	34.07	29.37	0.41	0.103 7	< 0.000 1	0.393 7
EI (MJ NE/day)	22.31[b]	24.50[a]	24.46[a]	25.51	22.00	0.31	0.003 2	< 0.000 1	0.434 1
G : F (g/kg)	357[b]	378[a]	399[a]	365	391	3.7	0.000 2	0.000 5	0.323 1
EC (g/MJ ME)	29.4[(a)]	28.0[(b)]	28.7[(ab)]	27.6	29.8	0.31	0.073 7	0.000 1	0.547 9
EC (g/MJ NE)	40.3[a]	37.0[b]	37.7[b]	36.9	39.7	0.40	0.001 1	0.000 2	0.571 9
Finisher									
ADG (g)	747[b]	862[a]	845[a]	841	795	10.6	< 0.000 1	0.024 2	0.848 5
ADFI (g)	2 857[(a)]	2 686[(ab)]	2 647[(b)]	2 900	2 560	39.0	0.072 1	< 0.000 1	0.093 6
EI (MJ ME/day)	34.95	36.00	36.53	38.2	33.45	0.49	0.414 3	< 0.000 1	0.011 0
EI (MJ NE/day)	25.82[b]	27.50[a]	28.09[a]	28.94	25.32	0.38	0.039 0	< 0.000 1	0.008 9
G : F (g/kg)	258[b]	317[a]	324[a]	289	306	4.1	< 0.000 1	0.025 0	0.018 8
EC (g/MJ ME)	21.0[b]	23.8[a]	23.7[a]	22.1	23.4	0.18	< 0.000 1	0.019 4	0.022 8
EC (g/MJ NE)	28.4[b]	31.1[a]	30.9[ab]	29.2	30.9	0.25	0.003 9	0.022 0	0.016 3
Total									
ADG (g)	816[b]	914[a]	909[a]	905	854	8.4	< 0.000 1	0.001 4	0.748 0
ADFI (g)	2 401	2 307	2 244	2 437	2 198	28.0	0.110 8	< 0.000 1	0.506 3
G : F (g/kg)	343[b]	392[a]	407[a]	370	388	3.7	< 0.000 1	0.019 9	0.587 6

ADFI = average daily feed intake; ADG = average daily gain; EC = energy conversion; EI = energy intake; FC = feed choice; G : F = gain to feed; HND = high nutrient density; LND = low nutrient density; SEM = standard error of means

[a,b]Mean values within a row without common superscript differ ($P < 0.05$); [(a,b)]Mean values within a row without common superscript tend to differ ($P < 0.1$)

https://doi.org/10.17221/111/2020-CJAS

Table 5. Effect of nutrient density and sex on the feeding behaviour

		Feed choice			Sex		SEM	*P*-value		
	LND	LND	HND	HND	♂	♀		diet	sex	diet*sex
Starter										
n meals/day	24.4^{b}	(8.0[1]) 23.8^{b} (15.8[2])		28.3^{a}	26.6	24.4	0.7	0.019 4	0.118 1	0.660 1
g/meal	60.7^{ab}	51.4^{c}	70.0^{a}	54.4^{bc}	62.4	55.8	1.3	< 0.000 1	0.010 5	0.418 6
g/min	13.3^{c}	15.6^{b}	17.5^{a}	15.8^{ab}	15.6	15.5	0.3	< 0.000 1	0.918 5	0.865 2
t/visit (min)	4.62^{a}	3.52^{c}	4.25^{ab}	3.72^{bc}	4.20	3.83	0.09	0.000 1	0.047 7	0.138 0
t/day (min)	109^{a}	(27.5) 94^{b} (66.5)		100^{ab}	103	99	1.9	0.003 8	0.368 6	0.964 3
Grower										
n meals/day	30.3	(8.1) 26.3 (18.2)		30.1	29.0	28.8	0.9	0.081 7	0.883 4	0.641 1
g/meal	84.2^{b}	60.6^{c}	101.6^{a}	73.6^{bc}	86.5	73.5	2.3	< 0.000 1	0.001 8	0.799 7
g/min	19.5^{b}	23.6^{a}	24.5^{a}	21.5^{ab}	22.7	21.8	0.4	0.000 4	0.341 0	0.894 4
t/visit (min)	4.50^{a}	2.77^{c}	4.40^{a}	3.55^{b}	3.99	3.58	0.12	< 0.000 1	0.068 4	0.435 0
t/day (min)	124^{a}	(22.9) 98^{b} (75.1)		105^{b}	114	104	2.0	< 0.000 1	0.009 9	0.541 3
Finisher										
n meals/day	31.8$^{(a)}$	(8.8) 26.1$^{(b)}$ 17.3)		27.8$^{(ab)}$	27.0	30.0	1.0	0.0770	0.1640	0.9626
g/meal	87.8^{b}	67.8^{c}	114.3^{a}	101.7^{ab}	102.0	83.8	2.9	< 0.0001	0.0005	0.8747
g/min	24.3^{b}	27.0^{ab}	29.5^{a}	26.5^{ab}	27.6	26.0	0.5	0.0059	0.1322	0.9696
t/visit (min)	3.72^{a}	2.63^{b}	4.18^{a}	3.78^{a}	3.77	3.40	0.11	< 0.0001	0.0642	0.6234
t/day (min)	119^{a}	(19.5) 91^{b} (71.5)		99^{b}	108	98	2.4	< 0.0001	0.0328	0.9023
Total										
n meals/day	29.9^{a}	(8.1) 25.8^{b} (17.7)		29.7^{a}	27.70	29.20	0.8	0.042 4	0.363 0	0.629 3
g/meal	78.8^{b}	60.1^{c}	97.1^{a}	74.0^{b}	82.7	72.2	2.0	< 0.000 1	0.002 0	0.630 8
g/min	19.5^{b}	21.6^{b}	24.5^{a}	21.7^{ab}	22.3	21.4	0.4	< 0.000 1	0.229 7	0.946 7
t/visit (min)	4.30^{a}	2.85^{c}	4.13^{a}	3.55^{b}	3.90	3.52	0.10	< 0.000 1	0.036 4	0.672 3
t/day (min)	119^{a}	(22.3) 93^{b} (70.7)		101^{b}	108	101	2.1	< 0.000 1	0.077 8	0.538 2

g/meal = amount of feed (g) per visit; g/min = amount of feed (g) per min; HND = high nutrient density; LND = low nutrient density; n meals/day = number of daily visits to the feeder; SEM = standard error of means; t/day = feeder occupation time per day in minutes; t/visit = feeder occupation time per visit in minutes

[1]daily visits or daily feeder occupation time in the feed choice group at the LND feeder; [2]daily visits or daily feeder occupation time in the feed choice group at the HND feeder; [a,b]Mean values within a row without a common superscript differ ($P < 0.05$); [(a,b)]Mean values within a row without common superscript tend to differ ($P < 0.1$)

The results of the feeding behaviour are shown in Table 5. Pigs of the LND and FC treatment consumed fewer meals per day compared to HND in the starter phase ($P < 0.05$). This effect changed to the opposite in the finisher phase when pigs receiving the LND diet trended to a higher amount of meals per day compared to the FC treatment ($P < 0.1$).

In all phases except the starter phase pigs fed the LND diet spent more time per day at the feeder ($P < 0.05$). The time per visit for feed intake compared to pigs receiving the HND diet, except in the finisher phase, also increased in LND compared to HND ($P < 0.05$). Interestingly, in the FC group contrary results were observed. The FC pigs spent more time per visit during the consumption of the HND diet. Only the FC treatment showed an enhanced consumption of the HND diet per meal. This effect disappeared when pigs were not allowed to choose the feed. Hence, no difference between LND and HND regarding the feed amount per meal was recorded ($P > 0.1$).

Male pigs showed higher ($P < 0.05$) feed consumption and time per meal than female pigs over the whole trial. No interaction between diet and sex was detected ($P > 0.05$).

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DISCUSSION

Feed choice

The results of the present study show that the chosen energy content (10.1–10.3 MJ NE per kg fresh matter) of the feed choice group was in line with the recommended energy levels of the selected nutrition societies for modern pig genetics (GfE 2008; NRC 2012). Similarly to McLaughlin et al. (1983), pigs chose higher amounts of LND in the first few hours after changing the diet in the feeder. However, after a short adaptation the ratio between LND and HND diet was kept constant until the next change of the feed in the feeder, indicating the animal's priority for an adequate nutrient supply. Similar results were observed by other authors [Ferguson et al. (1999), 5.9% : 94.1% (LND : HND); Orr (1980), 19% : 81% (LND : HND) and Ettle and Roth (2009), 18% : 82% (LND : HND)]. The higher proportion of HND in feed intake in the study of Ferguson et al. (1999) seems explainable by the lower lysine content in the diets.

Fattening performance

The ADG in the starter and grower phase was higher as estimated by the NRC (2012). This can be related to different genetics and to the higher amount of essential amino acids per kg feed applied in the present study. The ADFI of the FC and HND group was in line with the expectations of the NRC (2012). Pigs fed a diet low in energy and nutrients can increase their feed intake to satisfy their requirements until a certain point, where the physical satiety is reached (Beaulieu et al. 2009). Such a nutrient compensating instinct is well described in literature for various nutrients (Kyriazakis et al. 1990; Ettle and Roth 2009; Quiniou and Noblet 2012). However, in the present study the enhanced ADFI of the pigs receiving the LND diet could not compensate the lack of energy and nutrient intake. Tybirk (1989) showed that the gut capacity is a limiting factor in growing pigs. Pigs receiving a diet with 13.0 MJ ME/kg could cover their energy requirement at 40 kg body weight, whereas pigs receiving a diet with 12.0 MJ ME/kg cover their energy requirement at 60 kg body weight. These results can be supported by the present study, as pigs of LND (receiving a diet with 12.1 MJ/ME or 8.9 MJ/NE) were able to cover their energy requirement during the grower phase (55.6–90.0 kg). The lower ADG observed in the starter phase of the LND treatment can be explained by the fact that the piglets were fed the same diet until the start of the study and consequently the pigs were not able to compensate the lack of energy through higher feed intake (Castillo et al. 2007). Kyriazakis and Emmans (1995) reported that after switching to a diet with higher bulk content the feed intake will be reduced and after an adaption phase of 7 to 14 days it will increase successively, which can be confirmed by the present study.

In general, enhanced ADFI is directly associated with increased ADG (Schedle et al. 2008). However, in the present study, the contrasting results can be related to the reduced digestibility of the diet due to the high DF content (Noblet and Le Goff 2001). LND declined the G : F ratio, which is in line with studies reducing the energy content of the diet (Ettle and Roth 2009; Quiniou and Noblet 2012). Similar results were observed for the EC in the finisher phase of the present study. Contrary results were determined by the parameter EC in the starter phase, when no differences between LND and HND were observed, and in the grower phase, when LND improved EC compared to HND. Also Quiniou and Noblet (2012) showed declined G : F with decreasing dietary energy content by constant EC. The differences observed in the present study could be a result of using the equation of compound feed for ME estimation (Noblet et al. 1994; GfE 2008), which overestimates the fibre digestibility. Nevertheless, the present results confirm that pigs can adjust their energy demand over a wide range of energy concentration by adapting their feed intake.

In the starter phase no differences regarding performance parameters between barrows and gilts were observed. This is in line with the NRC (2012), where no differences between barrows and gilts with less than 50 kg body weight were considered. The well-described sexual dimorphism (de Haer and de Vries 1993a; NRC 2012) of increased ADG, ADFI, and daily EI as well as declined G : F in barrows compared to gilts developed in the grower phase in the present study. The formulation of diets covering the nutrient requirements of livestock, without oversupplying nutrients, is a strategy for sustainable animal nutrition (Schedle 2016). Hence, the present study supports that sexual dimorphism should be con-

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sidered for the precise and hence sustainable diet calculation at a specific body weight, however not for the energy content of the diet.

Feeding behaviour

Results of the feeding behaviour trials are widespread in literature. Hyun et al. (1997) reported fewer but longer and greater meals with lower total consumption time. Bigelow and Houpt (1988) showed a comparable daily total consumption time. The time for a visit was similar to Labroue et al. (1994) and de Haer and de Vries (1993a) but they had lower amounts of meals and daily feeder occupation time as well as a higher rate of feed intake. In contrast to the studies above, barrows in the present study consumed greater meals for a longer time (higher daily feeder occupation) than gilts in all stages of age. Kallabis and Kaufmann (2012) found also differences in higher amounts of fibre and fewer meals in the starter phase, whereas compared to them this effect could not be determined in the finisher phase of the present study.

Regarding the daily feeder occupation time, the present study is in line with Laitat et al. (2015) and Ramonet et al. (1999) where a higher amount of dietary fibre led to longer daily feeding duration with a reduced ingestion rate.

In studies assessing group housing and individual housing the individually housed pigs showed lower feed intake per visit, shorter but more visits and a higher daily feeder occupation time compared to group housed pigs (de Haer and Merks 1992; de Haer and de Vries 1993b). In the present study one feeder was for five animals in the LND and HND group, whereas two feeders for 10 animals in the FC group. In the discussed studies the animal to feeder ratio was higher [9 to 14 in Labroue et al. (1994); 8 in de Haer and de Vries (1993b) and de Haer and Merks (1992); 15 in Hyun et al. (1997)].

Hence, the results of the present study seem to explain the greater meal size and longer visits of the HND group and the reduced total daily feeding time compared to LND resulting from the preference of the HND feeder in the FC group. The animal density for the HND feeder was virtually higher indicating the importance of the animal to feeder ratio on feeding behaviour.

In accordance with the studies of de Haer and de Vries (1993a) and de Haer and de Vries (1993b) the present study showed that gilts had lower intake per visit and lower total daily feeder occupation time. However, the higher amount of meals per day could not be confirmed in the present study. A possible explanation for these differences could be that barrows and not boars were used in the present study (Labroue et al. 1994). In contrast to the studies above, there was no statistical difference between barrows and gilts within the FC group concerning the amount per visit and the time at the feeder. So, given the possibility of choosing the optimal diet, pigs show the same feeding behaviour.

CONCLUSION

The results demonstrate that pigs of modern genetics still have the ability to cover their energy and nutrient requirements choosing between diets differing in nutrient density without impairing performance. Even until a certain point of diluting the diet with DF, pigs can compensate their nutrient requirement by increasing ADFI, as occurred in LND. As expected, the pigs of FC preferred HND to achieve their genetic performance potential. However, pigs limited their feed intake of HND to approximately 80%, complementing their daily meal with LND, probably to fulfil a certain requirement of fibre in the diet.

Interestingly, regarding the feeding behaviour similar results for HND and LND but differences within the FC led to the assumption that besides the nutrient density also the animal to feeder ratio could have an effect on the feeding behaviour. The sexual dimorphism did not affect the chosen diet composition in any stage of growth, indicating no need for different energy contents in diets for sexed pigs.

Conflict of interest

The authors declare no conflict of interest.

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