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Influence of crude protein content, ingredient complexity, feed form, and duration of feeding of the Phase I diets on productive performance and nutrient digestibility of Iberian pigs[1,2]

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ABSTRACT: The influence of CP content and ingredient complexity, feed form, and duration of feeding of the Phase I diets on growth performance and total tract apparent digestibility (TTAD) of energy and nutrients was studied in Iberian pigs weaned at 28 d of age. There were 12 dietary treatments with 2 type of feeds (high-quality, HQ; and low-quality, LQ), 2 feed forms (pellets vs. mash), and 3 durations (7, 14, and 21 d) of supply of the Phase I diets. From d 7, 14, or 21 (depending on treatment) to d 35, all pigs received a common diet in mash form. Each treatment was replicated 3 times (6 pigs/pen). For the entire experiment, ADG ($P < 0.05$) and ADFI ($P < 0.01$) were less with the HQ than the LQ Phase I diets, but G:F was not affected. Pelleting of the Phase I diets did not affect ADG but improved G:F ($P < 0.01$). Feeding the Phase I diets from d 0 to 21 improved G:F ($P < 0.05$) but decreased ADG ($P < 0.01$) as compared with 7 or 14 d of feeding. Postweaning diarrhea (PWD) tended to be greater ($P = 0.06$) for pigs fed the HQ diets than pigs fed the LQ diets and pigs fed pellets than those fed mash ($P < 0.001$). Also, PWD was greater for pigs fed the Phase I diet for 14 or 21 d than those fed the diet for 7 d ($P < 0.01$). From d 0 to 21, ADG and G:F were not affected ($P > 0.10$) by feed quality, but feeding pellets or increasing the duration of feeding the Phase I diets improved G:F ($P < 0.01$). Also, in this period, PWD was greater with pellets than with mash and for pigs fed the Phase I diets for 14 or 21 d than for pigs fed the diet for only 7 d ($P < 0.01$). From d 21 to 35, pigs previously fed the LQ diet had greater ADG than pigs fed the HQ Phase I diets ($P < 0.001$). Also, pigs fed the Phase I diets for 21 d had decreased ADG ($P < 0.05$) and ADFI ($P < 0.001$) and reduced G:F ($P < 0.05$) than pigs fed these diets for 7 or 14 d. Organic matter digestibility was greater for pigs fed the HQ Phase I diets than pigs fed the LQ Phase I diets ($P < 0.05$). Pelleting improved TTAD of all nutrients ($P < 0.01$). It is concluded that HQ Phase I diets increased TTAD of nutrients but not feed efficiency of Iberian pigs from d 0 to 35. Also, pelleting improved energy and nutrient digestibility and feed efficiency. Increasing the duration of supply of the Phase I diets from 7 to 21 d improved feed efficiency but reduced ADG. Therefore, the use of LQ Phase I diets in pellet form for no more than 7 d after weaning is recommended in Iberian pigs.

Key words: diet complexity, growth performance, Iberian pig, nutrient digestibility, pelleting

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INTRODUCTION

The Iberian pig is an ancestral dark-haired breed with economical relevance in Spain and Portugal (Serrano et al., 2009a). Iberian pigs deposit more fat in the carcass and have a slower growth rate than conventional white pigs, therefore, their AA requirements are reduced (Nieto et al., 2003; Barea et al., 2011). In addition, Iberian pigs reared indoors

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have to be slaughtered after a minimum of 10 mo of age (BOE, 2007a; Serrano et al., 2009b), reducing the need to accelerate growth at early ages. Therefore, the need to use high-quality ingredients and high levels of CP are probably less in Iberian pigs than in conventional white pigs. Unfortunately, the information available on the nutrient requirements of Iberian pigs after weaning is very limited and, in practice commercial, nutrient specifications for Iberian piglets are often based on published requirements for conventional white pigs.

Feeding pellets usually results in improved feed efficiency (Medel et al., 2004). However, postweaning diarrhea (**PWD**) is usually greater with pelleted feed than with mash (Pluske et al., 2002), and, consequently, many pig producers prefer to use feeds in mash form. Feeding high-protein diets to pigs after weaning usually results in increased ADFI, but also in greater incidence of PWD, probably because of the negative effects of an excess of protein on microbial growth in the lower part of the gastrointestinal tract (**GIT**; Hermes et al., 2009). However, no data are available on the influence of feed quality and duration of feeding of Phase I diets on growth performance of Iberian pigs after weaning. The hypothesis of this research was that a reduction in the CP of the diet, together with the limitation of high-quality ingredients and duration of the supply of the Phase I diets, could result in similar or even better growth performance in Iberian pigs. The aim of this study was to investigate the effects of ingredient quality, feed form, and duration of supply of the Phase I diets on growth performance and nutrient digestibility of Iberian pigs weaned at 28 d of age.

MATERIALS AND METHODS

The experimental procedures described in this research were approved by the Animal Ethics Committee of Universidad Politécnica de Madrid, and were in compliance with the Spanish guidelines for the care and use of animals in research (BOE, 2007b).

Pig Husbandry, Diets, and Experimental Design

In total, 216 crossbred pigs (Iberian females × Duroc males) were obtained at weaning (28 ± 3 d of age and 6.9 ± 0.15 kg BW) from a commercial farm (Juan Jiménez, S.A.U., Murcia, Spain). After arrival to the experimental station, pigs were individually weighed and allotted in groups of 6 to 36 flat-deck pens (1.60 × 1.10 m), with an individual feeder and a nipple drinker. All pens had similar average BW and equal number of barrows and gilts. The pigs were kept on a 20 h/d light program, and had free access to feed and water throughout the experiment. The environmental conditions of the barn were controlled automatically according to the age of the pigs. Room temperature was maintained at 30 ± 1.5°C for the first week of the experiment, and then reduced 2°C per week until reaching 22°C. Pigs that showed signs of diarrhea, as assessed by veterinarian inspection, were treated via intramuscular injection (0.4 mL/10 kg BW of Excenel, Ceftiofur chlorhydrate; Pfizer S.A., Madrid, Spain) for 3 consecutive days.

Two Phase I diets with similar NE content (2580 kcal/kg) but differing in CP (20.5 vs. 18.5% CP), standardized ileal digestible (**SID**) AA (1.39 vs. 1.11% Lys), and percentage of inclusion of high-quality ingredients (heat-processed corn, soy protein concentrate, fish meal, and dried whey) were formulated. The SID Lys to NE ratio was 5.38 and 4.37 for the high-quality (**HQ**) and low-quality (**LQ**) Phase I diets, respectively. All of the remaining indispensable AA were formulated according to the ideal protein concept as proposed by De Blas et al. (2006). A source of AIA (Celite, acid-washed diatomaceous earth; Celite Hispánica S.A., Alicante, Spain) was included at 1% to all diets. No antibiotics or growth promoter additives, other than copper sulfate (160 mg/kg), were included in these diets. Each batch of the 2 Phase I diets (HQ and LQ diets) were divided into 2 portions. The first portion was fed in mash form, whereas the second portion was steam-pelleted (72 ± 2°C; Model 508–150, Mabrik, Barcelona, Spain) and passed through a 2.5-mm-diameter die. The temperature of the pellets at the exit of the press was 60 to 65°C. The pigs fed the Phase I diets for 7, 14, or 21 d and received a common commercial Phase II diet in mash form for 28, 21, or 14 d, respectively. The ingredient composition, calculated nutrient content (De Blas et al., 2010), and determined chemical analyses of the Phase I and Phase II diets are shown in Table 1.

The experiment was completely randomized, with 12 dietary treatments in a factorial arrangement with 2 feed qualities (HQ vs. LQ), 2 feed forms (pellets vs. mash), and 3 lengths of supply (7, 14, or 21 d) of the Phase I diets. Each treatment was replicated 3 times, and the experimental unit for all measurements was the individual pen.

Measurements and Laboratory Analysis

Pigs were weighed individually at 0, 7, 14, 21, 28, and 35 d of the experiment, and feed intake was measured per pen at the same ages. Feed wastage was collected daily from pans placed beneath the feeders and mortality was recorded. From these data, ADG, ADFI, and G:F were calculated by week, feeding period (d 0 to 21 and d 21 to 35), and cumulatively (d 0 to 35). The PWD index was estimated by pen as the proportion of days, in which pigs showed clinical signs of diarrhea

Table 1. Ingredient composition and calculated and determined analysis (% as-fed basis, unless otherwise indicated) of the experimental diets

Item	Phase I diets High quality	Phase I diets Low quality	Phase II diet
Ingredient, %			
Barley	5.0	10.0	31.0
Corn	10.0	25.0	12.0
Wheat	12.0	12.0	35.0
Heat-processed corn[1]	30.0	15.0	–
Fullfat soybeans	8.0	4.0	–
Soybean meal,[2] 47% CP	5.1	16.0	14.6
Soy protein concentrate,[3] 64% CP	4.0	–	–
Fish meal, 67% CP	8.0	4.0	1.3
Dried whey	12.0	6.0	–
Lard	2.3	3.8	2.6
Calcium carbonate	0.14	0.36	1.14
Monocalcium phosphate	0.47	1.01	0.94
NaCl	0.10	0.29	0.40
Choline chloride, 78%	–	–	0.03
L-Lys·HCl, 78%	0.44	0.35	0.53
DL-Met, 99%	0.20	0.14	0.10
L-Thr, 98%	0.20	0.13	0.12
L-Trp, 98%	0.08	0.04	0.01
L-Val, 96.5%	0.14	0.05	–
Formic acid, 70.7%	0.60	0.60	–
Celite[4]	1.00	1.00	–
Vitamin and mineral premix[5]	0.23	0.23	0.23
Calculated analysis[6]			
NE, kcal/kg	2580	2580	2435
CP	20.5	18.5	16.9
Ether extract	6.6	7.1	4.7
Crude fiber	2.4	2.6	3.3
Lactose	8.4	4.2	–
Lys	1.51	1.21	1.12
Standardized ileal digestibility			
Ile	0.79	0.65	0.58
Lys	1.39	1.11	1.02
Met	0.43	0.35	0.31
Met + Cys	0.81	0.63	0.58
Thr	0.86	0.69	0.61
Val	0.99	0.77	0.69
Ca	0.60	0.60	0.73
Cl	0.50	0.44	0.44
Na	0.23	0.21	0.18
Total P	0.67	0.67	0.57
Digestible P	0.40	0.40	0.31
Determined analyses[7]			
DM	90.8	90.3	89.0
GE, kcal/kg	4247	4179	4031
CP	20.7	18.1	16.7
Lys	1.50	1.19	NA[8]
Total ash	5.9	5.6	4.6

[1]The heat-processed corn was steam-cooked for 60 min (15 min at 90°C, 10 min at 117°C, and then settled for 35 min), cooled, dried (15 min at 140°C), and milled through a hammer mill (2.5-mm screen) before been included in the diets.

[2]Contained by analysis: 6.1% sucrose and 7.0% oligosaccharides (stachyose and raffinose). The trypsin inhibitor activity was 2.5 mg/g, the KOH solubility was 81.2%, and the protein dispersibility index was 16.2%.

[3]Contained by analysis: 0.60% sucrose and 0.61% oligosaccharides (stachyose and raffinose). The trypsin inhibitor activity was 1.1 mg/g, the KOH solubility was 66.5%, and the protein dispersibility index was 6.9%.

[4]Acid-washed diatomaceous earth (Celite Hispánica S.A., Alicante, Spain).

[5]Provided the following (per kilogram of diet): vitamin A (trans-retinyl acetate), 9000 IU; vitamin D_3 (cholecalciferol), 1750 IU; vitamin E (all-*rac*-tocopherol-acetate), 30 mg; vitamin K_3 (bisulfate menadione complex), 1.7 mg; riboflavin, 4 mg; pantothenic acid (d-Ca pantothenate), 12 mg; nicotinic acid, 20 mg; pyridoxine (pyridoxine·HCl), 2 mg; thiamin (thiamine mononitrate), 1.6 mg; vitamin B_{12} (cyanocobalamin), 0.025 mg; D-biotin, 0.1 mg; Se (Na_2SeO_3), 0.3 mg; I (KI), 0.7 mg; Cu ($CuSO_4.5H_2O$), 150 mg; Fe ($FeSO_4 \cdot 7H_2O$), 85 mg; Mn ($MnSO_4 \cdot H_2O$), 40 mg; and Zn (ZnO), 105 mg.

[6]According to De Blas et al., (2010).

[7]In duplicate. Data correspond to the diets fed in mash form.

[8]Not analyzed.

symptoms with respect to total number of days on trial as indicated by Mateos et al. (2006). At d 4, 11, and 18 of the experiment, representative samples (300 g) of feces were collected by rectal massage from at least 3 pigs from each of the 3 pen replicates that were fed the Phase I diets from d 0 to 21. Fecal samples were homogenized, and representative aliquots (50 g) were dried at 70°C for 48 h and stored at –20°C until chemical analysis.

Ingredients, feeds, and feces were ground with a laboratory mill (Retsch Model Z-I, Stuttgart, Germany) equiped with a 1-mm screen and analyzed for moisture by oven-drying (method 930.15), total ash by muffle furnace (method 942.05), and nitrogen by Dumas (Method 968.06; Leco Analyzer, Model FP-528; Leco Corp., St. Joseph, MI; AOAC, 2000). Gross energy was determined using an adiabatic bomb calorimeter (Model 1356; Parr Instrument Company, Moline, IL). The AA content of the Phase I diets was determined by ion-exchange chromatography (Hewlett-Packard 1100, Waldbronn, Germany) after acid hydrolysis, as indicated by De Coca-Sinova et al. (2008). Tryptophan was not determined. The AIA content of the Phase I diets and feces was determined as indicated by De Coca-Sinova et al. (2011). All analyses were conducted in duplicate, except for the AIA content of the diets that were determined in triplicate. The total tract apparent digestibility (**TTAD**) of DM, OM, GE, and CP of the Phase I diets were determined at d 4, 11, and 18 of the experiment as indicated by Medel et al. (1999).

Statistical Analysis

Data on growth performance and nutrient digestibility were analyzed as a completely randomized design with feed quality, feed form, duration of supply of the Phase I diets, and their interactions as main effects using the GLM procedure (SAS Inst. Inc., Cary, NC). The individual pen represented the experimental unit for all measurements. When significant differences among treatments were observed, means were separated using the Tukey test. Data on PWD index were not normal, and therefore the logistic analyses of CATMOD procedure of SAS were used. All differences were considered significant at $P < 0.05$, and P values between 0.05 and 0.10 were considered a trend. Because the number of replicates per treatment was small ($n = 3$; 6 pigs per replicate), the model might not be adequate to detect significant differences for the 3-way interactions for nutrient digestibility and growth performance traits from d 14 to 35 of the experiment.

RESULTS

Growth Performance and Postweaning Diarrhea

The energy and nutrient contents of the experimental diets were similar to expected values, indicating that the ingredients were mixed correctly (Table 1). Average mortality was 1.9% and was not related to treatment (data not shown). No interactions among main factors were found for any of the traits studied, and therefore only main effects are presented. Feed quality, feed form, and duration of feeding of the Phase I diets had effects on growth performance and PWD index throughout the experiment (Tables 2 and 3).

Crude Protein Content and Ingredient Complexity of the Phase I Diets

From d 0 to 7, piglets fed the HQ Phase I diets had similar ADG but better G:F ($P < 0.05$) than piglets fed the LQ Phase I diets. However, from d 7 to 14, feed quality did not affect any growth performance trait. Moreover, from d 14 to 21, piglets fed the LQ Phase I diets had greater ADG ($P = 0.08$) and ADFI ($P < 0.01$) than pigs fed the HQ diets. Consequently, from d 0 to 21, pigs fed the LQ Phase I diets had greater ADFI ($P < 0.05$) than pigs fed the HQ Phase I diets, but no effects were observed for ADG or G:F. From d 21 to 28, a period in which all pigs received the Phase II diet, pigs previously fed the LQ Phase I diets had greater ADG ($P < 0.05$) and ADFI ($P < 0.001$) than pigs fed the HQ diets, but no effects were detected for G:F. Similar results were observed from d 28 to 35. Consequently, in Phase II (d 21 to d 35 of the experiment), pigs previously fed the LQ Phase I diets had greater ADG ($P < 0.001$) and ADFI ($P < 0.001$) than pigs fed the HQ diets. Cumulatively (d 0 to 35 of the experiment), ADFI ($P < 0.01$) and ADG ($P < 0.05$) were greater for pigs previously fed the LQ Phase I diets than for pigs fed the HQ Phase I diets, but G:F was not affected.

From d 0 to 21, pigs fed the HQ Phase I diets tended to have greater PWD index than pigs fed the LQ diets ($P = 0.08$) with most of the differences occurring from d 7 to 14. Cumulatively (d 0 to 35), PWD index tended to be greater ($P = 0.06$) in pigs fed the HQ Phase I diets than in pigs fed the LQ Phase I diets.

Feed Form of the Phase I Diets

From d 0 to 7 of the experiment, pigs fed pellets tended to have decreased ADFI ($P = 0.07$) and had better G:F ($P < 0.001$) than piglets fed mash. Similarly, from d 7 to 14, pelleting of the Phase I diets reduced ADFI ($P < 0.05$) but improved G:F ($P < 0.01$). From d 14 to 21, no effects of feed form on growth performance were observed. From d 0 to 21, pigs fed pellets tended to have lower ADFI ($P = 0.05$) and had better G:F ($P < 0.01$) than piglets fed mash, but ADG was not affected. In Phase II (d 21 to 35), when all pigs were fed a common mash diet, growth performance was not affected by form of the Phase I diets. Consequently, for the entire experimental period (d 0 to 35), pelleting of the Phase I diets tended to reduce ADFI ($P = 0.05$) and improved G:F ($P < 0.01$) but no effects on ADG were detected.

From d 0 to 21 of the experiment, pelleting increased PWD index ($P < 0.001$) with effects being more evident from d 7 to 14 ($P < 0.001$) than from d 14 to 21 ($P < 0.05$). Also, for the entire experimental period (d 0 to 35), pelleting of the Phase I diets increased PWD ($P < 0.001$).

Duration of Feeding of the Phase I Diets

From d 7 to 14, pigs that were fed the Phase I diets continuously (d 0 to 14) had greater ADG ($P < 0.05$) and better G:F ($P < 0.05$) than pigs that were fed the Phase I diets for only 7 d. However, from d 14 to 21, an increase in the duration of feeding of the Phase I diets from 7 or 14 to 21 d reduced ADFI ($P < 0.001$). Also, in this period, ADG was greater for pigs fed the Phase I diets for 7 or 21 d than for pigs fed this diet for 14 d ($P < 0.05$). Consequently, G:F was improved in pigs fed the Phase I diets for 21 d as compared with pigs fed these diets for 7 d, and for both, better ($P < 0.001$) than for pigs fed these diets for 14 d. From d 0 to 21, pigs fed the Phase I diets for 21 d had similar ADG but reduced ADFI ($P < 0.05$) and greater G:F ($P < 0.001$) than pigs fed these diets for only 7 or 14 d. From d 21 to 28, a period in which all pigs were fed the common Phase II diet in

Table 2. Influence of quality, form, and duration of feeding of the Phase I diets on growth performance and postweaning diarrhea (PWD) of piglets from d 0 to 21 of the experiment[1]

	Feed quality		SE	Feed form		SE	Duration of feeding[2]				*P*-value[4]		
Item	High	Low	(*n* = 18)	Pellet	Mash	(*n* = 18)	7 d	14 d	21 d	SE[3]	Quality	Form	Duration
Phase I													
d 0 to 7													
ADG, g	270	258	15	267	261	15	270	270	252	19	0.558	0.813	0.740
ADFI, g	288	308	15	278	319	15	301	295	298	19	0.377	0.070	0.980
G:F	0.94	0.84	0.03	0.96	0.82	0.03	0.90	0.92	0.85	0.03	0.024	<0.001	0.195
PWD[5]	11.1	11.6		11.2	11.5		10.7	12.1	11.3		0.745	0.870	0.784
d 7 to 14													
ADG, g	332	362	13	353	342	13	313^{b}	378^{a}	352^{a}	16	0.121	0.555	0.031
ADFI, g	480	522	17	474	527	17	504	527	471	21	0.100	0.042	0.185
G:F	0.69	0.69	0.02	0.74	0.65	0.02	0.62^{b}	0.72^{a}	0.75^{a}	0.03	0.583	0.006	0.011
PWD	18.1	14.4		19.7	12.8		12.9^{b}	18.1^{a}	17.9^{a}		0.044	<0.001	0.039
d 14 to 21													
ADG, g	416	457	16	434	440	16	468^{a}	386^{b}	456^{a}	19	0.082	0.810	0.013
ADFI, g	716	783	17	737	762	17	792^{a}	806^{a}	651^{b}	21	0.009	0.315	<0.001
G:F	0.58	0.58	0.01	0.59	0.58	0.01	0.59^{b}	0.48^{c}	0.70^{a}	0.02	0.957	0.426	<0.001
PWD	12.0	9.9		12.7	9.3		8.1^{b}	12.3^{a}	12.5^{a}		0.185	0.032	0.028
d 0 to 21													
ADG, g	340	359	10	351	348	10	350	345	353	13	0.222	0.811	0.897
ADFI, g	495	537	14	496	536	14	532^{a}	543^{a}	473^{b}	17	0.039	0.054	0.010
G:F	0.69	0.67	0.01	0.71	0.65	0.01	0.65^{b}	0.64^{b}	0.75^{a}	0.01	0.357	0.001	<0.001
PWD	13.8	12.0		14.6	11.2		10.6^{b}	14.2^{a}	13.9^{a}		0.080	<0.001	0.003
Phase II[6]													
d 21 to 28													
ADG, g	503	554	13	526	531	13	561^{a}	595^{a}	430^{b}	16	0.010	0.788	<0.001
ADFI, g	931	1016	13	960	986	13	1025^{a}	1003^{a}	892^{b}	16	<0.001	0.165	<0.001
G:F	0.54	0.55	0.01	0.55	0.54	0.01	0.55^{a}	0.59^{a}	0.48^{b}	0.01	0.670	0.577	<0.001
PWD	2.2	1.3		1.7	1.6		1.4	1.8	1.8		0.313	0.840	0.838
d 28 to 35													
ADG, g	601	646	13	620	627	13	654^{a}	638^{a}	578^{b}	16	0.021	0.679	0.006
ADFI, g	1150	1233	19	1176	1207	19	1250^{a}	1256^{a}	1068^{b}	23	0.004	0.256	<0.001
G:F	0.52	0.52	0.01	0.53	0.52	0.01	0.52	0.51	0.54	0.01	1.000	0.689	0.183
PWD	1.2	1.3		1.7	0.8		0.8	1.4	1.6		0.823	0.104	0.436
d 21 to 35													
ADG, g	552	600	9	573	579	9	608^{a}	617^{a}	504^{b}	11	<0.001	0.618	<0.001
ADFI, g	1040	1125	13	1068	1096	13	1138^{a}	1129^{a}	980^{b}	16	<0.001	0.146	<0.001
G:F	0.53	0.53	0.01	0.54	0.53	0.01	0.53^{a}	0.55^{a}	0.51^{b}	0.01	0.574	0.432	0.038
PWD	1.6	1.3		1.7	1.2		1.1	1.6	1.7		0.543	0.224	0.445
Cumulatively (d 0 to 35)													
ADG, g	425	456	8	440	440	8	453^{a}	453^{a}	414^{b}	10	0.010	0.980	0.009
ADFI, g	713	772	12	725	760	12	774^{a}	777^{a}	676^{b}	15	0.002	0.052	<0.001
G:F	0.60	0.59	0.01	0.61	0.58	0.01	0.59^{b}	0.58^{b}	0.61^{a}	0.01	0.634	0.004	0.011
PWD	8.9	7.7		9.4	7.2		6.8^{b}	9.1^{a}	9.0^{a}		0.060	<0.001	0.002

[a–c]Within a row, means without a common superscript differ ($P < 0.05$).

[1]Pigs weaned at 28 ± 3 d (6.9 ± 0.2 kg BW).

[2]Days after weaning, in which pigs were fed the Phase I diets.

[3]From d 7 to 14, there were 12 replicates for the treatments with 7 d of duration of feeding of the Phase I diet and 24 replicates for the 14 d of duration of feeding of the Phase I diet. For all other periods, there were 12 replicates per treatment.

[4]None of 2-way or 3-way interactions were statistically significant ($P > 0.10$). The lowest *P*-value for the 3-way interactions observed was for PWD from d 0 to 21 ($P = 0.121$).

[5]Expressed as percentage of days with diarrhea with respect to total number of days on experiment (Mateos et al., 2006).

[6]All pigs received a common Phase II diet in mash form in this period.

Table 3. Influence of age, quality, and form of the Phase I diets on total tract apparent digestibility of nutrients[1]

Item,%	Age	SE (n = 12)	Feed quality High	Feed quality Low	SE (n = 6)	Feed form Pellet	Feed form Mash	SE (n = 6)	P-value[2] Age	P-value[2] Quality	P-value[2] Form
DM											
d 4	79.7[c]		80.3	79.1		81.8	77.6				
d 11	81.3[b]		81.5	81.1		82.8	79.7				
d 18	82.8[a]		83.7	82.0		84.6	81.1				
Avg.	81.3	0.4	81.8	80.7	0.4	83.1	79.5	0.4	<0.001	0.031	<0.001
OM											
d 4	83.5[b]		83.9	83.0		85.4	81.5				
d 11	84.7[b]		84.8	84.6		86.3	83.1				
d 18	86.3[a]		87.2	85.3		87.8	84.8				
Avg.	84.8	0.4	85.3	84.3	0.3	86.5	83.1	0.3	<0.001	0.035	<0.001
GE											
d 4	81.5[b]		81.8	81.2		83.8	79.2				
d 11	83.9[a]		84.1	83.7		85.6	82.2				
d 18	85.6[a]		86.6	84.3		87.5	83.7				
Avg.	83.6	0.5	84.2	83.1	0.4	85.6	81.7	0.4	<0.001	0.071	<0.001
CP											
d 4	75.2[b]		76.4	74.0		77.8	72.6				
d 11	75.6[b]		74.8	76.5		77.7	73.6				
d 18	80.9[a]		82.6	79.2		82.3	79.5				
Avg.	77.2	0.8	77.9	76.6	0.7	79.3	75.2	0.7	<0.001	0.062	<0.001

[a–c]Within a column, means without a common superscript differ (P < 0.05).

[1]Pigs weaned at 28 ± 3 d (6.9 ± 0.2 kg BW).

[2]None of 2-way or 3-way interactions were statistically significant (P > 0.10). The lowest P value observed for the 3-way interactions observed was for OM digestibility (P = 0.210)

mash form, pigs that were fed the Phase I diets for 7 or 14 d had greater ADG (P < 0.001) and ADFI (P < 0.001) and greater G:F (P < 0.001) than pigs fed these diets for 21 d. From d 28 to 35, increasing the duration of feeding of the Phase I diets from 7 or 14 d to 21 d decreased ADG (P < 0.01) and ADFI (P < 0.001) but had no effects on G:F. In Phase II, pigs previously fed the Phase I diets for 21 d had decreased ADFI (P < 0.001) and ADG (P < 0.001) than piglets fed these diets for only 14 or 7 d. Also in this period, pigs fed the Phase I diets for 21 d showed reduced G:F as compared with pigs fed these diets for only 7 or 14 d (P < 0.05). For the entire experimental period (d 0 to 35), decreasing the duration of feeding of the Phase I diets from 21 to 14 or 7 d resulted in greater ADG (P < 0.01) and ADFI (P < 0.001) but reduced G:F (P < 0.05).

Duration of feeding of the Phase I diets affected PWD index from d 0 to 21 d (P < 0.01). However, no effects were observed after 21 d of the experiment. For the entire experimental period (d 0 to 35) and from d 7 to 14 and d 14 to 21, pigs fed the Phase I diets for 14 or 21 d had more PWD than piglets fed the Phase I diets for 7 d (P < 0.01).

Total Tract Apparent Digestibility of Nutrients of the Phase I Diets

The TTAD of DM, OM, GE, and CP of the Phase I diets increased (P < 0.001) with age (Table 3). Piglets fed the HQ Phase I diets had greater (P < 0.05) TTAD of DM and OM and tended to have greater TTAD of GE (P = 0.07) and CP (P = 0.06) than piglets fed the LQ diets. Pelleting improved (P < 0.001) TTAD of DM, OM, GE, and CP at all ages.

DISCUSSION

Crude Protein Content and Ingredient Complexity of the Phase I Diets

The effect of ingredient complexity and CP content of the weaning diet on growth performance of young pigs is a subject of debate (Goodband et al., 2006; Berrocoso et al., 2012a). In the current experiment, the use of HQ Phase I diets, characterized by the greater inclusion of high-quality ingredients and its increased CP and AA contents, improved G:F from d 0 to 7, but no effects were observed thereafter. In fact, for the entire experimental period (d 0 to 35), pigs that were fed the LQ Phase I diets had similar feed efficiency and better ADG than piglets fed the HQ Phase I diets, in spite of their lower concentration in CP and key indispensable AA. The reduction in ADFI observed in the current trial with the HQ diets as compared with LQ diets, resulted in a decrease in ADG from d 0 to 35 of the experiment. The results support the data of Barea et al. (2007) and García-Valverde et al. (2008) indicating that, as compared with conventional white pigs, the AA requirements of Iberian pigs are satisfied at relatively smaller AA concentration. From d 0 to 21 of the experiment, ADFI was greater in pigs fed the LQ (18.5% CP) than in pigs fed the HQ diets (20.5% CP). Quiniou et al. (1995) reported that an increase in CP of the diet from 17.7 to 24.3% of feed, with similar indispensable AA contents, reduced ADFI in conventional white pigs.

The PWD index was greater in pigs fed the HQ diets than in pigs fed the LQ diets. Hansen et al. (1993) and Jin et al. (1998) indicated that once the AA requirements are satisfied, the digestive health of the pigs improved as the CP content of the diet was reduced. In this respect, Bikker et al. (2006) and Htoo et al. (2007) reported that ammonia concentration in the small intestine of the pigs and the growth of harmful microbes increased as the CP content of the diets increased. Moreover, Hermes et al. (2009) reported that a decrease in the CP content of the diet improved the integrity of the gut barrier. In fact, Heo et al. (2009) observed that a reduction in dietary CP from 24 to 18%, while maintaining the levels of key indispensable AA, was an effective strategy to minimize PWD in young pigs.

The inclusion of increased high-quality ingredients in the Phase I diets has been considered as an important factor for improving growth performance of pigs after weaning. Kim and Easter (2001) and Gaines et al. (2005) reported that the inclusion of fish meal in the diet improved piglet growth, and Mahan (1993) and Nessmith et al. (1997) reported that the inclusion of 7.5% dried whey increased feed intake and growth rate in early weaned pigs. However, in the current trial, pigs had similar ADG and G:F from d 0 to 21 of the experiment when fed the HQ than when fed the LQ Phase I diets, confirming the suggestion of Goodband et al. (2006) and indicating that the digestive capacity of pigs after 40 to 45 d of age (approximately 11 to 12 kg BW) was large, and that there was no need of including greater amounts of high-quality ingredients in these diets. Similarly, Berrocoso et al. (2012b) reported no differences in growth performance of conventional white pigs from 21 to 41 d of age when fed a diet based on cooked maize and increased lactose (14%) and fish meal (10%) or a diet based on raw corn and reduced lactose (7%) and fish meal (4%). During Phase II, pigs previously fed the LQ diets had greater ADG and ADFI than pigs fed the HQ Phase I diets, probably because of the reduced incidence of PWD observed in pigs fed the LQ diet.

Nutrient digestibility increased with age; results that agree with most published research in conventional white pigs and is consistent with the development of the villus of the mucosa of the small intestine as the pig become older (Ball and Aherne, 1987; Vicente et al., 2008). Also, nutrient digestibility was greater in pigs fed the HQ Phase I diets than in pigs fed the LQ Phase I diets, data that are consistent with the greater inclusion of high-quality ingredients used (Bikker et al., 2006; Mateos et al., 2007; Menoyo et al., 2011).

Feed Form of the Phase I Diets

From d 0 to 21 of the experiment, pelleting reduced ADFI and improved G:F without affecting ADG, consistent with data of Medel et al. (2004), who reported significant improvements in feed efficiency but not ADG in piglets fed pellets. In contrast, Sukemori et al. (1999) and Kim et al. (2005) observed that feeding pellets increased ADFI and ADG of young pigs. Unfortunately, feed wastage and PWD incidence were not measured in these 2 reports, and thus data on real feed intake and feed efficiency among trials cannot be compared. Hancock and Behnke (2001) and Medel et al. (2004) indicated that most of the recorded increases in ADFI with pellet feeding were due to a reduction in feed wastage. In fact, in the current research feed wastage from d 0 to 21 was 64% greater in pigs fed mash than in pigs fed pellets (23.8 vs. 14.5 g/d; data not shown), confirming that most of the beneficial effect of pelleting on feed efficiency could be attributed to a reduction in feed wastage. From d 0 to 21, pigs fed the Phase I diets in pellet form had reduced ADFI than pigs fed the Phase I diets in mash form or the Phase II diet that was also supplied as mash. It is of interest to note that the week after pigs were changed from the Phase I pelleted diets to the Phase II mash diet, feed wastage was increased (data not shown) and G:F was reduced. This information indicates that a change in feed form from pellets to mash during these early stages of life might affect feeding behavior of pigs (Steidinger et al., 2000). Consequently, the practice of changing feed form from pellets to mash, often practiced used under commercial conditions to reduce the incidence of PWD during the first weeks of life, might hinder voluntary feed intake and reduce growth performance of pigs.

The PWD index was greater in pigs fed pellets than in pigs fed mash. Kil and Stein (2010) suggested that pellet feeds move faster through the GIT, resulting in more undigested nutrients reaching the large intestine. Because of the friction and pressure applied during the process, pelleting reduces particle size of the feed (Abdollahi et al., 2011). Mateos et al. (2012) in broilers and Canibe et al. (2005) in pigs reported that fine grinding changed nutrient digestibility and the environment conditions in the GIT, which in turn, might increase the proliferation of less-beneficial microflora.

Nutrient digestibility was greater in pigs fed pellets than in pigs fed mash, a finding that was consistent with the finer particle size of the pelleted feed, which facilitates the contact between nutrients and digestive enzymes (Smits et al., 1994; Wondra et al., 1995;

Medel et al., 2004). Fine grinding, followed by friction, shearing, and heating during pelleting, disrupts the structure of the cell wall, releasing the lipids contained in the oil bodies (Huang, 1992), as well as the starch from the protein matrix of corn and other ingredients (Gracia et al., 2009). Consequently, lipid digestibility and the susceptibility of starch to α-amylase activity might increase with fine grinding.

Duration of Feeding of the Phase I Diets

The authors have found very limited information on the effects of duration of supply of the Phase I diet on growth performance of conventional white pigs (Mahan et al., 1998; Heo et al., 2008), and no reports are available for Iberian pigs. Mahan et al. (1998) reported similar ADG from 0 to 4 wk after weaning of piglets fed a Phase I diet for 1, 2, or 3 wk. Heo et al. (2008) observed that feeding a low-CP diet, well balanced in indispensable AA for 7 to 10 d after weaning, reduced PWD in pigs as compared with feeding a high-CP diet, which is in agreement with the results of the current research. In the current experiment, pigs fed the Phase I diets for 7 or 14 d had better ADG but reduced feed efficiency from d 0 to 35 than pigs fed these diets for 21 d. It was observed that ADG and feed efficiency decreased when the pigs were changed from the Phase I diets to the Phase II diet, irrespective of the quality of the Phase I diet used (HQ or LQ). Moreover, in all cases, pigs recovered during the second week after the change, once they were adapted to the new feed. For example, from d 7 to 14 of the experiment, pigs that were changed to the Phase II diets at d 7 (and, thus, they had consumed Phase I diets for only 7 d) had decreased ADG and poorer G:F than pigs that received the Phase I diets from d 0 to 14. However, from d 14 to 21, pigs that were changed to the Phase II diet at d 7, recovered and had greater ADG and G:F than pigs fed the Phase I diet from d 0 to 14. The results indicate that pigs fed the Phase I diets for a short period of time adapted to the Phase II diets (low feed quality) with similar efficiency to that of pigs fed these diets for longer periods. Consequently, probably because of their decreased growth rate and reduced nutrient requirements, Iberian pigs with a well-developed GIT and reared under good management practices, might not require diets with greater amount of high-quality ingredients and of indispensable AA to optimize performance after 7 d postweaning.

It is concluded that the use of high-quality Phase I diets increased TTAD of nutrients but did not affect growth performance of Iberian pigs weaned at 28 d of age, indicating that the AA requirements and the need of including high-quality ingredients in the diet, are less for Iberian pigs than for conventional white pigs. Also, pelleting improved nutrient digestibility and feed efficiency, but increased the incidence of PWD as compared with mash feeding. The improvements in feed efficiency observed with pellets, together with the lack of effect on ADG, indicate that most of the benefits of pelleting were a consequence of a decrease in feed wastage, with minor effects of improved nutrient digestibility. An increase in the duration of supply of the Phase I diets from d 7 to 21 after weaning improved overall feed efficiency but reduced ADFI and ADG. Consequently, the use of Phase I diets of LQ in pellet form for the first 7 d after weaning is recommended in Iberian pigs.

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