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Reducing weaning-feed protein content as an alternative to the use of antibiotics

Didier GAUDRÉ
IFIP-Institut du Porc, BP 35104, 35651 Le Rheu Cedex, France
didier.gaudre@ifip.asso.fr

Reducing weaning-feed protein content is the first actionable criterion put forward as a way to reduce the incidence of common digestive diseases affecting piglets in the stressful first few days immediately after weaning. Recent research on piglet requirements for amino acids prompted this study to address the scope for reducing protein content in the weaning feeds on offer today. We led a set of trials to evaluate the digestible lysine requirements of weaned piglets and observe the consequences of shifts in diet protein content at weaning on performances at end of post-weaning. The rationale is that a reduction in pig growth performances in the weaning period, due to a limited protein supply, would be acceptable if it serves to cut out the use of antibiotics with no substantial incidence on later pig performances.

Reducing weaning-feed protein content to reduce the use of antibiotics is effectively possible. It translates into a drop in feed efficiency that may or may not come with a reduction in growth rate. These performance lags are attenuated or even cancelled out at whole post-weaning-phase scale, as compensatory growth performance gains can emerge after the first two weeks after weaning period. Under current feed material availability conditions, a weaning-feed net protein content of 17% is feasible provided that lysine-to-energy ratio is kept below 1.1 g of digestible lysine per MJ NE. This reduction in weaning-feed protein content is only workable if the system also factors in the nutritional values of the follow-on post-weaning feed. Once the animals are successfully through the period weaning adaptation, they need to be farmed in non-limiting production conditions in terms of herd-system and diet-system management. In the weaning feed, the incorporation of good-quality protein needs to be thought through case by case according to on-farm pig breeding conditions.

La réduction de la teneur en protéines des aliments de sevrage en tant qu'alternative à l'usage des antibiotiques

La réduction de la teneur en protéines de l'aliment sevrage est le premier critère avancé pour réduire l'incidence de pathologies digestives fréquentes dans les jours qui suivent le sevrage. Compte tenu des récents travaux menés sur les besoins en acides aminés, cette étude fait le point des capacités de réduction des taux de protéines des aliments de sevrage offertes aujourd'hui. Des essais sont réalisés afin d'évaluer les besoins en lysine digestible du porcelet au sevrage et d'observer les conséquences des modifications du régime azoté au moment du sevrage sur les performances en fin de post-sevrage. Une réduction des performances de croissance des animaux dans la période de sevrage, due à un apport protéique restreint, peut être acceptable s'il permet un arrêt de l'usage des antibiotiques et se révèle sans incidence forte sur les performances ultérieures. La réduction de la teneur en protéines des aliments en période de 1er âge dans le but de réduire l'usage de l'antibiothérapie est possible. Elle se traduit par une baisse d'efficacité alimentaire accompagnée ou pas de celle de la vitesse de croissance. Ces diminutions de performances sont amoindries, voire annulées à l'échelle de la totalité du post-sevrage, des compensations de performances pouvant apparaître après la période de 1er âge. Dans les conditions de disponibilité des matières premières actuelles, un taux de protéines de l'aliment 1er âge de 17 % est envisageable à la condition de retenir un ratio lysine/énergie inférieur à 1,1 g de lysine digestible par MJ EN. Il faut tenir compte des valeurs nutritionnelles de l'aliment 2ème âge pour que cette réduction de la teneur en protéines de l'aliment 1er âge soit réalisable. Après la phase d'adaptation consécutive au sevrage, il faut mettre les animaux dans des conditions de production non limitantes en termes de conduites d'élevage et alimentaire. Dans l'aliment sevrage, l'incorporation de matières protéiques de qualité est à raisonner selon les conditions d'élevage.

Keywords: net protein content, weaning feed, antibiotics, disease, amino acids
Mots clés : taux de protéines, aliment au sevrage, antibiotiques, pathologie, acides aminés

Background & Objectives

Reducing weaning-feed protein content is generally the first actionable criterion put forward as a way to reduce the incidence of common digestive diseases affecting piglets in the stressful first few days immediately after weaning. The increased market uptake of synthetic amino acids has facilitated this transition in the past few years. Recent research on piglet requirements for amino acids such as valine, leucine, isoleucine and histidine prompted this study to address the scope for reducing protein content in the weaning feeds on offer today. After first collecting and compiling the amino acid composition data available on weaning stage-specific feedstuffs, we led a set of trials to evaluate the digestible lysine requirements of weaning piglets and observe the consequences of shifts in net protein diet at weaning (4-week-old piglets) on performances at end of post-weaning (6 weeks post-weaning). The rationale is that a reduction in pig growth performances in the weaning period, due to a limited protein supply, would be acceptable if it serves to cut out the use of antibiotics with no substantial incidence on later pig performances.

Excess dietary protein plays a role in digestive disorder events, which is explained this way— it has a buffer effect on gastric pH, increasing it to levels that compromise digestive system function, while high net protein levels may also have the effect of elevating pH in the distal small intestine. Fermentative protein substrate content of the gut affects its native microbial populations. Proteolytic fermentation processes in the gut led to the production of compounds that are irritants to intestinal epithelium, such as ammonia, indole compounds, branched short-chain fatty acids, amines and phenols. Furthermore, in the event of infection challenge, the increase in net protein content will drive a rise in intestinal nitrogen flow into the gut and, from there, drive a rise in proteolytic fermentation processes in the colon and small intestine. Finally, the presence of proteolytic bacteria and their fermentation products also risks compromising intestinal permeability.

Material & Methods

Diet strategies

The first step of this study was to determine, based on feed formulation, how far down protein content could be reduced without overly increasing feed cost and without straying from the ideal protein profile extended to ten amino acids (see Table 1). We thus collected the nutritional values of weaning stage-specific feedstuffs. The net energy and digestible amino acid contents of these protein sources were estimated based on published reference values or, where reference values were missing, assigned according to the technological treatments applied and similarity to analogues for which these same nutritional values have been clearly determined. The outcome of this preliminary formulation work then served to estimate a target weaning-feed protein level in the 16%–17% range, whereas industry currently practices levels at between 18 and 20%.

Table 1: Ideal protein profile selected as basis

Amino acid	%[1]
Methionine	30
Methionine + Cystine	60
Threonine	65
Tryptophan	19
Valine	65-70[2]
Isoleucine	52
Leucine	100
Phenylalanine	54
Tyrosine	40
Histidine	32

1: Expressed as percent ratio of lysine content requirement (digestible amino acids)
2: 70% for trial 1, 65% for trial 2

Working up from this benchmark, two trials were led in the IFIP experimental farm stations at Villefranche-de-Rouergue (Aveyron) and Romillé (Ille-et-Vilaine). The first trial was designed around reducing the ratio of digestible lysine per MJ net energy (NE). The second trial was designed to compare different feed compositions sharing the same 17% protein content.

Trial 1 compared the effects of 4 weaning diet feeds formulated with lysine-to-energy ratios of 1.3, 1.2, 1.1 and 1.0 g digestible lysine per MJ NE, respectively (Table 2, and see annexes for the full dataset). In parallel to the reduction in lysine-to-energy ratio, the protein contents were also progressively decreased (20.3%, 19.0%, 17.5% and 16.4%). Formulation rates of protein-concentrate feed material were held constant across all four feeds—only soybean

Table 2: *Main ingredients and main characteristics of trial-1 weaning feeds*

Lysine-to-energy ratio[1]	1.3	1.2	1.1	1.0
Proteins (%)	20.3	19.0	17.5	16.4
Lysine (g/kg)	14.9	13.8	12.6	11.5
NE (MJ/kg)	10.6	10.6	10.7	10.8
Maize (%)	30.0			
Wheat (%)	26.7	30.5	34.5	37.7
Soybean meal (%)	18.6	15.0	11.0	8.0
Vegetable protein concentrate[2], %	8.0			

[1] : in g digestible lysine per MJ NE
[2]: including 3% soybean protein concentrate, 3% extruded soybean meal, 1% potato protein, 1% corn gluten meal

meal content varied. All feeds maintained the ideal protein balance defined in Table 1.

Trial 2 compared 4 diet strategies. A first control diet (CTRL19) was devised based on a protein content of 19% and a lysine-to-energy ratio of 1.2 g of digestible lysine per MJ NE (Table 3, and see annexes for the full dataset). A second control diet (CTRL17) was similar to the first for the source materials used except that protein content was reduced down to around 17% and the lysine-to-energy ratio was consequently protein content-corrected (i.e. to 1.0 g of digestible lysine per MJ NE). Two further diets were built on the same nutritional values as CTRL17 but reducing soybean meal to a strict minimum (1% inclusion rate). The first test diet used vegetable-protein sources (VEG17) while the second test diet used animal-protein sources (milk products only) (ANI17).

At the end of the weaning phase (2 weeks post-weaning), all the piglets received the same post-weaning feed (see Table 4 for details of the main characteristics) right through to the end of the trial (6 weeks post-weaning). All feeds were offered ad libitum and the amounts consumed were weighed.

Table 4: *Main ingredients and main characteristics of the post-weaning feeds*

Trial	1	2
Proteins, %	18.0	17.5
Lysine, g/kg	12.2	11.7
EN, MJ/kg	9.7	9.5
Digestible lysine/MJ NE	1.15	1.10
Wheat (%)	41.6	35.2
Soybean meal (%)	24.5	16.7

In trial 1, the feeds were blended by the IFIP feed mill at Villefranche-de-Rouergue (Aveyron). In trial 2, the weaning feeds were blended by the INRA's feed mill facility at Saint-Gilles (Ille-et-Vilaine) and the post-weaning feedstuffs was sourced from one of the IFIP Romillé station's regular suppliers. Feed samples were collected over the course of the trial (one sample per week per feed) then pooled at the end of the group post-weaning stage to form a representative sample of the diet the piglets received. Analyses led on these samples confirmed that actual contents matched expected contents. Amino acid analysis was performed for all four weaning feeds in trial 2 (see the annexes for full results).

Amino acid contents as analyzed were ratioed to the expected contents, then expressed as a percentage called quantitative recovery. Considering that good quantitative recovery is bracketed between 90 and 110%, the analyses confirmed the quality of feed manufacture, as the majority of amino acids analyzed fell in the 95–105% interval. Note, however, that we found systematic deficits in sulphur-containing amino acids (methionine and cystine) and in histidine, and more so with the ANI17 diet than the other diets, almost certainly due to using nutritional values that were less precise on composition for certain source feed materials, especially whey protein concentrate.

Table 3: *Main ingredients and main characteristics of trial-2 weaning feeds*

Diets	CTRL19	CTRL17	VEG17	ANI17
Proteins (%)	19.0	16.7	17.1	16.5
Lysine (g/kg)	13.7	12.1	12.1	12.0
NE (MJ/kg)	10.5	10.6	10.8	11.2
Wheat (%)	27.5	33.2	36.8	36.6
Soybean meal (%)	16.0	11.5	1.1	0.7
Vegetable protein concentrate[1], %	9.3	8.0	15.0	3.8
Animal protein concentrate[2], %	-	-	-	22.1

[1] : extruded soybean meal, soybean protein concentrate, potato protein, wheat gluten
[2]: skim milk powder and whey protein concentrate

Pig breeding conditions and experimental design

Trial 1 was led in biosecure pig breeding conditions, with 360 piglets allotted across 24 pens at a density of 0.30 m^2 per pig. Only pig performances were measured. Trial 2 was led in two batched groups, where the second group was managed in bioinsecure pig breeding conditions, i.e. the rooms were not cleaned after the first group was emptied. For each group, 24 pens were built, each designed to hold 10 piglets (0.30 m^2 per pig). Weanling piglets were batch-blocked by individual liveweight and gender in a complete block design. Sex ratio in each pen was identical for all 4 pens in a given block. Ventilation management consisted in maintaining an initial temperature of 27°C on the day of weaning, then subsequently reducing temperature by 0.5°C every week (i.e. down to 24°C at the end of the post-weaning period).

Measurements

Each pig was weighed at weaning, then at the end of the weaning period and again at the end of the post-weaning period. Pig performances (growth rate, daily feed intake and feed to gain ratio) were compared in each diet treatment. In trial 2, pig performance measurements were completed by measuring faecal dry matter at d 7 and d 14 post-weaning on 96 pigs per group, i.e. on 40% of the trial-2 population. This method replaced faecal score, which we considered more subjective due to interoperator variability. The method was practiced with the pigs moved outside the pens for each faecal sampling to facilitate a smooth and patient sampling process. The samples were then over-dried for 48 h. Blood samples were also taken at d 14 post-weaning in each blocked group on 48 pigs representing 20% of the trial-2 population. These samples served to determine number of red and white blood cells (or count) expressed in thousand cells per µL of blood, concentration of haemoglobin (g/L), packed red cell volume (or haematocrit) expressed in volume of total blood, and mean corpuscular volume corresponding to the ratio of haematocrit to red blood cell count (expressed in μm^3). Differential white blood cells counts were also performed to identify the number of white blood cells (expressed in thousand cells per µL) typed as neutrophils, eosinophils and basophils and as lymphocytes and monocytes.

Statistical analysis

All statistical analysis used SAS software (v9.4, SAS Inst. Inc. Cary, NC). Pen was the experimental unit for all statistical measurements. In trial 1, diet performances were compared by linear regression (REG procedure). In trial 2, each group was tested by ANOVA (GLM procedure) including diet and block as factor effects. Mean performances per diet were compared using the Tukey test.

Results

Table 5 reports the results of trial 1. Lysine-to-energy ratio of the weaning feed had no effect on daily feed intake in weaning and post-weaning program phases. In weaning phase, growth rate and feed to gain ratio improved significantly by 20 g/d and 0.09 kg/kg, respectively, as lysine-to-energy ratio was increased by 0.1 g/MJ NE. Pig weight at the end of the weaning period was significantly increased by 0.3 kg linearly with increasing lysine-to-energy ratio. The linear effect of lysine-to-energy ratio of the weaning feed was equally significant for post-weaning feed-period growth rate and feed to gain ratio, but in the opposite direction to the weaning

***Table 5:** Pig performances according to lysine-to-energy ratio of the weaning feed*

Lysine-to-energy ratio	1.3	1.2	1.1	1.0	Linear effect[1]
Weight at weaning (kg)	8.6				ns
Weaning period					
ADG[2] (g/d)	375	362	338	317	*
ADFI[2] (g/d)	450	440	458	450	ns
F/G[2] (kg/kg)	1.21	1.22	1.37	1.45	**
Weight at end of weaning period (kg)	13.8	13.7	13.3	13.0	*
Post-weaning period					
ADG[2] (g/d)	640	632	647	669	**
ADFI[2] (g/d)	1186	1184	1191	1197	ns
F/G[2] (kg/kg)	1.79	1.81	1.77	1.73	*
Weight at end of post-weaning period (kg)	31.8	31.4	31.4	31.8	ns
Whole period					
ADG[2] (g/d)	552	543	544	552	ns
ADFI[2] (g/d)	934	932	942	942	ns
F/G[2] (kg/kg)	1.65	1.67	1.69	1.67	ns

*[1] : Linear effect of weaning feed lysine-to-energy ratio; ns= non-significant, * = significant at a 5% level, **= significant at a 1% level*
[2]: ADG = average daily gain, ADFI = average daily feed untake, F/G = feed to gain ratio

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period: growth rate decreased by 10 g/d and feed to gain ratio rose by 0.02 kg/kg in the post-weaning period as lysine-to-energy ratio of the weaning feed was increased by 0.1 g/MJ NE, thus revealing a compensatory growth performance phase when all the pigs received the same feed. At final outcome, there was no gap when performances were observed at the scale of the whole trial period (41 days for pigs weaned at 4 weeks).

Tables 6 and 7 report the results of trial 2 in biosecure and bioinsecure pig breeding conditions. Regardless of pig breeding conditions, growth rate and feed intake were unaffected by diet in both weaning and post-weaning period. Diet had a significant effect on weaning-period and post-weaning-period feed to gain ratio in the first batch of the trial in biosecure pig breeding conditions, but not in the second batch led in bioinsecure pig breeding conditions. In biosecure pig breeding conditions, weaning-period feed to gain ratio was significantly lower (P=4%) on the CTRL19 diet than the CTRL17 diet (-6.7%), and tended (P=6%) to be lower (by 6.2%) in the CTRL19 diet than the VEG17 diet. The gap between CTRL19 and ANI17 weaning feed to gain ratios (-5.6%) was not significant (P=11%). The effect of weaning diet was significant (P<1%) in the post-weaning period. In contrast to the weaning period, the CTRL19 diet showed a significantly higher feed to gain ratio than the VEG17 and ANI17 diets, at +2.2% vs VEG17 and +1.9% vs ANI17 (P=2%) and tended (P=8%) to be higher (by 0.9%) in the CTRL19 diet than the CTRL17 diet. The effect of weaning diet on feed to gain ratio measured across the whole trial period was not significant.

Scratches and wounds, number of white blood cells and type-pattern of white blood cell differentials were not signi-

***Table 6:** Pig performances according to weaning feed in biosecure pig breeding conditions*

	Diets				Statistics[1]	
	CTRL19	CTRL17	VEG17	ANI17	Effect	RSD
Population per diet	60					
Weight at weaning (kg)	9.4				B**	0.0
Weaning period[3]						
ADG[2] (g/d)	314	300	305	309	-	29
ADFI[2] (g/d)	400	407	403	408	B*	26
F/G[2] (kg/kg)	1.28a	1.37b	1.36ab	1.35ab	D*, B**	0.05
Weight at end of weaning period (kg)	13.8	13.7	13.6	13.7	B**	0.4
Post-weaning period[3]						
ADG[2] (g/d)	636	645	662	636	B**	25
ADFI[2] (g/d)	1073	1054	1068	1032	B**	37
F/G[2] (kg/kg)	1.68b	1.64ab	1.61a	1.62a	D**, B^t	0.03
Weight at end of post-weaning period (kg)	30.3	30.3	30.8	30.2	B**	0.7
Whole period[3]						
ADG[2] (g/d)	524	524	537	522	B**	17
ADFI[2] (g/d)	833	827	824	809	B**	23
F/G[2] (kg/kg)	1.60	1.58	1.56	1.56	B**	0.03
Scores and samples[3]						
Scratches	5.9	5.1	5.3	3.7		2.1
Wounds	2.0	0.6	3.6	1.6		2.4
Faecal dry matter after one week (%)	25.0a	26.1a	31.1b	30.5b	D**	2.6
Faecal dry matter after two weeks (%)	26.2ab	23.5a	31.5bc	29.5bc	D**	3.4
Red blood cell count (10^3/µL)	6321	6493	6329	6058	B**	360
Haemoglobin (g/L)	110.0	102.8	104.3	102.5	D^t	5.1
Haematocrit, %	35.4	33.6	33.5	32.8	D^t, B**	1.7
Mean corpuscular volume, µm^3	56.2c	51.8a	53.2ab	54.3bc	D**, B**	1.3
White blood cell count (10^3/µL)	17.8	16.7	19.3	15.8		3.4
Neutrophils (10^3/µL)	10.3	9.8	9.0	8.6		3.3
Eosinophils (10^3/µL)	0.3	0.1	0.2	0.1		0.2
Basophils (10^3/µL)	0.02	0.01	0.03	0.02	B*	0.03
Lymphocytes (10^3/µL)	6.7	6.4	9.6	6.7		3.2
Monocytes (10^3/µL)	0.5	0.4	0.8	0.4		0.4

*[1] Based on ANOVA factorizing the effects of diet and block; RSD = residual standard deviation, D = diet effect, B = block effect; Significance levels = t: p<0.10, *: p<0.05, **: p<0.01. Data are reported as adjusted means.*
[2]: ADG = average daily gain, ADFI = average daily feed untake, F/G = feed to gainn ratio
[3] a,b: different letters for the same criterion indicate significantly different means based on the Tukey test (P<0.05).

***Table 7:** Pig performances according to weaning feed in bioinsecure pig breeding conditions*

	Diets				Statistics1	
	CTRL19	CTRL17	VEG17	ANI17	Effect	RSD
Population per diet	60				-	-
Weight at weaning (kg)	8.8				B**	0.0
Weaning period[3]						
ADG[2] (g/d)	272	229	246	273		36
ADFI[2] (g/d)	358	329	348	380	B*	39
F/G[2] (kg/kg)	1.32	1.44	1.42	1.40	B*	0.09
Weight at end of weaning period (kg)	12.6	12.0	12.2	12.6	B**	0.5
Post-weaning period[3]						
ADG[2] (g/d)	602	576	579	590	B**	25
ADFI[2] (g/d)	982	950	934	957	B**	48
F/G[2] (kg/kg)	1.63	1.65	1.61	1.62		0.05
Weight at end of post-weaning period (kg)	28.3	27.0	27.3	28.0	B**	1.0
Whole period[3]						
ADG[2] (g/d)	487	454	462	479	B**	25
ADFI[2] (g/d)	764	733	729	755	B**	42
F/G[2] (kg/kg)	1.57	1.61	1.57	1.58	B*	0.04
Scores and samples[3]						
Scratches	5.6	5.1	8.0	5.8		2.9
Wounds	1.3	0.3	2.0	1.1		1.4
Faecal dry matter one week post-weaning (%)	24.5	24.7	27.4	27.0	D^t	2.1
Faecal dry matter two weeks post-weaning (%)	25.7	26.3	25.6	28.0	B*	1.8
Red blood cell count (10^3/µL)	6524ab	6763b	6438ab	6214a	D^t	323
Haemoglobin (g/L)	102	101	100	99		5.0
Haematocrit, %	33.0	32.8	32.5	31.8		1.6
Mean corpuscular volume, µm^3	50.7	48.7	50.7	51.1		2.1
White blood cell count (10^3/µL)	18.8	18.1	17.8	17.6		2.7
Neutrophils (10^3/µL)	8.8	7.8	7.5	7.7		2.3
Eosinophils (10^3/µL)	0.5	0.4	0.3	0.4		0.2
Basophils (10^3/µL)	0.10	0.08	0.08	0.06		0.09
Lymphocytes (10^3/µL)	8.7	8.9	9.1	8.6		1.2
Monocytes (10^3/µL)	0.8	0.9	0.8	0.8		0.3

*[1] Based on ANOVA factorizing the effects of diet and block; RSD = residual standard deviation, D = diet effect, B = block effect; Significance levels = t: p<0.10, *: p<0.05, **: p<0.01. Data are reported as adjusted means.*
[2]: ADG = average daily gain, ADFI = average daily feed untake, F/G = feed to gain ratio
[3] a,b: different letters for the same criterion indicate significantly different means based on the Tukey test (P<0.05).

ficantly modified by diet in the two groups. In biosecure pig breeding conditions, faecal dry matter content one week post-weaning was significantly higher on the VEG17 and ANI17 diets compared to the CTRL19 and CTRL17 diets. At two weeks post-weaning, faecal dry matter content was still significantly lower in the CTRL17 diet than in the VEG17 and ANI17 diets, tended (P=7 %) to be lower in the CTRL19 diet than the VEG17 diet, but was not significantly different between the CTRL19 and ANI17 diets. In bioinsecure pig breeding conditions, there was a trend (P=6%) towards a diet effect on faecal dry matter content one week post-weaning, but between-diet comparisons did not find significant differences. At two weeks post-weaning, faecal dry matter content showed no diet effect.

In biosecure pig breeding conditions, red blood cell count was not statistically different between diets. In bioinsecure pig breeding conditions, red blood cell count tended (P=7%) to show a diet effect, where the test for multiple pairwise comparisons of means found a significant difference between CTRL17 and ANI17 diets. In biosecure pig breeding conditions, haemoglobin content and haematocrit tended (P=8%) to show a diet effect, where the test for multiple pairwise comparisons of means on these two factors showed trends between the CTRL17 and ANI17 diets (P=9% for haemoglobin and P=6% for haematocrit). There were significant diet effects (P<1%) on mean corpuscular volume in biosecure pig breeding conditions: CTRL19 diet led to significantly higher mean corpuscular volume than the CTRL17 and VEG17 diets, and ANI17 diet led to significantly higher mean corpuscular volume than the CTRL17 diet. There were no diet effects on haemoglobin, haematocrit and mean corpuscular volume in bioinsecure pig breeding conditions.

Discussion

Taken together, the results show that pig performances, when considered at whole trial period scale, were unaffected by the type of diet given in the weaning period. This is likely largely due to the length of the weaning period, which makes up just a third of total trial period, and the fact that performance gaps emerging in the weaning period ultimately get diluted in the post-weaning period. To illustrate, the 20 g/d growth rate obtained in the weaning-diet period, which equates to a weight gain of around 2% (280 g after 14 days to reach a mean liveweight of 13.5 kg), represents just 1% of the liveweight recorded at the end of the post-weaning (280 g after 40 days to reach a mean liveweight of 31 kg) equivalent to 7 g/d growth rate measured across the whole trial period (280 g obtained after 40 kg post-weaning). Likewise, a 0.1 kg/kg improvement in feed to gain ratio in the weaning-diet period equates to just a 0.03 kg/kg improvement in feed to gain ratio at post-weaning-phase scale. For type of diet given in the weaning period to have a significant effect on whole trial period performances, the improvement differential in growth rate and feed efficiency recorded at exit from the weaning phase would have to hold significant thereafter, with the pigs continuing to benefit from a headstart gained earlier. However, this is not what our results show.

Two times over, pig performance reductions recorded in the weaning period were caught up in the post-weaning period. In trial 1, this compensatory effect was observed on both growth rate and feed to gain ratio. In trial 2, in biosecure pig breeding conditions, this compensatory effect only concerned feed to gain ratio, as there was no growth rate differential in the weaning period. The improvement in feed to gain ratio observed in the catch-up phase can be explained by differences in pig liveweight and thus in nutritional requirements of less heavy pigs. This same pattern has already been observed in our own previous trials (Gaudré, 2011) during which a reduction in growth rate in post-weaning translated into a significant improvement in feed to gain ratio at early grow-finish. Here, factoring for the mean weight differential during the growing period was able to explain about half of the observed improvement in feed to gain ratio. However, this maintenance energy requirement was calculated based on pigs housed individually in metabolic cages. Noblet *et al.* (1999) concluded that nutrient utilization level is almost certainly lower in these conditions and that the maintenance requirement thus calculated underestimates the maintenance requirement for pigs reared in routine conditions. Visceral mass was able to explain much of the variation in maintenance energy requirements, especially as visceral mass contributed three times more to maintenance energy requirements than muscle mass (Noblet *et al.*, 1999), and amino acid-dense feeds are known to increase viscera accretion (Chiba, 1994). Other hypotheses can be put forward to explain this improvement in feed efficiency, which may be due to lower fat-to-lean deposition rate, better digestion of nutrients, or better net nitrogen utilization (Donker *et al.*, 1986). De Greef *et al.* (1992) showed that an increase in fat-to-lean deposition rates in protein-restricted pigs that are subsequently realimented is ultimately of little value, as this increase fails to wholly compensate for the initial restriction-induced loss of lean deposition. It cannot be ruled out that the compensatory growth performances observed here may be the outcome of a better digestibility plus better metabolic utilization of amino acids for the pigs that had received an amino acid-limiting weaning feed followed by an amino acid-adequate post-weaning feed. Note that in both trials, post-weaning-feed lysine-to-energy ratio was midway between that of the weaning feeds (1.15 and 1.10 g digestible lysine per MJ NE, respectively). This means that pigs in the weaning period learn to accommodate this limiting input and adapt their mechanisms of nutrient utilization proportionately. Once feed conditions become non-limiting, pig performances then show the benefits of this adaptation strategy.

The haemoglobin content and percent haematocrit measured here are of the same scale as those measured by Jolliff & Mahan (2011) on same-aged pigs (38 days) that had received iron injections at birth, i.e. 113 g/L haemoglobin and 34.3% haematocrit. Jolliff & Mahan found that haemoglobin and percent haematocrit at weaning decreased significantly with increased pig bodyweight: at 17 d of age, pigs that weighed < 4.9 kg had a mean haemoglobin of 114 g/L and a mean percent haematocrit of 37.5% whereas pigs that weighed > 7.0 kg showed a lower mean haemoglobin of 103 g/L and a lower mean percent haematocrit of 34.5%. Number of white blood cells measured here is similar to the number already measured for pigs at weaning on the same site as trial 2 (Machet, 2014), at 18.89 ± 5.59 thousand per mm³. Number of white blood cells increases through post-weaning, as shown by Morrow-Tesch & Andersson (1994), in pigs weaned at 5 w of age then at one week post-weaning and 3 weeks post-weaning, at 12.8, 13.4 and 17.1 thousand per mm³, respectively. However, values measured by Machet (2014) in a study led on two farms only found this progressive increase in one of the farms.

Scores and samples performed here to compare the effect of diet strategies showed differences according to biosecurity of pig breeding conditions. Bioinsecure pig breeding conditions reduced the gaps observed in normal biosecure pig breeding conditions in terms of faecal dry matter. The increase in faecal dry matter content found for the two complex diets (ANI17 and VEG17) in biosecure pig breeding conditions disappears in bioinsecure pig breeding conditions. Bioinsecure pig breeding conditions also diluted diet effects on red blood cell measures. In biosecure pig breeding conditions, mean corpuscular volume showed a significant diet effect while both haemoglobin and percent haematocrit showed diet-effect trends. In bioinsecure pig breeding conditions, red blood cell count tended to show a diet effect, but that was all. On the animal performance factors front, there was a significant diet effect on feed to gain ratio in biosecure pig breeding conditions but not in bioinsecure pig breeding conditions. This finding suggests that pig breeding conditions outweigh pig responses to the different diets, within the limits of the nutritional values of the feeds tested in this study. By extension, the improvement in feed nutritional quality obtained by diversifying feed protein sources and incorporating those feed materials that offer the highest protein quality does not pay off into market value when on-farm pig health conditions progressively decline.

Conclusion

Reducing weaning-feed protein content to reduce the use of antibiotics is effectively possible. It translates into a drop in feed efficiency that may or may not come with a reduction in growth rate depending on the feed protein contents targeted and feed lysine-to-energy ratio used. These performance reductions are attenuated or even cancelled out if considered at whole post-weaning-phase scale, as compensatory growth performance gains can emerge early after the weaning period. However, our study set-up likely encouraged this compensatory growth performance gains, as the animals receiving an amino acid-limited weaning feed were then given a more amino acid-concentrated post-weaning feed. The pig body could have first adapted to this restricted input by readjusting its mechanisms of nutrient utilization, to enable both better digestibility and better protein metabolism and then, when dietary supply subsequently became greater, unlocked this nutrient utilization potential, thus enabling a better feed efficiency. These compensatory growth performances have been widely reported in the literature. Note too that we did not measure change in body composition, which would have shed further light on the observed pig performance patterns.

As things stand, under current feed material availability conditions, a weaning-feed protein content of 17% is feasible provided that lysine-to-energy ratio is kept below 1.1 g of digestible lysine per MJ NE. To resituate in context, the IFIP sets nutritional recommendations at 1.3 g digestible lysine per MJ NE for programs where pigs are weaned at 21–28 d of age. Furthermore, this reduction in weaning feed protein content is only workable if the system also factors in the nutritional values of the follow-on post-weaning feed. Once the animals are successfully through the weaning adaptation period, they need to be farmed in non-limiting production conditions both in herd management terms and diet management terms.

On the feed composition front, the incorporation of highly quality protein needs to be thought through case by case according to on-farm pig breeding conditions. In bioinsecure pig breeding conditions, the added cost of incorporating highly quality protein visibly fails to pay off into added market value. It emerges that this type of feed loses added value in bad pig health management conditions, where stronger hygiene measures and cleaning-disinfecting procedures are likely to be more of a priority than finding alternative nutritional solutions.

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ANNEXES

Composition and nutritional characteristics of the weaning diets

Trial 1

Lysine-to-energy ratio	1.3	1.2	1.1	1.0
Composition (%)				
Corn	30.0			
Wheat	26.7	30.5	34.5	37.7
Soybean meal	18.6	15.0	11.0	8.0
Whey	10.0			
Soybean protein	3.0			
Extruded soybean	3.0			
Potato protein	1.0			
Corn gluten meal	1.0			
Soybean oil	2.7	2.5	2.5	2.4
Calcium carbonate	0.8	0.9	1.0	1.0
Dicalcium phosphate	0.9	0.9	0.9	0.9
Premix	0.6			
Salt	0.4			
Lysine HCl	0.61	0.58	0.56	0.51
DL-methionine	0.26	0.22	0.19	0.15
L-threonine	0.25	0.23	0.21	0.18
L-tryptophan	0.07	0.07	0.06	0.05
L-valine	0.16	0.14	0.14	0.10
Natuphos	0.005	0.005	0.005	0.005
Nutritional characteristics				
Dry matter (%)	88.9	88.8	88.8	88.7
Proteins (%)	20.3	19.0	17.5	16.4
Fats (%)	5.4	5.2	5.2	5.1
Minerals (%)	5.8	5.8	5.7	5.6
Crude fiber (%)	2.6	2.5	2.4	2.2
Starch (%)	35.6	37.9	40.3	42.3
NE (MJ/kg)	10.6	10.6	10.7	10.8
Calcium (g/kg)	8.9	9.3	9.5	9.6
Phosphorus (g/kg)	5.8	5.7	5.6	5.5
Lysine (g/kg)	14.9	13.8	12.6	11.5
Dig. lysine (g/kg)	13.8	12.7	11.7	10.6
In % digestible lysine				
Methionine	39	38	37	36
Meth. + Cystine	60	60	60	60
Threonine	65	65	65	65
Tryptophan	19	19	19	19
Valine	70	70	70	70
Isoleucine	55	55	55	56
Leucine	106	108	110	115
Phenylalanine	63	63	63	65
Tyrosine	44	45	45	47
Histidine	32	32	32	33

Trial 2

Diets	CTRL19	CTRL17	VEG17	ANI17
Composition (%)				
Wheat	27.5	33.2	36.8	36.6
Corn	15.0			
Barley	15.0			
Whey	10.0			
Soybean meal	16.0	11.5	1.1	0.7
Extruded soybean	5.0	4.5	5.5	1.5
Soybean protein	2.8	2.0	6.0	2.0
Potato protein	1.5	1.5	2.0	
Wheat gluten			1.5	3.0
Whey protein				8.2
Skim milk powder				13.8
Oil	3.3	3.4	3.2	3.7
Premix	0.5			
Salt	0.4			
Calcium carbonate	1.2	1.2	1.3	1.5
Dicalcium phosphate	0.8	0.8	0.8	0.2
L-lysine HCl	0.47	0.46	0.50	0.31
DL-methionine	0.22	0.18	0.15	0.11
Threonine	0.20	0.19	0.18	0.13
Tryptophan	0.45	0.45	0.4	0.3
Valine	0.05	0.04	0.03	
Phytase	0.015			
Nutritional characteristics				
Dry matter (%)	89.0	88.9	89.2	89.5
Proteins (%)	19.0	16.7	17.1	16.5
Crude fiber (%)	2.9	2.7	2.4	2.0
Fats (%)	6.0	6.0	6.0	6.0
Ash (%)	6.2	6.0	5.6	5.4
Starch (%)	34.1	37.5	39.9	39.6
Calcium (g/kg)	10.2	10.3	10.1	10.3
Phosphorus (g/kg)	5.8	5.6	5.5	4.7
Dig. P (g/kg)	3.5	3.5	3.5	3.5
Na (g/kg)	2.4	2.4	2.4	2.4
NE (MJ/kg)	10.5	10.6	10.8	11.2
Lactose (%)	6.3	6.3	6.3	10.7
Lysine (g/kg)	13.7	12.1	12.1	12.0
Dig. lysine (g/kg)	12.5	11.0	11.0	11.0
In % digestible lysine				
Methionine	38	37	35	37
Meth. + Cystine	60	60	60	60
Threonine	65	65	65	65
Tryptophan	19	19	19	19
Valine	65	65	65	67
Isoleucine	57	56	57	60
Leucine	101	101	106	116
Phenylalanine	65	64	67	62
Tyrosine	44	44	47	47
Histidine	33	32	32	32

Amino acid profiles (trial 2)

Diets[1]	CTRL19			CTRL17			VEG17			ANI17		
Dry matter (%)	89.0	89.9	90.1	88.9	90.0	90.0	89.2	90.0	90.1	89.5	90.4	90.2
Proteins (%)	19.0	19.2	19.4	16.7	17.0	17.6	17.1	17.5	17.6	16.5	16.4	16.4
Amino acids (g/kg)												
Lysine	13.7	13.7	13.7	12.1	12.3	12.4	12.1	12.1	12.3	12.0	11.4	11.7
Methionine	5.0	4.6	4.8	4.3	3.9	4.1	4.2	3.8	3.9	4.3	3.6	4.1
Cystine	3.2	2.9	2.9	2.9	2.7	2.7	3.2	2.8	2.9	2.9	2.5	2.5
Threonine	9.2	9.2	9.2	8.1	8.2	8.3	8.2	8.1	8.0	8.1	7.5	7.5
Tryptophan	2.7	2.7	2.7	2.4	2.5	2.5	2.4	2.5	2.5	2.4	2.4	2.4
Isoleucine	8.1	7.8	8.0	7.0	6.9	7.1	7.2	7.0	7.2	7.6	7.1	7.1
Valine	9.3	9.1	9.3	8.2	8.1	8.4	8.2	8.2	8.4	8.5	8.3	8.3
Leucine	14.2	14.2	14.3	12.5	12.5	12.9	13.0	12.9	13.2	13.9	13.5	13.4
Phenylalanine	9.0	8.9	9.1	7.8	7.9	8.1	8.2	8.1	8.3	7.4	7.3	7.3
Tyrosine	6.2	6.2	6.3	5.4	5.4	5.6	5.8	5.5	5.7	5.7	5.6	5.6
Histidine	4.6	4.2	4.3	4.0	3.7	3.8	4.0	3.7	3.7	3.9	3.7	3.6
Quantitative recoveries of amino acids, expressed as % of expected content												
Lysine		100	100		102	102		100	102		95	98
Methionine		92	96		91	95		90	93		84	95
Cystine		91	91		93	93		88	91		86	86
Threonine		100	100		101	102		99	98		93	93
Tryptophan		100	100		104	104		104	104		100	100
Isoleucine		96	99		99	101		97	100		93	93
Valine		98	100		99	102		100	102		98	98
Leucine		100	101		100	103		99	102		97	96
Phenylalanine		99	101		101	104		99	101		99	99
Tyrosine		100	102		100	104		95	98		98	98
Histidine		91	93		93	95		93	93		95	92

[1] : for each diet, the first column gives expected content and the second and third columns give the quantitative contents recovered by analysis for group 1 and group 2, respectively

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