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N° 24

Managing growth and carcass quality of growing pigs fed low protein diets

Feeding low protein diets to pigs is one of the best preventive techniques to reduce the nitrogen pollution load from pig husbandry. By reducing the nitrogen input on farm, low protein diets limit the nitrogen output converted into nitrate and ammonia (see Ajinomoto Eurolysine Information N°22). Furthermore, in some commodity situations it may be of interest to take advantage of the lower cost for low protein feedstuffs.
The development of low protein diets in pig production is sometimes restricted, because of the possible association with lower growth performance and fatter carcass.

Do low protein diets lead systematically to depressed performance and fatter carcass ?

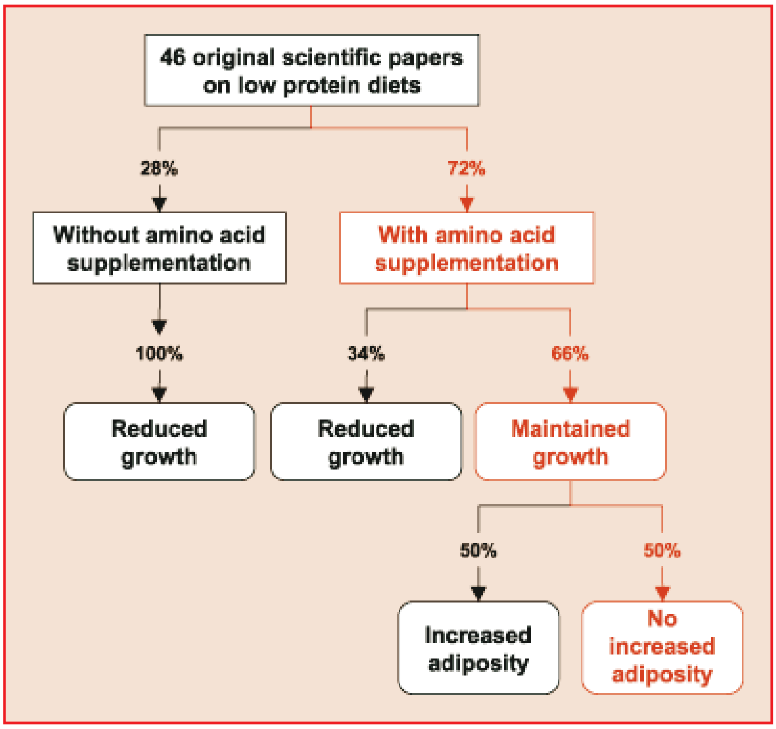
What does the literature report ? How can amino acid nutrition impact growth and carcass quality ? Should the energy contribution of low protein diets be revised in order to reach high lean meat content ?
The study of these questions, developed in this bulletin, reveals that when amino acid and energy supplies are estimated properly, with accurate and practical nutritional systems (digestible amino acids, net energy), carcass quality, as well as pig growth performance can be kept under control.

Habbe Fotografie

What does literature report ?

A literature review was conducted in order to study the effect of diets with reduced protein content on growth performance (nitrogen retention and/or weight gain) and carcass quality (protein and lipid content) at slaughter in growing-finishing pigs. Only trials reporting diets characteristics, growth performance and carcass quality measurements and where feed protein level was reduced from adequate to lower levels were collected. As a results forty six original scientific papers published between 1986 and 1999 were studied. The results of this review are presented in figure 1.

fig. 1 Impact of low protein diets on pig performance and carcass quality, schematic summary of literature review



Conclusions of the literature review

- all trials conducted without amino acid supplementation (13 experiments) resulted in a significant reduction in animal performance associated with increased carcass adiposity;
- among the remaining trials (33 experiments) conducted with industrial amino acid supplementation, 66% (22 experiments) reported no detrimental effect on growth performance;
- but half of these latter trials (11/22 experiments) still reported fatter carcasses.

The results of the literature review support the idea that a reduction in the dietary protein content requires an adapted amino acid supplementation to maintain performance level at optimum. Moreover, the frequently observed increased carcass fatness indicates that more energy is consumed and/or the energy is more efficiently used with low protein diets.
Manipulating feed protein level should take account of changes in amino acid supply and in energy utilisation.

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**see "literature review: list of references".*

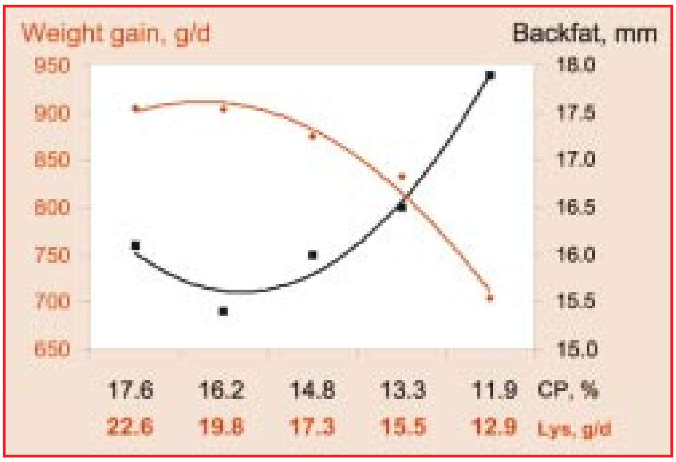
Amino acid nutrition and growth

Limiting feed protein content by reducing the amount of protein rich feedstuffs in the diet reduces the amount of both essential and non essential amino acids fed to the animal. Without any compensatory supplementation essential amino acids (lysine, threonine, methionine, tryptophan,...) amino acid levels may fall below a critical level, which is the animal requirement for each individual essential amino acid. Should the intake of one essential amino acid drop below the corresponding requirement, pig performance would drop accordingly. The deficient amino acid is then called limiting, since it penalizes animal performance. The limitation is cancelled by supplementing with the corresponding amount of industrial amino acids.

Decreasing feed protein level without supplementing with L-lysine...

Lysine is the first limiting essential amino acid for growth in pig feeds. A lysine deficiency penalizes protein synthesis and thus weight gain. As a consequence, the energy that is not retained as protein contributes to increased carcass fatness (figure 2). Adding L-lysine in feed formulation allows reduction of dietary protein level while keeping lysine content of the feed at the requirement for optimal growth.

fig. 2 Effect of reducing crude protein level without any L-lysine supplementation (Castell et al., 1994: castrates & females; 25 to 98 kg body weight)



Decreasing feed protein level without balancing amino acids...

The results by Homb and Matre (1989) support the hypothesis that the reduction in performance with low protein diets is due to a reduction of dietary essential amino acid content (table 1). L-lysine supplementation partially restores growth performance of pigs fed a low protein diet but weight gain is even more enhanced when adding L-threonine and DL-methionine.

tab.1. Effect of supplementing low protein diets with industrial amino acid on pig performances (Homb & Matre, 1989: castrates & females; 24 to 101 kg body weight; 2.2 kg of feed/day)

Diet	high protein	low protein	low protein + L-lysine	low protein + AA[1]
Crude protein, %	17.5	13.2	13.5	13.7
Lysine, %	0.89	0.60	0.90	0.90
Threonine, %	0.69	0.51	0.56	0.66
Met. + cyst., %	0.69	0.56	0.56	0.66
Weight gain, g/d	807[a]	635[d]	715[c]	777[b]

[1] L-lysine + L-threonine + DL-methionine

The amino acid composition of body proteins is quite independent of live weight, genotype and gender (Bikker, 1994; Hess, 1999). Essential amino acid requirement is thus generally expressed relatively to the most limiting: lysine. The ideal protein is a dietary amino acid profile in which all essential amino acids are balanced against lysine in order to maximize nitrogen retention and thus performance. Table 2 reports the ideal protein profiles published by Henry in 1984 and updated by Wang and Fuller in 1989 and Chung and Baker in 1993.

tab.2. The ideal protein: minimum ratios of essential amino acids relative to lysine

Reference	Henry 1984	Wang and Fuller 1989	Chung and Baker 1993
Lysine	100%	100%	100%
Threonine	60%	72%	65%
Methionine + cystine	60%	63%	60%
Tryptophan	18%	18%	18%
Isoleucine	60%	60%	60%
Valine	70%	75%	68%

The increasing availability and affordability of industrial amino acids (L-lysine, L-threonine, DL-methionine, L-tryptophan) facilitates dietary protein reduction while keeping lysine level at the requirement and balancing essential amino acids (ideal protein).
Results of Kies et al. (1992) confirms the possibility to avoid significant detrimental effect of low protein diets on nitrogen retention (see "improving the estimation of amino acid availability"). He maintains nitrogen retention and growth performance of the pigs by poly-supplementing low protein diets with industrial amino acids (table 3).

tab.3. Reducing dietary protein level with L-lysine, L-threonine, DL-methionine and L-tryptophan (Kies et al., 1992: castrates & females; growing phase from 26 to 60 and finishing phase from 60 to 95 kg body weight; feeding level adjusted to body weight)

Protein growing (G) / finishing (F), %	18 / 16	15 / 13	12 / 10	Effect
Lysine, %	0.94 / 0.86	0.94 / 0.86	0.94 / 086	-
Threonine, % lysine	71	60	60	-
Methionine + cystine, % lysine	63	60	60	-
Tryptophan, % lysine	23	19	19	-
Feed intake (G+F), g/d	2023	1989	2017	ns
N retention G, g/d/kg$^{0.75}$	1.22	1.11	1.04	ns
N retention F, g/d/kg$^{0.75}$	1.08	1.10	0.94	ns
Weight gain, g/d	845	840	820	ns

Is the non essential amino acid supply at risk ?

Wang and Fuller (1989) demonstrated that nitrogen utilisation is optimal when at least 45% of the nitrogen is brought by essential amino acids. This concept of an adequate balance between essential and non-essential amino acids for optimal nitrogen utilization at about 50:50 was confirmed by Gotterbarm et al. (1998), Heger et al. (1998) and Lenis et al. (1999). In commercial diets, the contribution of nitrogen from non essential amino acids always represents more than 50% of the nitrogen supply. Inversely the contribution of nitrogen from essential amino acids always represents less than 50% (or even less than 45%) of the nitrogen supply, as illustrated in figure 3.

The relative contribution of essential and non essential amino acids to total nitrogen supply seems to be independent of the crude protein level in the feed (figure 3A). This latter point results from the fact that when reducing feed protein level, both essential (histidine, phenylalanine, leucine,...) and non-essential amino acids are reduced. Both fractions being reduced at the same time, the balance between essential and non essential is kept more or less constant at around 45:55. This phenomenon is detailed in the experimental diets of Le Bellego et al. 2001b (table 4).

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tab.4. Breakdown of nitrogen between essential and non essential amino acids in experimental diets of Le Bellego et al. 2001b (corresponding performance results are detailed in table 9)

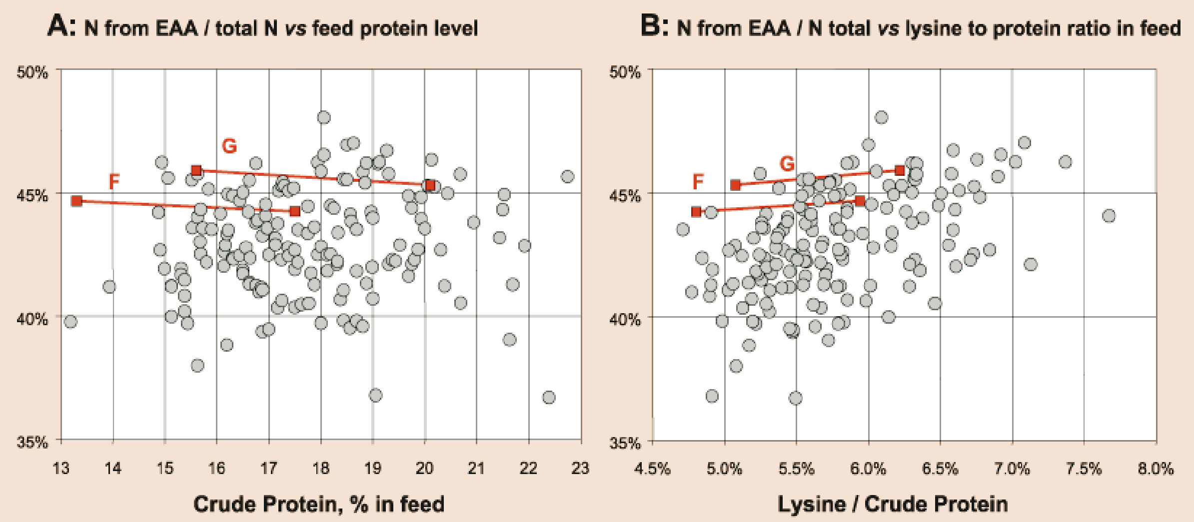
Diet	Growing		Finishing	
Crude protein, %[1]	**20.1**	**15.6**	**17.5**	**13.3**
Ingredients, %				
Wheat	32.74	38.46	35.55	41.43
Maize	34.96	40.80	37.93	43.21
Soybean meal	26.55	13.55	20.78	8.15
Wheat bran	2.50	2.50	2.50	2.50
L-lysine HCl		0.43		0.41
DL-methionine		0.10		0.07
L-threonine		0.17		0.15
L-tryptophan		0.04		0.04
L-isoleucine		0.03		0.04
L-valine		0.08		0.07
Minerals and vitamins	3.25	3.85	3.20	3.95
Dig. Lysine, % feed[3]	0.87	0.86	0.71	0.69
Total Lysine, % feed[2]	1.02	0.97	0.84	0.79
Nitrogen content, g/kg feed[3]				
in feed	32.0	24.4	27.8	20.6
in essential amino acids	14.5	11.2	12.3	9.2
in non essential amino acids	17.5	13.2	15.5	11.4
Breakdown of nitrogen[3]				
essential amino acids	45%	46%	44%	45%
non essential amino acids	55%	54%	56%	55%

[1] for a 87.3% dry matter; [2] analyzed values; [3] calculated from analysed values

According to Fuller (1989) and Gotterbarm et al. (1998) a 45:55 essential to non essential nitrogen would correspond to a 6.5% lysine:crude protein ratio and is the ratio optimising nitrogen retention. In commercial diets this correspondence (6.5%<=>45:55) is not so clear (Figure 3B) and furthermore most diets were below the optimum concentration.

In conclusion, reducing the crude protein level in the feed does not affect the relative contribution of essential and non essential amino acids to total nitrogen supply. In addition, increasing the lysine:crude protein ratio of practical growing-finishing pig diets over 6.5% and consequently the nitrogen provided by essential amino acids above 45%, may improve nitrogen utilisation.

fig. 3 Ratio between nitrogen brought as essential amino acids and total nitrogen in feed (n=174 samples of European commercial growing-finishing pig diets analysed by Ajinomoto Eurolysine in 1997 and 1998, F and G segments correspond resp. to Le Bellego et al. 2001b grower diets and finisher diets, respectively)



Improving the estimation of amino acid availability

Accounting for all amino acids by supplementing with the deficient ones, is required to formulate high performing low protein diets accurately. However, some experiments still report a tendency for lower nitrogen retention and performance, particularly for very low protein diets (Kies et al., 1992). The explanation lies in most cases in a mis-evaluation of the amount of amino acid available to the animal.

Part of the whole essential amino acids content of the feed is altered by the digestion process and some compulsory oxidations and thus not available for protein synthesis. The best practical estimation of amino acids availability today is their standardised ileal digestibility. Indeed by accounting for the basal endogenous losses, the standardized digestibility (also called true digestibility) coefficients provide a closer estimate of amino acids availability than apparent ileal coefficients. Tables such as CVB, 1998 or AmiPig (2000) provide values of standardised ileal digestibility coefficients for a wide range of feedstuffs used in pig feeding.

Results published by Jondreville et al. (1995) support the idea that formulating on a standardised ileal digestible basis allows the lowering of the protein level of the feed while maintaining animal performance (table 5).

tab.5. Reducing crude protein level with amino acid supplementation on a standardized ileal digestible basis (Jondreville et al., 1995: castrates & females; 24 to 60 kg body weight; feeding level: ad libitum)

Crude protein, %	16	14.1 + AA[1]	Effect
Total lysine, %	0.88	0.87	
Digestible lysine, %	0.83	0.83	-
Digestible threonine, % lysine	61	61	-
Digestible met.+cyst., % lysine	60	61	-
Digestible tryptophan, % lysine	23	21	-
Feed intake, g/d	1900	1900	ns
Weight gain, g/d	784	789	ns
Feed efficiency, kg/kg	2.44	2.41	ns

[1] L-lysine + L-threonine + DL-methionine + L-tryptophan.

Low protein diets spare energy from excess nitrogen metabolism
The literature review summarised previously, points out that half of the experiments conducted with amino-acid supplemented low protein diets report an increased fatness which can depreciate carcass value.
This possible effect of low dietary protein content was investigated by Noblet et al. (1987). In this experiment a control diet (17.8% protein) was compared to two low protein diets (15.3% protein), one with no supplemental amino acid and one supplemented with L-lysine in order to achieve the same level of performance as with the control (table 6).

tab.6. Effects of dietary protein content on energy utilization (Noblet et al., 1987: females, 19.5 kg body weight + 7 weeks; feeding level restricted at 22.0 kJ ME/day)

Crude protein, %	17.8	15.3	15.3 + L-lysine	Effect
Lysine intake, g/d	12.9[a]	10.8[b]	12.8[a]	$P < 0.01$
ME intake, MJ/d	22	22	22	-
Fat gain, g/d	118[a]	132[c]	124[b]	$P < 0.01$
Muscle gain, g/d	338[a]	294[b]	337[a]	$P < 0.01$
Weight gain, g/d	700[a]	649[b]	699[a]	$P < 0.01$

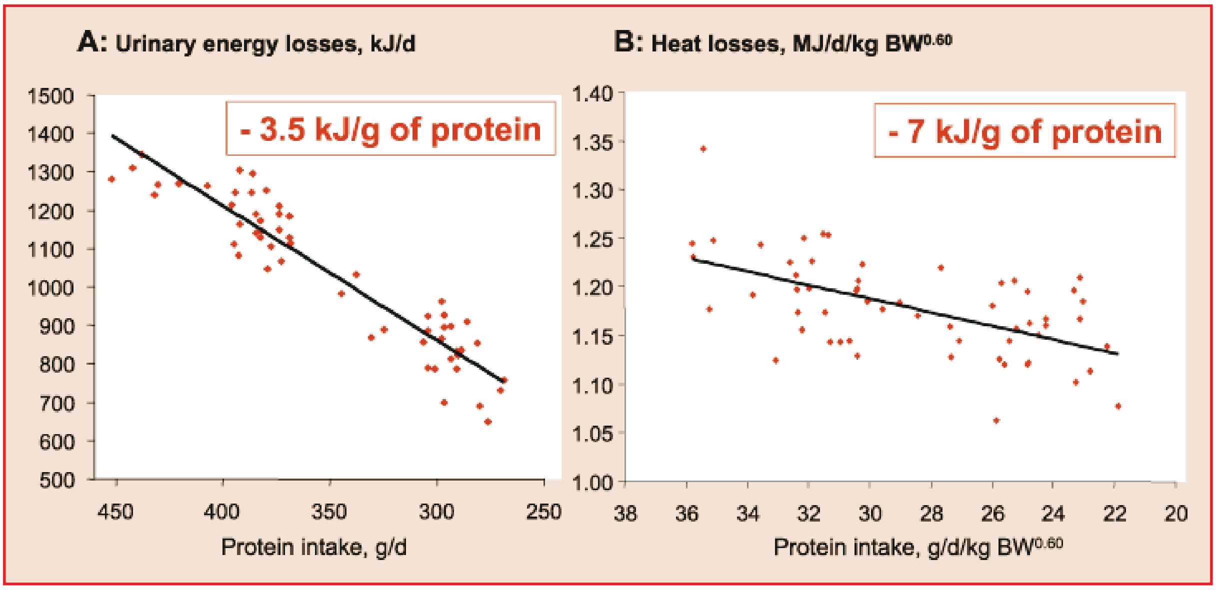
These results show that for a given metabolizable energy intake (ME) energy retention is higher when pigs are fed diets with reduced protein content. But, this additional energy is mainly retained as fat and the effect is increased when the optimal level of performance is not achieved due to inadequate amino acid supplementation.
The benefit of reduced dietary protein content on energy utilization was recently reassessed in a series of trials. Le Bellego et al. (2001a, figure 4) demonstrated on growing pigs that the reduction of dietary protein content spares energy by :

1) decreasing the energy excretion in urine associated with nitrogen excretion, estimated as 3.5 kJ per g of reduced protein intake;

2) decreasing the energy losses as heat. A lower nitrogen intake spares 7 kJ per g of reduced protein intake.

The better energetic efficiency of diets with reduced protein content explains the reported higher carcass fatness (table 7).

fig. 4 Effect of protein intake on urinary energy and heat losses
(Le Bellego et al. 2001a: castrates, 65 kg body weight, fed at 1.90 MJ NE/day)



tab.7. Effect of protein level with amino acid supplementation on energy utilization
(Le Bellego et al., 2001a: castrates, 65 kg body weight, 1.90 MJ NE/d/kg BW0.60)

Crude protein, %	18.9	16.7	14.6	12.3	Effect
NEg4[1], MJ/kg	10.25	10.35	10.44	10.51	-
Digestible lysine g/MJ NE	0.76	0.76	0.76	0.76	-
Weight gain[2], g/d	1064	1035	1020	1050	ns
Heat losses[3]	1.27[a]	1.23[ab]	1.20[b]	1.19[b]	P < 0.01
Energy retention[2]	1.13[a]	1.19[b]	1.23[bc]	1.25[c]	P < 0.01

[1] according to Noblet et al. 1994.
[2] measured over 7 days inside a respiration chamber.
[3] in MJ/d/kg $BW^{0.60}$, adjusted for zero activity and for a DE intake of 2.51 MJ/d/kg $BW^{0.60}$.

Efficient energy system should account for feed protein level

The decrease in urinary energy excretion and heat production associated with the reduction in dietary protein content is not taken into account in all energy systems. For example, the benefit on energy excretion in urine is not included in the digestible energy (DE) system, but is considered in the metabolizable energy (ME) and net energy (NE) systems. Moreover, the reduction in heat losses is exclusively taken into account in the NE system. Therefore, the NE system appears so far as the only system able to account for the better utilization of energy occurring with low protein diets. Results of Le Bellego et al. (2001a), confirm the accuracy of the NE system published by Noblet et al. (1994) and its superiority compared to the DE or ME system to predict the energy retention of the animals. These data demonstrate that at identical NE intakes low protein diets do not affect energy retention (table 8).

tab.8. Effect of protein level with amino acid supplementation on energy utilization (Le Bellego et al., 2001a: castrates, 65 kg body weight, 1.90 MJ NE/kg BW0.60)

Crude protein, %	18.9	16.7	14.6	12.3	Effect
NE intake[1]			1.82		
Heat losses[1]	1.29[a]	1.23[b]	1.19[bc]	1.17[c]	$P < 0.01$
Energy retention[1]	1.15	1.20	1.22	1.22	ns

[1] in MJ/d/kg $BW^{0.60}$, adjusted for zero activity and for a NE intake of 1.82 MJ/d/kg $BW^{0.60}$.

Validation of NE system for low protein diets

1/ pigs fed restrictively

Results by Canh et al. (1998) confirm the possibility to control carcass lean meat content and adiposity by feeding growing pigs various protein levels but identical amounts of NE and digestible essential amino acids (table 9).

tab.9. Effect of low protein diets on performance and carcass composition (Canh et al., 1998: castrates; 52 to 104 kg body weight)

Crude protein, %	16.5	14.5 + AA[1]	12.5 + AA[1]	Effect
Digestible lysine g / MJ NE	0.76	0.76	0.76	-
Weight gain, g/d	805	805	797	ns
Backfat, mm	15.2	15.4	15.9	ns
Muscle, mm	56.9	56.5	57	ns
Lean meat, %	57.2	57.1	56.7	ns

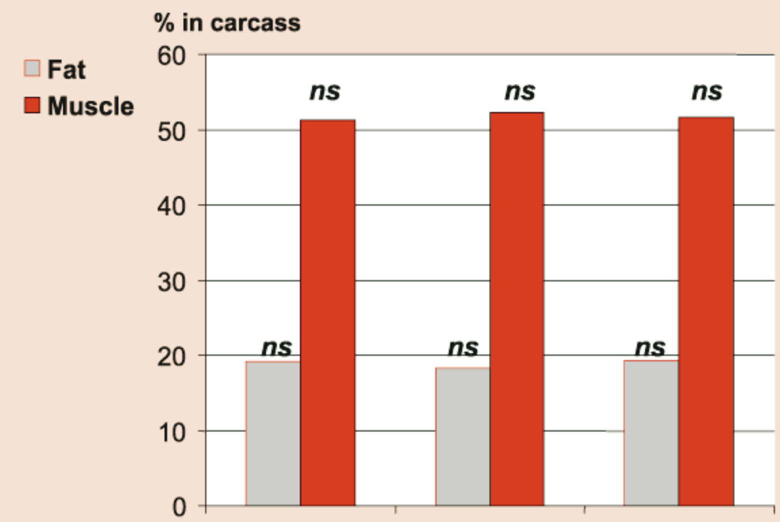
[1] L-lysine, L-threonine, DL-methionine and L-tryptophan.

But, when pigs are fed ad libitum, NE intakes cannot be controlled. Under such conditions, does dietary protein reduction result in variations in feed intake ?

2/ pigs fed ad libitum

In the experiment by Dourmad et al. (1993), pigs were fed ad libitum with diets formulated at identical NE and digestible essential amino acid contents. Results showed that it is possible to reduce dietary protein level without affecting feed intake and consequently NE and digestible essential amino acid intakes. Thus, growth performance and carcass quality were not affected (figure 5). These results are in total agreement with those of Canh et al. (1998).

fig. 5 Effect of low protein, amino acid supplemented diets on carcass quality of pigs fed ad libitum (Dourmad et al., 1993: diets containing 0.69 g digestible lysine/MJ NE; castrates & females; 55 to 105 kg body weight)



Crude protein,%	17.8	15.5	13.6	
Feed intake, g/d	2292	2319	2307	*ns*
Weight gain, g/d	846	867	852	*ns*

In practice, reducing dietary protein level results in an increased NE content. The work of Le Bellego et al. (2001b) confirm that under such conditions pigs adjust their feed intake to dietary NE content (table 10).

tab. 10. Effect of low protein diets on performance and carcass composition (Le Bellego et al., 2001b: castrates; growing phase from 27 to 65 kg and finishing phase from 65 to 100 kg; ad libitum)

Crude protein G / F diet, %	20.3 / 17.6	15.8 / 13.4	Effect
Amino acid supplementation[1]	-	+	-
Fat addition (4%)	-	-	-
NE[2] MJ/ kg (87% Dry matter)	10.1 / 10.2	10.3 / 10.4	-
Digestible lysine g/MJ NE G / F	0.85 / 0.70	0.85 / 0.70	-
Feed intake, g/d	2752[a]	2575[b]	$P < 0.01$
NE intake, MJ/d	28.14	27.02	ns
Weight gain, g/d	1098	1057	ns
Lean meat, %	58.7	59.7	ns
Fat, %	25.7	24.1	ns

[1] L-lysine, L-threonine, DL-methionine, L-trytophan, L-isoleucine and L-valine.
[2] according to Noblet et al. 1994.

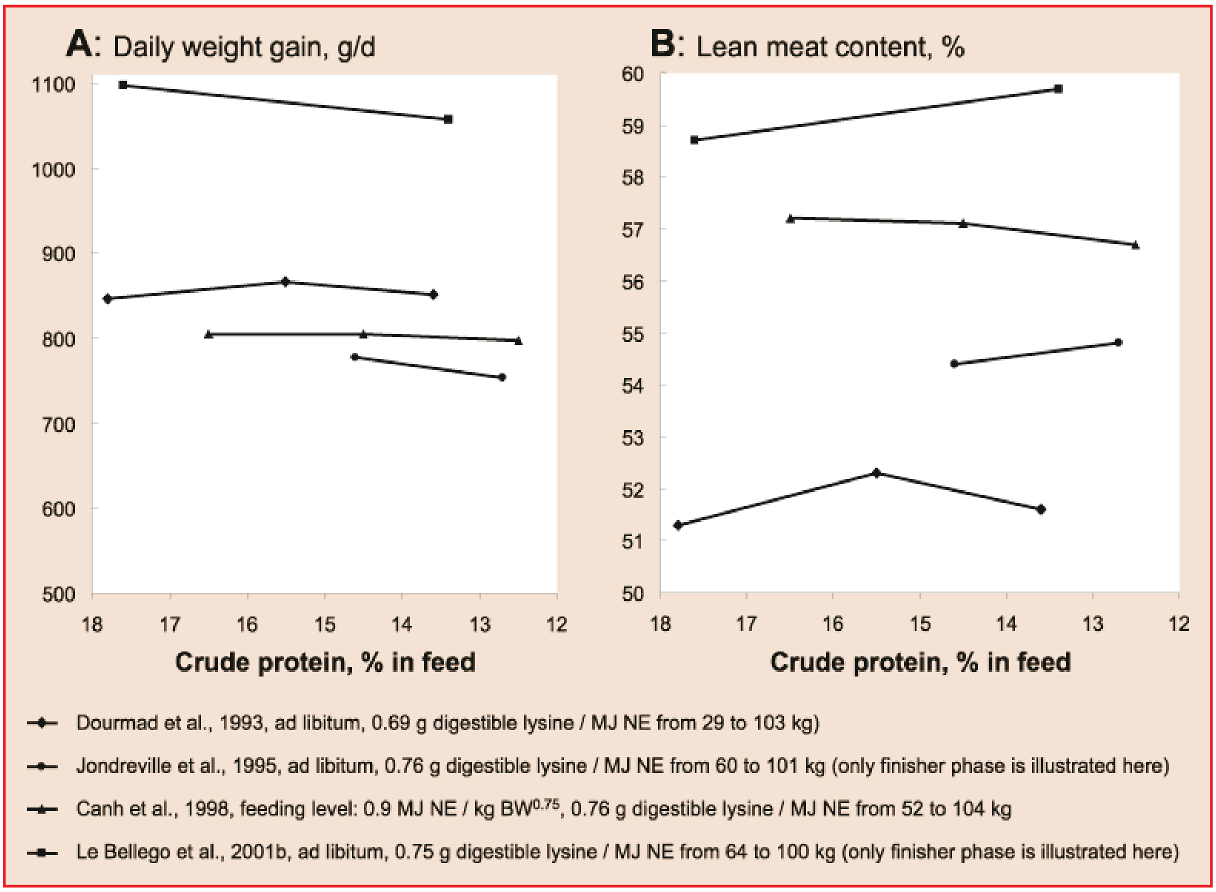
These results confirm that pigs fed ad libitum regulate their feed intake on the quantity of NE ingested. Consequently, the energy available for deposition as proteins and fat is not affected. In these conditions, adjusting the level of digestible essential amino acids to the net energy content of the diet (targeting a given digestible amino acids to net energy ratio) allows similar digestible essential amino acids intakes. Then, the partition of energy between protein and fat deposition is not affected as well as weight gain and carcass adiposity.

Decreasing feed protein level to what extent ?

The technical feasibility of reducing dietary protein content without penalising growth and especially carcass composition is demonstrated by the experiments described here-below. Figures 6A and 6B show that regardless of experimental conditions or performance level, dietary crude protein level can be reduced down to 13.5-12.5% in the finisher phase without detrimental impact on growth and carcass quality. In these experiments :

- All diets were formulated based on net energy.
- The digestible lysine level was adjusted on the net energy.
- The diets was balanced for all essential amino acids. Diets were supplemented with the required amino acids (lysine, threonine, methionine, tryptophan,...) in order to reach the right proportions of digestible amino acids against digestible lysine (Ideal Protein).

fig. 6 Effect of reducing the crude protein level in the feed on daily weight gain and on lean meat content of the carcass

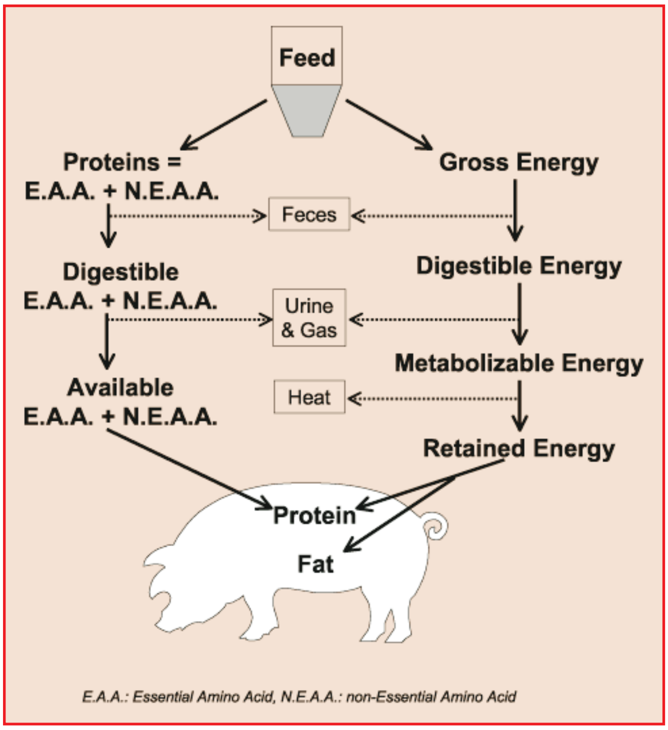


Conclusion

Reducing dietary protein content impacts both amino acid and energy content of the diet (figure 7). It thus requires the use of an adequate nutritional system (digestible amino acids and net energy) to control growth and carcass composition and to take advantage of diets with lower protein contents. In practice, to control growth performance and carcass adiposity in growing-finishing pigs, low protein diets should be formulated:

- with adjusted levels of digestible lysine to Net Energy
- with optimal ratios of essential amino acids relative to lysine (ideal protein)
- using amino acids standardized ileal digestibility coefficients.

fig. 7 Utilization of dietary amino acids and energy for body weight gain (protein and fat)



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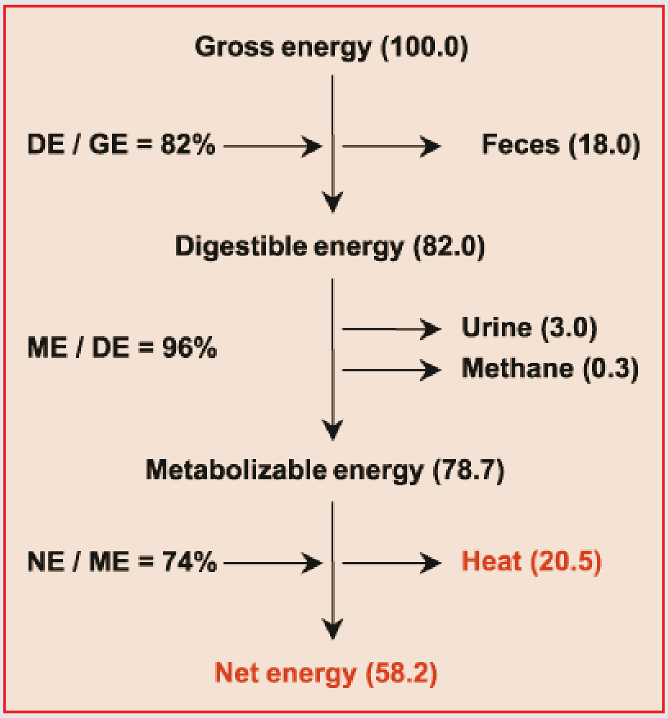
The net energy system

The energy contained in the feed, called gross energy, is not entirely available for the pig. An important fraction of the gross energy is lost in feces, urine, methane and as heat. Different systems have been proposed to estimate or predict the dietary energy effectively available for the animal. Each system corresponds to a different energy utilization level and takes into account different energy losses (figure 8).
The Digestible (DE) and Metabolisable (ME) energy systems result in rather comparable relative energy value of feedstuffs, except for protein-rich ingredients that have lower relative energy values in the ME system. Methane energy loss is quite small in pigs (<0.5% of gross energy).

fig. 8 Energy systems in pigs (Noblet et al. 1994)



The net energy (NE) system considers heat loss (25% of ME on average) that is dependent on nutrient composition (Noblet et al., 1994, table 11) with subsequent differences in the relative energy values of feedstuffs when expressed on DE or ME and NE systems. According to the low efficiency of dietary protein, the efficiency of low protein diets is higher than for conventional diets.

tab.11. Efficiencies of utilization of ME of nutrients for NE

	Protein	Starch	Fat
NE / ME	0.58	0.82	0.90

Equations for predicting the NE value (MJ/kg of DM) of diets from their DE or ME contents and chemical characteristics (g/kg of DM) obtained on 61 diets were proposed by Noblet et al. (1994):

NEg4 = 0.703 x DE + 0.0066 x EE + 0.0020 x ST - 0.0041 x CP - 0.0041 x CF
NEg7 = 0.730 x ME + 0.0055 x EE + 0.0015 x ST - 0.0028 x CP - 0.0041 x CF

CP: crude protein; EE: ether extract (fat); ST: starch; ADF: acid detergent fiber; CF: crude fiber; DE: digestible energy; ME: metabolizable energy.

These equations and NE values of current feedstuffs and ingredients for pigs are available into a formulation software: the net energy calculator[3].

[3] *Available on request at Ajinomoto Eurolysine or download at http://www.lysine.com*

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AJINOMOTO EUROLYSINE

153, rue de Courcelles, 75817 Paris, Cedex 17
Tel : (33) 01 44 40 12 12 - Fax (33) 01 44 40 12 13

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