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N° 26

Threonine requirement in pigs
Benefits of L-threonine supplementation

The increased use of cereals in pig diet formulation and the lowering of feed protein content, together with the subsequent increased use of free lysine to match the animals requirement, has led nutritionists to consider more and more precisely the threonine level as it becomes a limiting amino acid in many practical formulas. Besides its utilisation for protein synthesis (growth and milk synthesis), threonine is involved in some other physiological functions, such as digestion and immunity. As a consequence, the whole threonine requirement is likely to vary according to the importance of each function. Assessing threonine requirement for given physiological stage is then key for formulating amino acid balanced feed.

How do pigs respond to threonine balance ?

Is the question addressed in this bulletin where threonine requirement in piglets, growing-finishing pigs and sows is reviewed based on a compilation of literature data and recent trial results. Some elements of threonine involvement in maintenance, digestion and immunity are also documented.

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Growing pigs response to increased threonine levels

In order to bring a broad and solid approach of growing pigs response to threonine balance, a literature review on the effect of the Thr:Lys ratio on the performance of piglets (below 25 kg body weight) and growing finishing pigs (between 16 and 120 kg body weight) was conducted. Only the articles reporting the feedstuffs composition of the experimental diets and amino acid levels were considered for this review. When not given by the authors, the ileal standardised digestible amino acid contents of the experimental diets were calculated using the coefficients of the AmiPig (2000) table.

■ Threonine requirement in piglets

Six different trials were collected (this review was already published in Ajinomoto Eurolysine Information N°25, dedicated to piglet amino acid nutrition). Table 1 summarises the experimental designs and table 2 reports diet composition and nutrients levels. In these six trials, the incremental Thr:Lys ratios were obtained by L-threonine addition to a basal diet, except for Gâtel and Fekete, 1989b whose experimental diets varied in protein levels. Piglet response to L-threonine supplementation (feed intake, weight gain and feed conversion ratio) is presented in table 3.

tab. 1. Summary of experimental designs (6 piglet trials, 5 papers).

Reference[1]	Age at weaning, d	Weight range	Crude protein, %	Energy value MJ/kg	Animals per treatment	Housing
Lewis & Peo, 1986	21-28	4 to 14 kg	15.9	-	16	groups of 4
Gatel & Fekete, 1989a	28	8 to 25 kg	20	13.5 DE	105	groups of 6 or 7
Gatel & Fekete, 1989b	28	8 to 25 kg	17.7 to 23.8	13.5 DE	96	groups of 6 or 7
Adeola et al., 1994	-	10 to 20 kg	18.1	-	6	individual
Schutte et al., 1996	-	10 to 20 kg	18.5	9.7 NE	40	groups of 10
Usry, 1999	-	11 to 23 kg	19.0	13.9 ME modified	220	groups of 22

1 ad libitum feeding.

tab.2. Composition and main nutritional values of the experimental diets (6 piglet trials, 5 papers).

	Lewis & Peo, 1986	*Gâtel & Fekete, 1989a*	*Gâtel & Fekete, 1989b*	*Adeola et al., 1994*	*Schutte et al., 1995*	*Usry, 1999*
Barley					35.0	
Wheat		72.0	64.4 - 80.2			
Corn				20.0	15.0	63.0
Sorghum	63.7					
Soybean meal	12.5	23.2	14.8 - 31.4	20.0	14.0	29.5
Peas					5.0	
Tapioca					10.5	
Oat groats	15.0					
Fish meal	2.5				2.0	
Fat				4.0	1.3	3.6
Corn starch				37.4		
Skim milk powder				5.0		
L-lysine	0.67	0.47	0 - 0.53	0.67	0.22	0.23
L-threonine	0 - 0.3	0 - 0.17	0 - 0.20	0 - 0.26	0 - 0.2	0 - 0.15
DL-methionine	0.05	0.07	0 - 0.07	0.22	0.17	0.07
L-tryptophan	0.03		0 - 0.2	0.04	0.04	
L-isoleucine	0.07					
Others	5.49	4.2	4.2	12.7	11.21	3.6
Crude protein, %	15.9	20.0	17 - 23.8	13.1	18.5	19.0
Energy, MJ/kg		13.5 DE	13.5 DE		9.7 NE	12.6 ME
Digestible amino acids, %[1]						
Lysine	1.15	1.13	1.05	0.90	1.00	1.11
Threonine	0.45 - 0.75	0.60 - 0.77	0.48 - 0.71	0.34 - 0.60	0.52 - 0.72	0.72 - 0.87

[1] *ileal standardised basis*

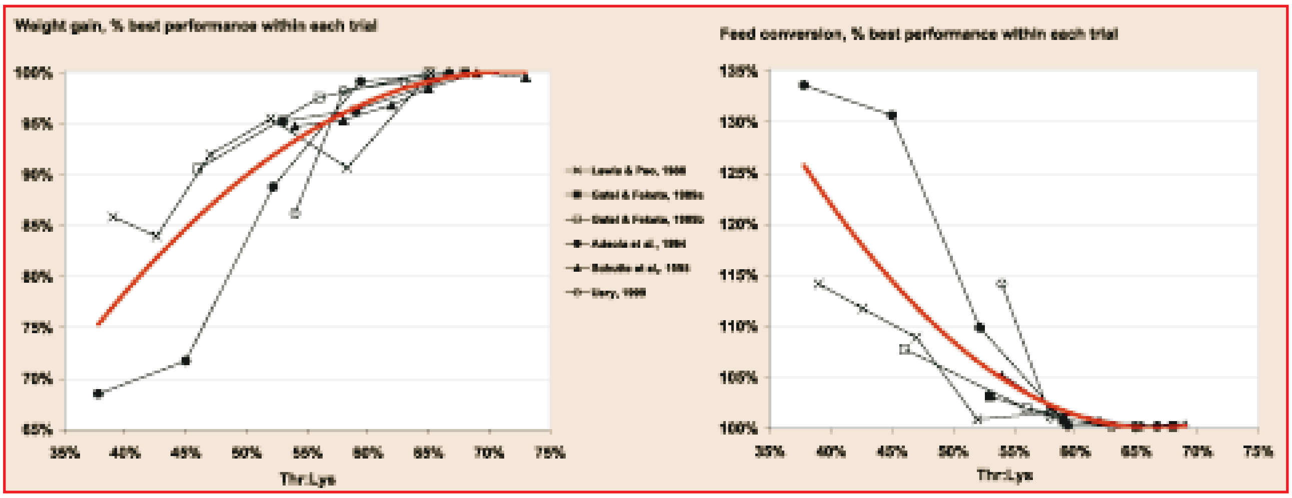
tab.3. Response of piglets to increased Thr:Lys ratio[1] (6 piglet trials, 5 papers).

Lewis & Peo, 1986	[4-14 kg]					
Thr : lys	39	43	47	52	58	65
Feed intake, g/d	511	489	522	502	480	522
Weight gain, g/d	268	262	287	298	283	312
FCR, kg/kg	1.91	1.87	1.82	1.68	1.70	1.67
Gâtel & Fekete, 1989a	[8-25 kg]					
Thr : lys	53	59	68			
Feed intake, g/d	920	946	940			
Weight gain, g/d	526	532	552			
FCR, kg/kg	1.75	1.71	1.7			
Gâtel & Fekete, 1989b	[8-25 kg]					
Thr : lys	46	56	65	68		
Feed intake, g/d	1040	1070	1070	1030		
Weight gain, g/d	567	611	626	595		
FCR, kg/kg	1.84	1.74	1.71	1.74		
Adeola et al., 1994	[10-20 kg]					
Thr : lys	38	45	52	59	67	
Feed intake, g/d	987	1011	1052	1072	1080	
Weight gain, g/d	337	353	437	488	492	
FCR, kg/kg	2.93	2.86	2.41	2.20	2.20	
Schutte et al., 1995	[10-20 kg]					
Thr : lys	54	58	62	65	69	73
Feed intake, g/d	691	674	676	683	695	700
Weight gain, g/d	453	456	463	471	478	476
FCR, kg/kg	1.53	1.48	1.46	1.45	1.46	1.47
Usry, 1999	[11-23 kg]					
Thr : lys	54	58	63	68		
Feed intake, g/d	735	741	741	757		
Weight gain, g/d	454	517	522	526		
FCR, kg/kg	1.62	1.43	1.42	1.44		

[1] Ileal standardised basis

Because of the variation in absolute performance level due to weight ranges, genotypes, experimental conditions, and in order to identify the response to threonine balance throughout these trials, the results were expressed on a relative scale, i.e. in percentage of the best performance observed within each trial (figure 1).

fig.1. Effect of the thr:Lys ratio (ileal standardised digestible basis) on weight gain and feed conversion ratio (relative to best response within each trial) in piglets from 4 to 25 kg.



The analysis of the results on a relative scale shows that increasing the Thr:Lys ratio through L-threonine supplementation allows piglet performance to be optimised (weight gain and feed conversion) with a maximum response obtained with a Thr:Lys ratio at 65% (standardised ileal digestible basis).

■ Threonine requirement in growing - finishing pigs

In growing finishing pigs, 12 articles were collected reporting 16 trials with pigs between 16 and 120 kg. Experimental designs are summarised in table 4. Similar to the piglet trials, the incremental Thr:Lys ratios were obtained by L-threonine addition to a basal diet. Diets compositions and nutrients values are presented in table 5.

tab.4. Summary of experimental designs (6 growing-finishing pig trials, 12 papers).

	Taylor et al. 1982	Conway et al. 1990	Schutte & De Jong, 1995	Chang et al. 2000 a & b	Sève et al., 1993	Lenis et al., 1990 a & b
Weight range, kg	25 - 55	17 - 50	20 - 40	16 - 56	25 - 50	35 - 65 & 65 - 105
Number of pigs per pen	-	6	10	-	3	1
Number of pigs per treatment	8	24	40	25	10	16
Number of treatments	8	5	6	3 per sex	6	4
Total number of pigs in trial	64	120	240	150	60	64
Genotype	LW x Ld	DLd x GY	DLd x Pt	(Yk x Ld x Dc)	Pt x LW	(GY x (GY x NL))
Sex	gilts	barrows & gilts in separate pens	barrows & gilts in separate pens	barrows & gilts in separate pens	barrows & gilts in separate pens	barrows & gilts
	Lenis and Van Diepen, 1990	**Saldana et al., 1994**	**Schutte et al., 1997 a & b**	**Lynch, 2000 a & b**	**Cadogan et al. 1998**	**Usry, 2000**
Weight range, kg	65 - 95	58 - 96	50 - 95	50 - 95	60 - 100	90 - 120
Number of pigs per pen	8	2	8	13 - 14	10	8 - 10
Number of pigs per treatment	32	20	48	140	40	43
Number of treatments	4	5	8	5	5 per sex	5
Total number of pigs in trial	128	100	384	714	600	215
Genotype	(GY x (GY x NL))	(YkxLd) x (DcxHp)	LW x DLd	(Ld x LW) x meat-line sire	Bunge	PIC 337XC22
Sex	barrows & gilts in separate pens	barrows & gilts in separate pens	gilts	barrows & gilts in separate pens	boars, barrows & gilts in separate pens	barrows & gilts in separate pens

tab.5. Composition and nutritional values of the experimental diets (16 growing-finishing pig trials, 12 papers).

Composition, %	Taylor et al. 1982	Conway et al. 1990	Schutte & De Jong, 1995	Cheng et al. 2000 a	Cheng et al. 2000 b	Sève et al. 1993	Lenis et al., 1990 a & b	Lenis and Van Diepen, 1996	Saldana et al., 1994	Schutte et al. 1997 a	Schutte et al. 1997 b	Lynch, 2000 a	Lynch, 2000 b	Cadogan et al. 1998 60-75 kg	Cadogan et al. 1998 75-100 kg	Uzu, 2000
Barley	88.50		35.00					25.00		15.00	1.00	15.00	15.00	25.00	38.70	
Corn		38.20	15.00	71 - 78	71 - 80			15.30		2.00	31.00					90.00
Wheat						82.60	15.00			45.00	1.00	48.00	40.00	62.00	52.00	
Rye											12.00					
Lupine														5.80	2.73	
Peas			5.00				8.50				10.00	22.50	24.30			
Manioc / tapioca			14.42				34.10	33.50		8.20	2.70					
Sorghum									95.34							
Soybean meal	4.00		14.70	14.5 - 17.6	14.5 - 16.7		9.50	5.50		9.00	1.40			2.00		5.20
Rapeseed meal											7.50					
Hominy (corn) feed		40.00					9.00									
Peanut meal						7.74										
Alfalfa								6.00								
Wheat gluten						3.65										
Wheat middlings			2.00							18.00	11.00	7.60	13.20			
Wheat bran							15.00									
Corn gluten feed								5.50		1.90	13.00					
Corn starch						1.16			0.20							
Skim milk powder								1.50								
Soya oil			0.60					1.40		0.50	2.50					
Animal fat				1.7 - 4.3	1.7 - 4.8		2.00					1.20	2.00			1.50
Fish meal	2.00		2.00													
Meat & bone meal		10.70	1.00											1.00	1.00	
Whey powder			3.00													
Molasses			2.00	4.00	4.00		4.00	3.00		4.00	4.00	3.00	3.00			
Others	3.48	12.30	4.71	2.50	2.65	4.00	2.30	2.30	2.63	3.10	2.00	2.20	2.18	3.93	4.00	3.00
L-lysine HCl	0.50	0.86	0.21	0.83-0.49	0.77-0.63	0.58	0.31	0.53	0.69	3.00	0.32	0.39	0.17	0.40	0.37	0.34
L-threonine	0 - 0.36	0 - 0.2	0 - 0.23	0.12-0.42	0.13-0.42	0 - 0.27	0 - 0.15	0 - 0.17	0 - 0.2	0 - 1.2	0 - 1.2	0 - 0.18	0 - 0.09	0 - 0.27	0 - 0.25	0 - 0.13
DL-methionine	0.12	0.05	0.13	0.15-0.21	0.22	0.04	0.15	0.12	0.05	0.70	0.05			0.09	0.53	
L-tryptophan	0.03	0.06	0.03			0.03	0.06	0.06	0.06		0.05			0.02	0.01	0.02
L-isoleucine		0.19					0.07	0.10	0.03					0.01	0.02	0.05
L-valine		0.08				0.01		0.03								
L-histidine		0.09						0.06								
Crude protein, %	12.9	16.4	17	17	17	16.4	13.7	13.4	10.5	14.7	15.1	14.8	16.6	13.4	11.7	10
energy, MJ/kg		9.8 NE	9.5 NE	14.8 DE	14.6 DE	13.4 DE	9.04 NE	9.4 NE	14.0 DE	9.08 NE	9.08 NE	9.6 NE	9.7 NE	9.47 NE	9.35 NE	13.7 ME
Fat, %	1.5		2.8				3.4	3		2.4	4.6	3.9	3.8	2.3	2.1	
Crude fiber, %	3.7		3.8				4	3.8		3.4	4.4	4.4	4.8	3	3.4	
Digestible amino acids, %*																
Lysine	0.86	1.1	0.81	1	1.12	0.77	0.77	0.73	0.63	0.71	0.71	0.78	0.75	0.74	0.7	0.58
Threonine	0.38-0.53	0.52-0.69	0.37-0.81	0.47-0.87	0.53-0.75	0.37-0.64	0.40-0.53	0.38-0.53	0.24-0.43	0.34-0.46	0.34-0.47	0.38-0.56	0.46-0.55	0.35-0.67	0.30-0.56	0.29-0.41

*Ileal standardised basis

Pigs response (weight gain and feed conversion) to increased Thr:Lys ratios is reported in figure 2.

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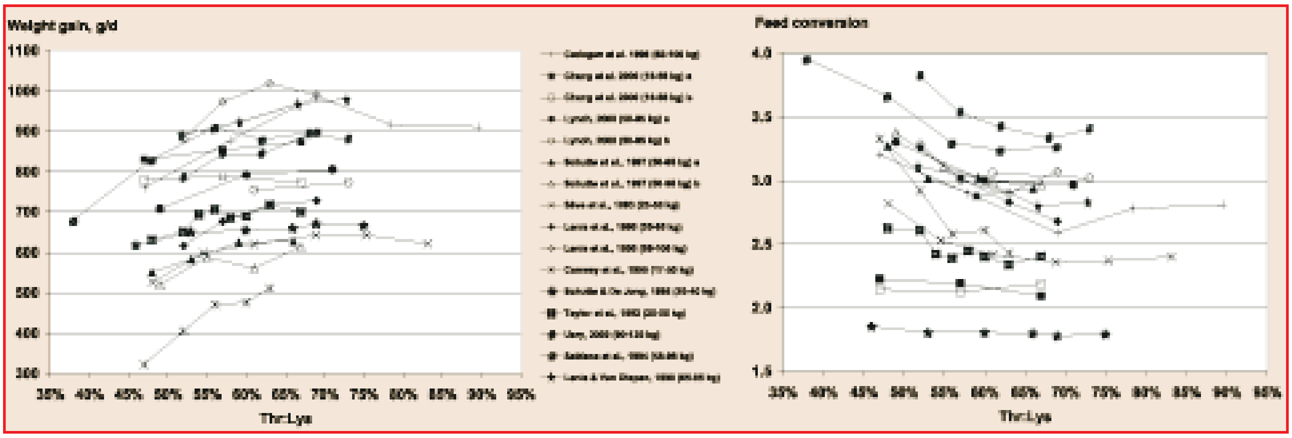
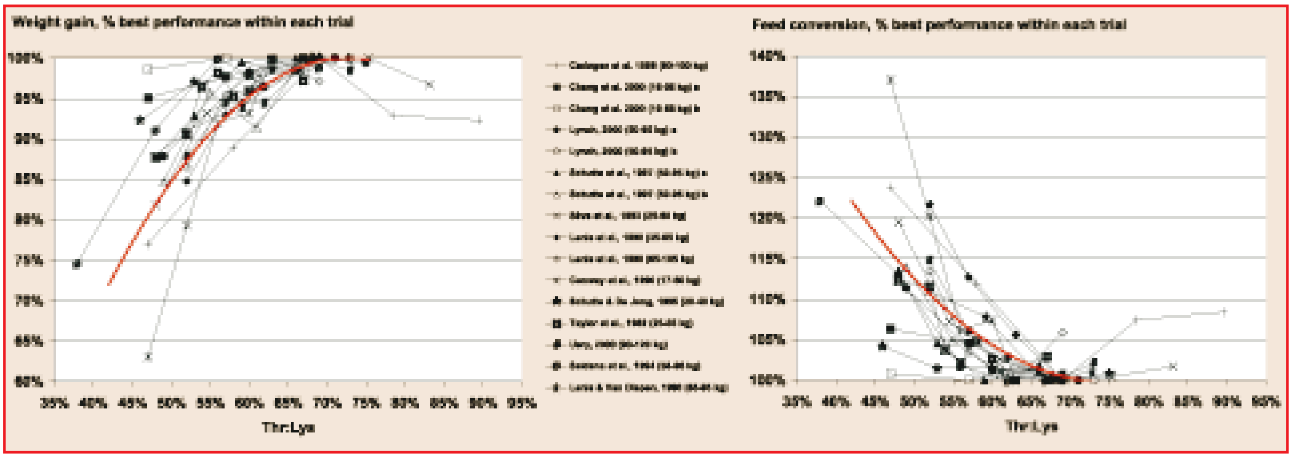
fig.2. Effect of the Thr:Lys ratio (ileal standardised digestible basis) on weight gain and feed conversion in pigs from 16 to 120 kg.



As with the piglet study in order to observe the response to threonine balance while integrating differences in performance levels among trials, results were expressed in percentage of the best performance within each trial (figure 3).

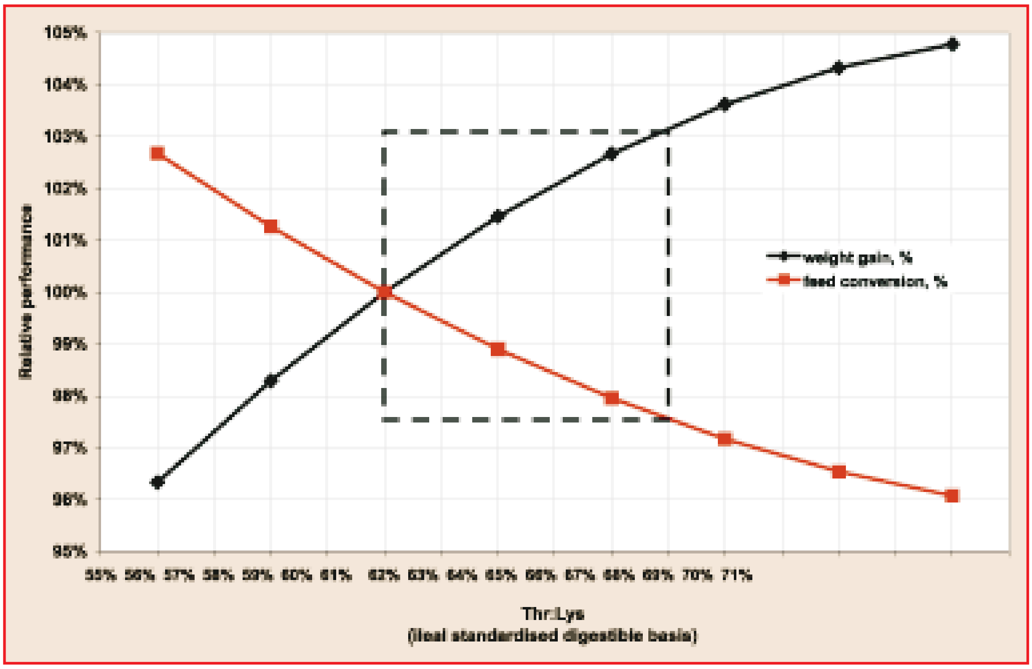
Even on a relative scale, the data in growing finishing pigs seems to reveal a higher variability in threonine response than in piglets. This is partly due to the higher number of experiments studied compared with the piglet phase (16 vs 6 trials). Throughout this extended number of trials, variations in animal health status, diet composition and pig body weight is likely to be responsible for the differences in optimal Thr:Lys levels. Indeed, 6 trials out of 16 conclude in an optimal Thr:Lys ratio slightly below 65%, whereas the other 10 trials conclude in optimal Thr:Lys ranging from 67 to 73% (69%, on average). Finally, in most trials and on average (figure 3), the optimal Thr:Lys ratio in growing finishing pigs is at least 65% (ileal standardised digestible basis).

fig.3. Effect of the Thr:Lys ratio (ileal standardised digestible basis) on weight gain and feed conversion (% of the best performance within each trial) in pigs from 16 to 120 kg.



The polynomial equations fitted to weight gain and feed efficiency dose response curves (figure 3) allow to quantify the average relative improvement obtained in each criteria when modulating Thr:Lys ratio. These averaged dose response curves show that when Thr:Lys ratio is increased through L-threonine supplementation from 60 up to 65%, weight gain is improved by 3 points and feed conversion by 2.5 points (figure 4).

fig.4. Effect of the increase in Thr:Lys ratio through L-threonine supplementation on the relative evolution of weight gain and feed conversion in feed conversion in pigs from 16 to 120kg, derived from figures 3.



Reference: base 100 with ileal standardised digestible Thr:Lys = 60%
Weight gain (%) = -2.9877 x Thr:Lys² + 4.3392 x Thr:Lys - 0.5755
Feed conversion (%) = 2.0587 x Thr:Lys² - 3.0863 x Thr:Lys + 2.1544

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Sows response to increased threonine levels

Threonine requirement in gestating sows

Gestating sows are heavy animals and therefore have a high maintenance requirement. As the whole threonine requirement depends on both tissue deposition and maintenance expenditure, threonine requirement of the gestating sow would logically be closer to the maintenance requirement (see Info 3). As a consequence, the optimal Thr:Lys ratio in the gestating sow is higher than for the growing pig as indicated by many official recommendations (table 6).

tab.6. Threonine recommendations for gestating sows.

	ARC, 1981	Dourmad, 1997[1]	NRC, 1998
Thr:Lys	84%	71%	70%

[1] Ajinomoto Eurolysine Information Bulletin N°21

However, these recommendations were mostly obtained through calculations based on the threonine maintenance requirement of Fuller *et al.* (1989), and few experimental validations were available until the recent work by Dourmad and Etienne (2002). Based on nitrogen retention the authors assessed successively lysine (Exp. 1, table 6 and figure 5) and threonine (Exp. 2, table 7 and figure 6) requirements. The two trials were conducted in a 4x4 latin square design on 8 and 16 gestating sows for the lysine and the threonine response, respectively. Based on the results of the first trial the authors could define a sub-limiting lysine (0.33%) to implement the threonine ratio study.

tab.7. Composition and nutritional values of diets in the work by Dourmad and Etienne (2002) Exp. 1 : lysine response, Exp. 2 : threonine response.

	Exp. 1	Exp. 2
Wheat	30.88	40.00
Corn	45.00	-
Barley	-	34.34
Sugar beet	9.50	9.00
Corn gluten	10.00	-
Corn starch		11.10
Others	4.25	4.08
L-lysine·HCl	0 to 0.30	1.85
L-threonine	0.41	0 to 0.10
DL-methionine	-	0.37
L-tryptophan	0.26	0.05
L-isoleucine	-	0.69
L-valine	-	0.66
Crude protein, %	14.3	9.3
Ether extract, %	2.36	3.55
Crude fibre, %	3.30	5.33
ME, MJ / kg	13.7	12.88

Fig.5. Lysine requirement in gestating sows (Dourmad and Etienne, 2002).

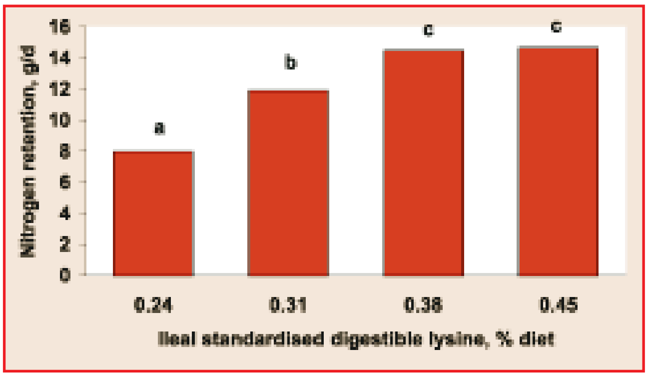
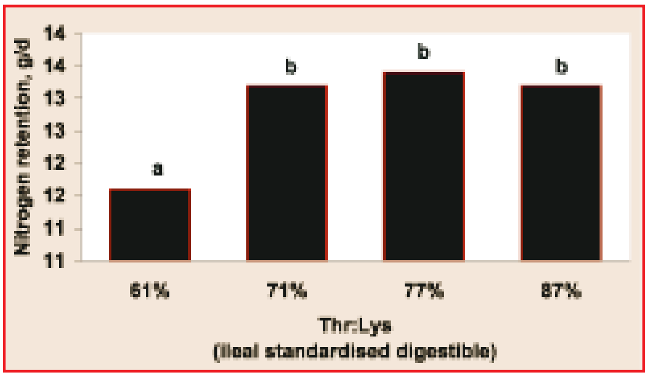
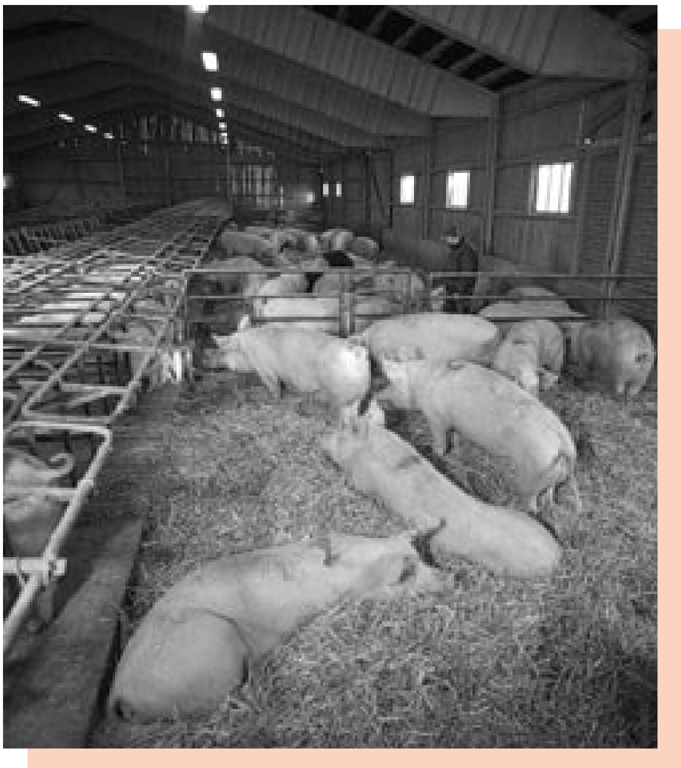


fig.6. Optimal Thr:Lys ratio in gestating sows (Dourmad and Etienne, 2002).



The results of Dourmad and Etienne (2002) confirm that the Thr:Lys ratio that optimises performance in gestating sows is higher than in growing-finishing pigs and is above 70% (ileal standardised digestible basis).



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■ Threonine requirement in lactating sows

Like gestating sows, the threonine requirement of the lactating sow is expected to be higher than in lighter animals. This is confirmed by the work published by Westermeier *et al.* (1998) and Paulicks *et al.* (1998). These authors investigated the threonine requirement in 72 multiparous lactating sows over a 35 days lactation period. In this study the Thr:Lys ratio was increased through L-threonine addition in a semi-synthetic basal diet. Table 8 reports the basal diet composition and the nutrient values.

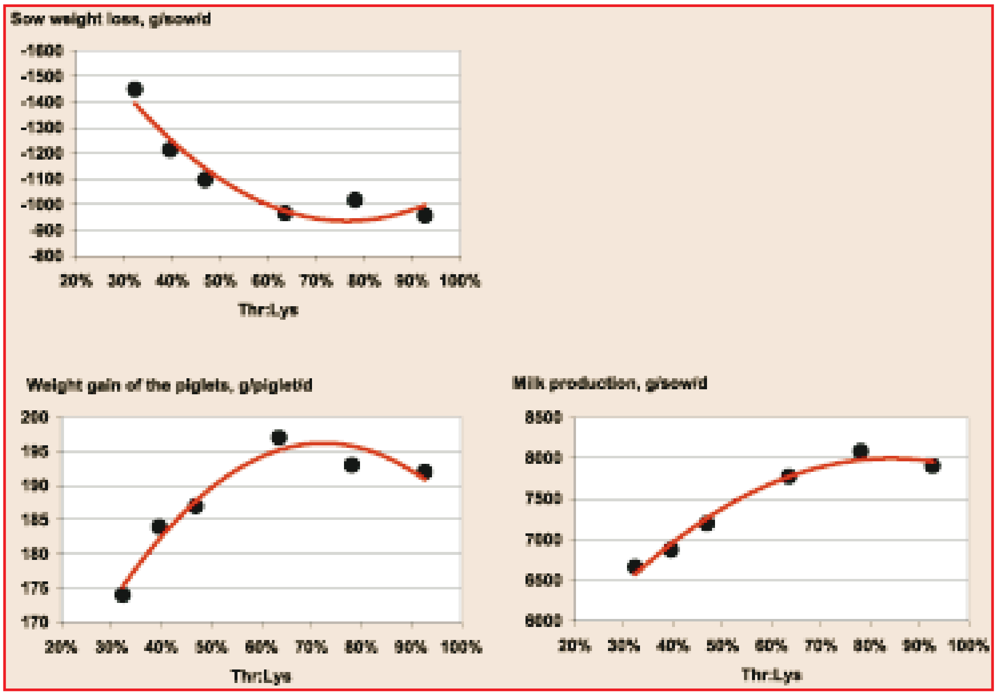
tab.8. Composition and analysed nutrient contents (Westermeier et al., 1998 Paulicks et al., 1998).

Ingredients	(%)	Nutrients	Analysed , g/kg
Wheat	44,0	Drymatter	901
Wheatglutenmeal	8,5	Crude protein	145
Maize starch	23,0	Crude fat	20
Sugar	9,0	Crude fiber	54
Soybean oil	1,0	T. Lysine	9,6
Cellulose	6,0	T. Threonine	3,1
Others	5,5	T. Tryptophan	1,8
L-lysine HCl	0,92	ME (MJ/kg)	13,5
L-threonine	0 - 0,64		
Other free AA*	1,93		

*Methionine, Tryptophan, Valine, Histidine, Leucine, Isoleucine, Phenylalanine

The progressive addition of L-threonine decreased sow body weight losses across lactation and increased milk production and thus litter weight gain. The Thr:Lys ratio minimising sow body weight loss and maximising milk production and litter weight gain was found to be above 74% on a total amino acid basis (figure 7). This corresponds to at least 72% on an ileal standardised digestible basis, as the diets used in this study were semi-synthetics and therefore highly digestible.

fig.7. Effect of the Thr:Lys ratio on lacting sow performance (Westermeier et al. 1988 and Paulicks et al. 1998)



The optimal Thr:Lys ratio in lactating sows found by Westermeier *et al.* (1998) and Paulicks *et al.* (1998) is higher than the one reported by Cooper *et al.* (2001), who found 69% on a total basis as an optimal Thr:Lys ratio (corresponding to about 65% on an ileal standardised digestible basis). However, as stated by the authors, this result was obtained on sows that were not losing weight over the lactation period. Such a situation where sows gain weight (or maintain it) is rather unusual since in practice sow body weight losses across lactation could reach 15 to 20 kg (Boyd *et al.*, 2000; Renaudeau *et al.*, 2001). In the Cooper *et al.* (2001) work, due to the high feed intake capacity of the sows, the essential amino acid needs including threonine were exclusively provided through the diet with no contribution of body tissue mobilisation. This is the main explanation for the relatively low Thr:Lys ratio found by these authors. Indeed, the work of Kim *et al.* (2001) suggests that when essential amino acids are exclusively originating from the diet, the optimal Thr:Lys ratio would be 65%, while when essential amino acids are coming from tissue mobilisation the optimal Thr:Lys would be 75%. This is in good agreement with the results of Westermeier *et al.* (1998) and Paulicks *et al.* (1998) and confirms that when amino acid needs during lactation are covered by a combination of dietary supply and tissue mobilisation, the optimal Thr:Lys ratio in lactating sows is at least 70% ileal standardised digestible.

Habbe Fotografie

Conclusions

Based on the literature review and recent trial results, the optimal Thr:Lys ratio in piglets is confirmed at 65% ileal standardised digestible basis. For growing-finishing pigs 65% ileal standardised digestible basis seems to be a minimum level for optimising growth rate and feed efficiency (10 out of 16 trials studied found their optimum above 67%). For sows, as a result of a requirement for maintenance on one side and milk production on the other side, the Thr:Lys ratio that optimises the reproductive performance of the sow is at least 70% during both gestation and lactation.

Threonine requirement in pigs

	Thr:Lys*
Piglet	= 65 %
Growing - finishing pig	> 65 %
Gestating sow	> 70 %
Lactating sow	> 70 %

**ileal standardised digestible basis*

Habbe Fotografie

Info 1 Threonine is the second limiting amino acid in pig diets

The ranking of limiting amino acids is assessed by determining the protein level at which each amino acid becomes limiting. This latter protein level is determined by both the amino acid specifications set for the diet and by the ingredients proposed to match these specifications.

In order to assess in a standard situation the ranking for limiting amino acids, a grower and a finisher diet were tested with respectively 0.90 and 0.70% standardised digestible lysine while the minimum amino acid ratios defined by Henry (1993) were applied (65%, 60%, 18% resp. for Thr:Lys, M+C:Lys and Trp:Lys). The feedstuffs used in the formulations were wheat, barley and soybean meal, described by their protein and digestible amino acids levels reported either in the AmiPig (2000) table or the CVB (2001) table.

Figure 8 illustrates the protein levels at which each amino acid becomes limiting for the described examples.

fig.8. Ranking limiting amino acids in wheat-barley-soybean meal diets for growing and finishing pigs.

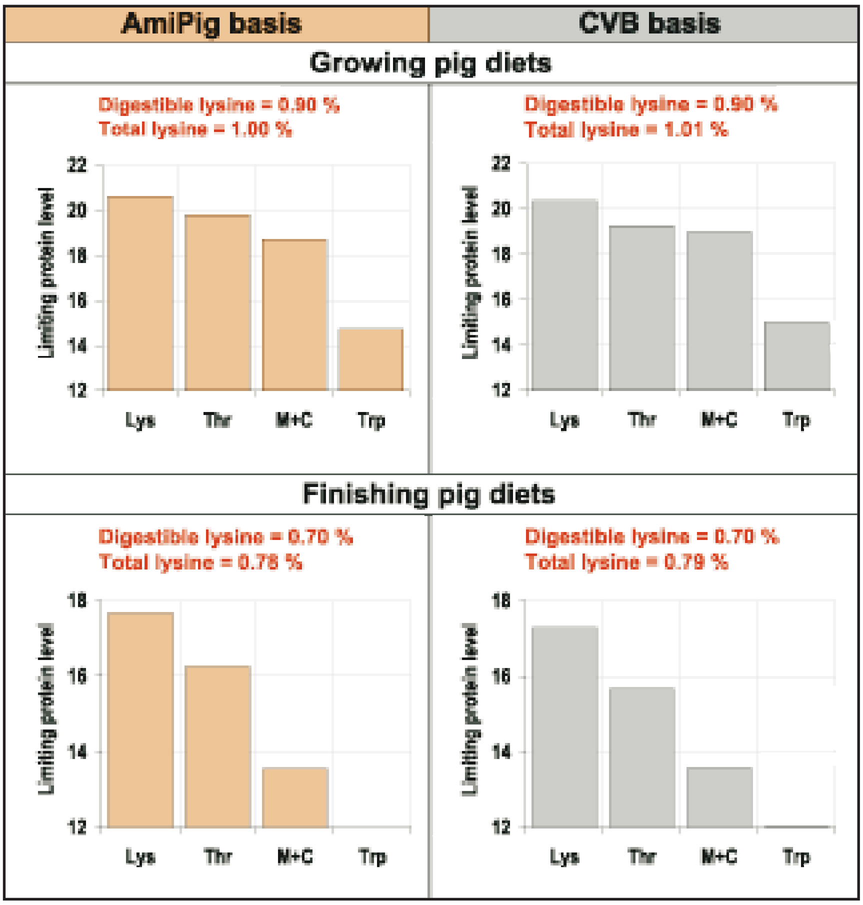


Figure 8 confirms that, according to both the AmiPig (2000) and the CVB (2001) table, lysine is the first limiting amino acid in pig diets. Using the above described specifications, without free lysine supplementation, it was not possible to formulate a grower and a finisher diet below 20.6 and 17.7% crude protein level, respectively. Without free threonine supplementation, it was not possible to decrease dietary protein level below 19.8 and 16.2%, respectively, while maintaining a 65% Thr:Lys ratio. This formulation exercise shows, that threonine is the second limiting essential amino acid, after lysine and before sulfur amino acids, in wheat-barley-soybean meal based diets.

Info 2 Threonine : a key nutrient for the gut

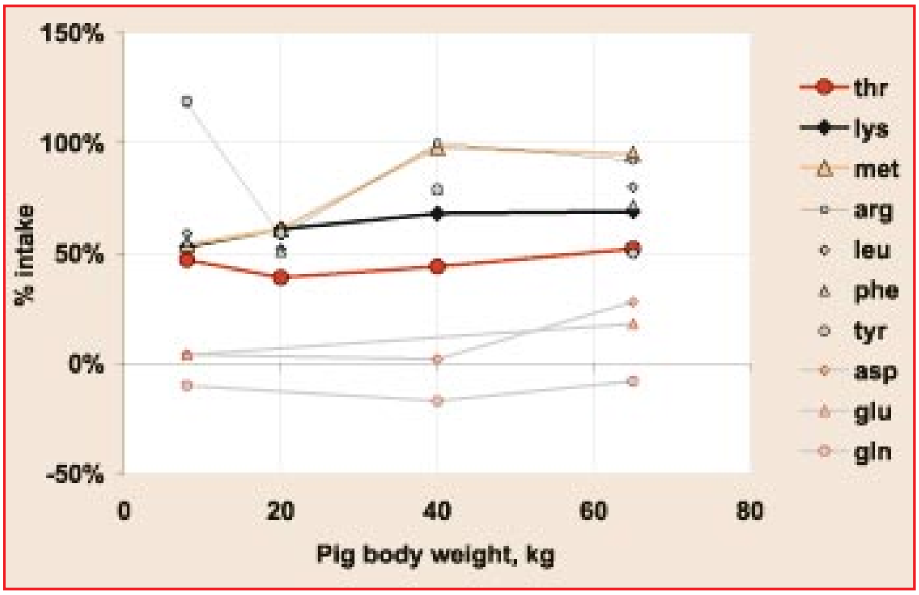
A major fraction of dietary threonine, similar to other amino acids, is absorbed in the upper part of the small intestine - named the ileum. The remaining fraction is recovered at the end of the ileum (undigestible amino acid).

The threonine fraction that is absorbed by the ileum is not entirely delivered in the portal blood which collects the nutrients from the digestion process. Indeed, a significant part of the digestible threonine may be uptaken by the digestive tract itself. Stoll *et al.* (1998) ran an experiment using an isotope tracer on 28 day-old piglets (8 kg). They showed that only 40% of the luminal threonine reaches the portal blood. In other words, the enterocytes use 60% of the threonine, which is twice more than what was found for lysine in the same study.

The importance of threonine uptake by the gut is also confirmed by Bertolo *et al.* (1998). The latter authors compared the threonine requirement of neonatal piglets (3 day-old weighing about 2 kg) fed parentally (threonine brought directly into the blood via a jugular catheter) with the requirement of piglets fed orally. They observed that the quantity of threonine required to maximise nitrogen retention (traced by phenylalanine oxidation) was more than twice that for piglets receiving threonine orally (i.e. via the ileum) compared with those receiving threonine directly into the blood. They concluded that in orally fed piglets the gut consumed 55% of the threonine intake.

Burrin *et al.* (2001) reviewed the proportional net portal balance of amino acids in pigs and came out with the data illustrated on figure 9. They assessed that threonine appearance in the portal blood barely exceeded 50%, while it could be 75% for lysine.

fig.9. Proportional net portal balance (% digestible amino acids intake) of dietary amino acids in the pig (Burrin et al., 2001).



This important threonine uptake by the gut is consistent with the high threonine content of digestive secretions, among which is mucus. The mucus gel layer, secreted by Goblet cells scattered along the gut villi (figure 10), covers the wall of the digestive tract and protects the gut against digestive enzymes and physical damage by digesta. Mucus is mostly made of water (95%) and mucins (5%). Mucins are large molecular weight glycoproteins particularly rich in threonine (figure 11).

fig. 10. Diagram of the digestive epithelium and picture of mucus secretion by goblet cells.

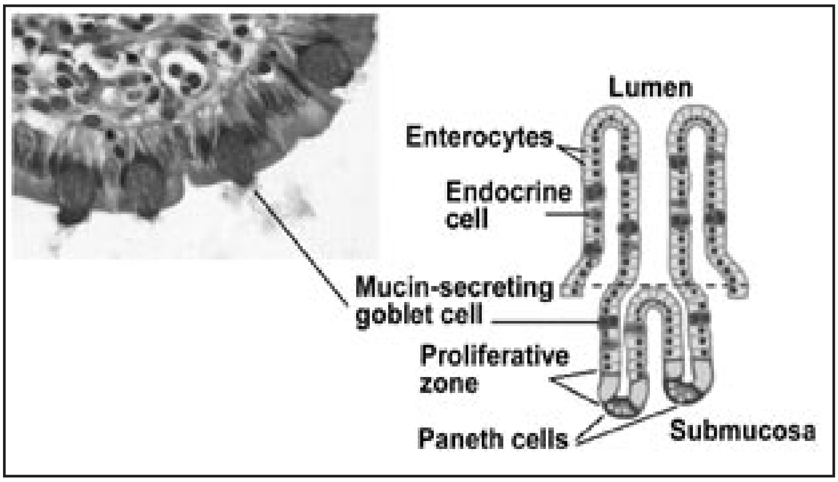
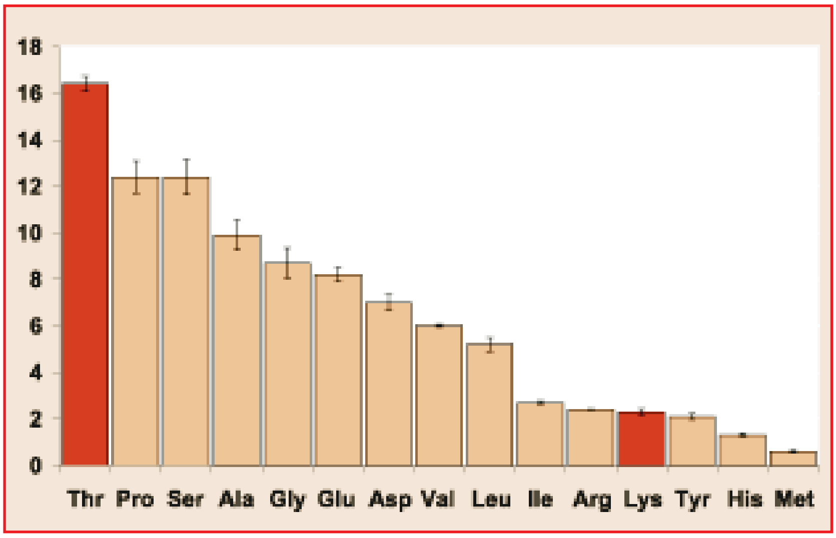
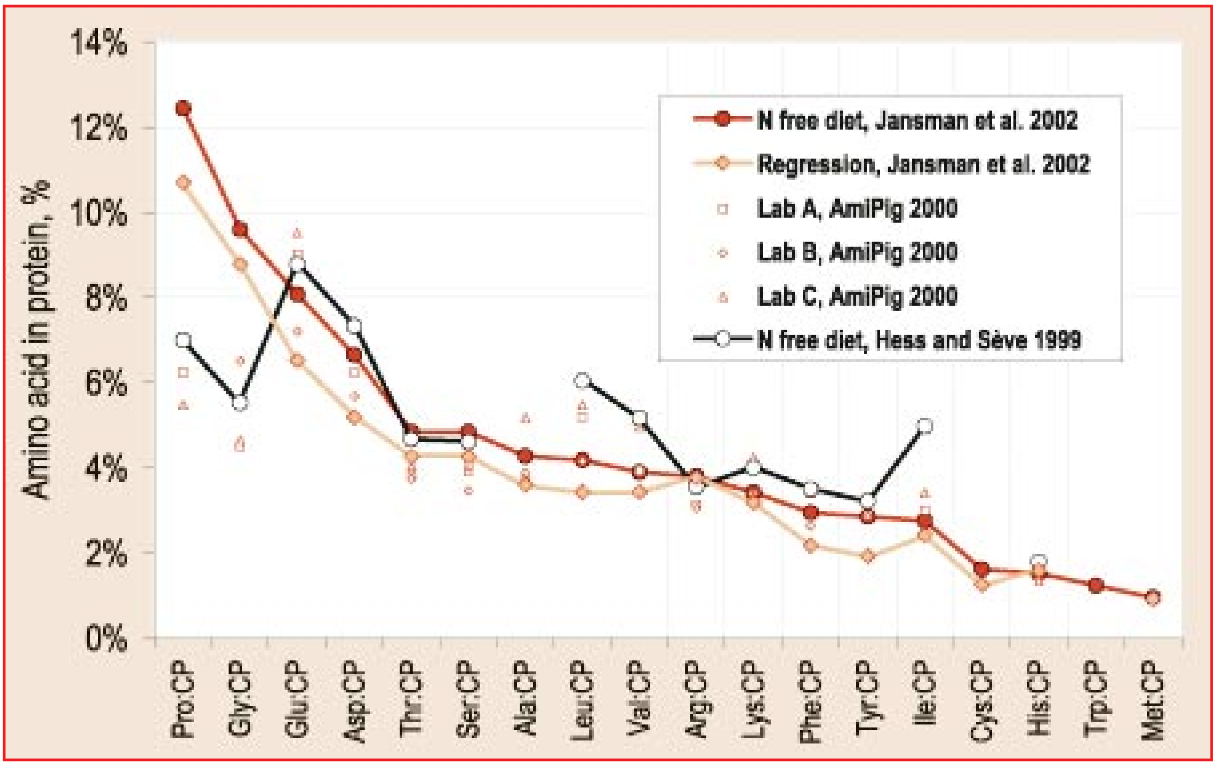


fig. 11. Mucin amino acid composition (Ball, 2002 adapted from Lien et al., 1997 in % crude mucins).



Due to the low digestibility of mucins, its constitutive amino acids cannot be re-absorbed, hence their high recovery in the endogenous losses collected at the end of the ileum (Hoskins 1984; Jansman *et al.*, 2002). According to Lien *et al.* (1997), mucins contribute to about 30% of threonine in endogenous losses. Thr:Lys ratio in endogenous losses reaches 120% (average data of endogenous profiles reported in figure 12) compared with 57%, on average, in the pig carcass (Mahan and Shields, 1998).

fig.12. Amino acid profiles of basal ileal endogenous losses (Jansman et al., 2002; Amipig, 2000, Hess and Sève, 1999).



Based on Bertolo *et al.* (1998) earlier work, Ball *et al.* (1999, 2002) and Law *et al.* (2000) hypothesised that part of the difference between orally and intravenously fed piglets was due to threonine usage for mucin production. They measured mucosal weight and mucus production in piglets (2 day old, 2 kg neonate piglets) fed an adequate or a deficient threonine diet (table 9). They observed, in the piglets fed the threonine deficient diet, a severe depression of mucin production and lower mucosal weights in association with a higher incidence of non infective diarrhoea. Intravenous administration of the adequate threonine dose restored partially the digestive function but not back to the level obtained with an adequate threonine dose given orally. Based on these results, the authors concluded that adequate threonine supply is needed for gut growth, structure and function.

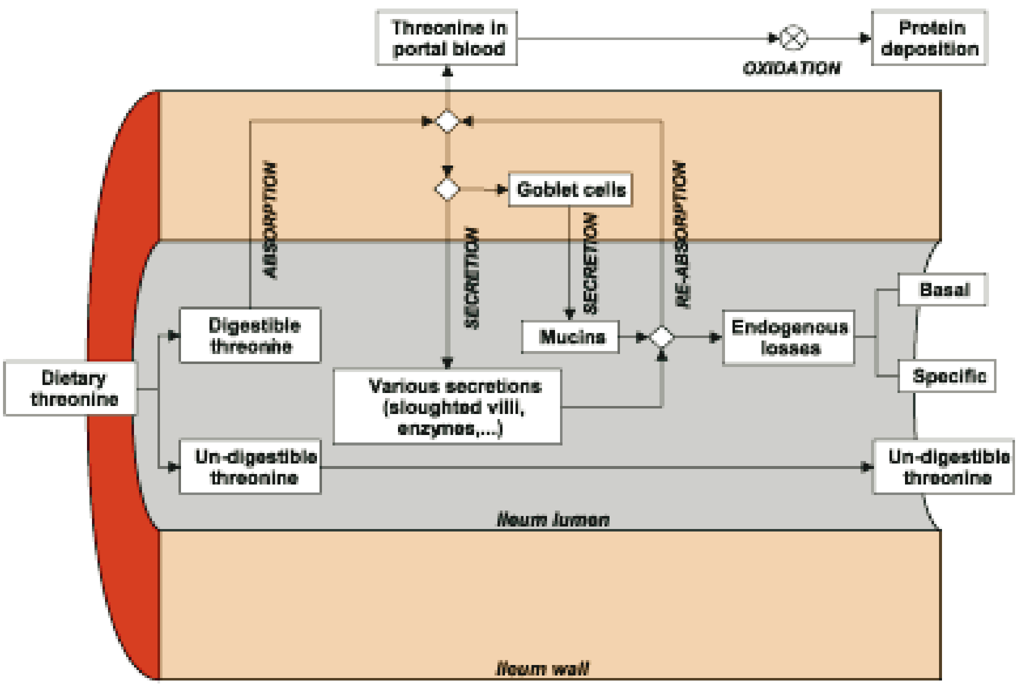
tab.9. Effect of threonine deficiency on digestive function in neonate pigs (Ball et al., 1999, 2002; Law et al., 2000).

Threonine treatments			
Level	**Adequat**	**Deficient**	**Adequat**
Threonine, g/kg/d	**0.6**	**0.1**	**0.6**
Route	**Orally**	**Orally**	**Intravenously**
Mucosal weight, g			
Duodenum	1.100[a]	0.625[b]	0.914[ab]
Proximal jejunum	19.37[a]	11.52[b]	17.61[ab]
Ileum	6.41	4.53	5.99
Colon	3.59[a]	1.78[b]	3.24[a]
Mucins production, µg/2cm intestine			
Duodenum (P<0.05)	59.6	11.0	46.6
Diarrhea			
Mean daily score [1]	0.05[a]	1.63[b]	0.20[b]
Pigs with diarrhea	1/6	6/6	2/6
Length of diarrhea, d	2	35	9
Average severity [2]	1.50[b]	2.82[a]	2.21[b]

[1] *Mean daily score from 0 to 3 : average of the sum of daily scores per number of days*
[2] *Mean severity score from 0 to 3 : average daily scores on days where diarrhea was present*
a,b denote significance by LSD multiple comparison test (P<0.05)

All of these studies confirm that a significant part of the threonine intake is utilised by the gut itself and is used for the synthesis of endogenous secretions and particularly mucus (figure 13). Considering the importance of digestive secretions for gut health and for the digestive process, an adequate dietary threonine level is key to allow for proper gut function.

fig.13. Schematic representation of treonine flow in the pig gut.



Info 3 Does threonine requirement increase with body weight ?

Several literature references report an increase of the optimal Thr:Lys ratio with the maintenance requirement as the pig is getting heavier or older (Table 10). Starting from an optimal Thr:Lys about 65% in young animals they suggest it should increase up to 68 or 70% in late finishing pigs.

tab.10. Recommendations for Thr:Lys ratio according to pigs body weight.

Reference	Body weight range, kg	Thr : Lys
Baker (2000)	5-20	65
	20-50	67
	50-110	70
NRC (1998)	3-5	65
	5-10	64
	10-20	64
	20-50	64
	50-80	68
	80-120	68

These recommendations (NRC, 1998; Baker, 2000) are derived from the maintenance requirement of Fuller *et al.* (1989). The latter authors estimated the lysine and the threonine maintenance requirement at 36 and 53 mg/kg BW0.75, respectively, which results in a 147% Thr:Lys ratio for maintenance (to be compared with the 57% Thr:Lys ratio found on average for pig carcass composition as reviewed by Mahan and Shields, 1998). This highlights the importance of threonine for the maintenance function and links the whole threonine requirement with animal body weight : the heavier the animal, the higher the threonine requirement.

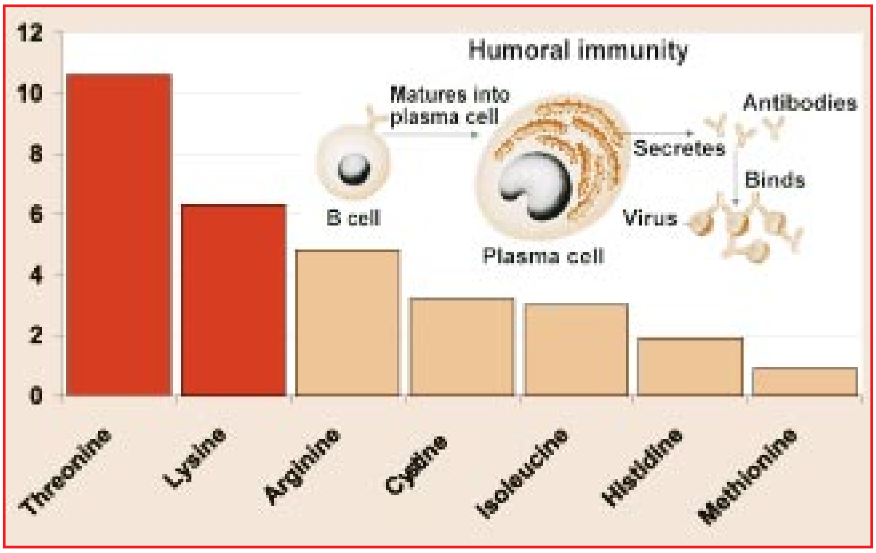
The high Thr:Lys ratio assessed for maintenance by Fuller *et al.* (1989) is consistent with the high contribution of threonine in the digestive function, which is one component of maintenance (see Info 2). However, Moughan (1999) suggested that the Thr:Lys ratio in maintenance would be 73% and therefore lower than reported by Fuller *et al.* (1989). The extent of threonine contribution to maintenance requirement and its subsequent effect on the optimal Thr:Lys ratio according to body weight, would then possibly deserve a refinement.

From the zootechnical standpoint, based on the data reviewed in the earlier section, no clear impact of pig body weight could be distinguished within the growing pigs and the finishing pigs trials. Such an impact might have been hidden by inter-trials bias (pig health status, diet composition, growth potential,...). But, the comparisons between optimal Thr:Lys ratio found in piglets (65% for animals weighing between 10 and 25 kg), in growing-finishing pigs (at least 65% for animals weighing from 20 to 120 kg) and in sows (at least 70% for animals weighing about 200 kg or even more), reveal a trend for a higher threonine requirement in heavier animals. Finally, the increase of the Thr:Lys ratio with pig body weight due to an increased maintenance requirement remains to be demonstrated in a zootechnical trial.

Info 4 Relationship between dietary threonine and immune function

The humoral immunity implies the secretions of immunoglobulins (also named antibodies) by mature B lymphocytes in the blood. Immunoglobulins after reaching the site of the infection, recognise, bind and inactivate their antigens. Like mucins (see Info 3), they are globular glycoproteins which contain high amount of threonine (figure 14; Bowland, 1966; Liu and Putnam, 1979; Low *et al.*, 1979).

fig. 14. Immunoglobulins essential amino acid profile (%) and secretion pattern (adapted from Bowland, 1966 quoted by Han and Lee, 2000).



Because of the high threonine content of immunoglobulins, some authors have hypothesised that dietary threonine deficiency would affect immunoglobulins production. They have tested the impact of feeding different threonine levels on antibody secretions.

Cuaron *et al.* (1984) have shown for sows receiving a sorghum diet that, while lysine is the first limiting amino acid for nitrogen retention, threonine is likely to be the first limiting amino acid for production of immunoglobulins G (IgG, the most abundant immunoglobulins traced in plasma, table 11). Sows fed a diet supplemented with threonine had 25% more IgG in plasma than sows fed the basal diet. No similar impact was observed with extra lysine.

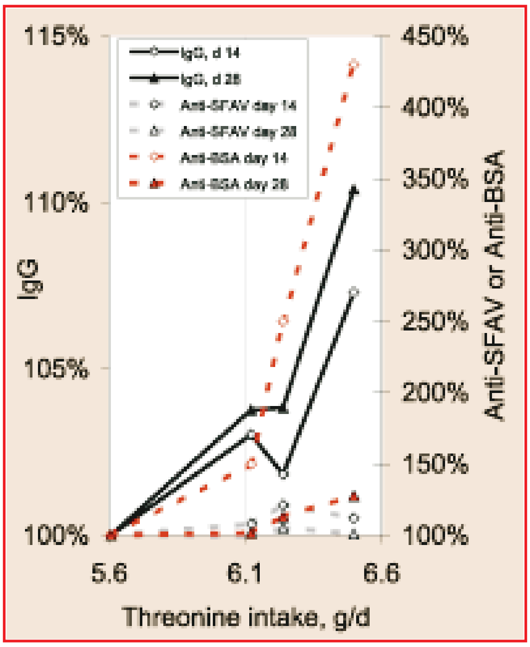
Likewise, Hsu *et al.* (2001) have demonstrated the impact of dietary threonine supply on immunoglobulin production. Sows fed added threonine during gestation produced milk with the highest IgG level at farrowing (+30%) and 10 days after (+8%). However, 20 days after farrowing when fed a common lactation diet these sows and their piglets showed the lowest IgG levels of all treatments (table 11). The authors concluded that the extra IgG received by piglets diminished their endogenous production but they did not comment on the drop also observed in sow plasma and whey. It would have been interesting to prolong the threonine treatment over a full lactation to check if such treatment could have maintained sow and piglet plasma IgG levels.

tab.11. Impact of dietary threonine on sow and piglets immunoglobulins circulating levels.

	Cuaron et al., 1984						Hsu et al., 2001			
	Control	Basal	Basal + Thr	Basal + Lys	Basal + Thr+Lys		Control	Basal	Basal + Thr	
Main ingredients (%)										
Corn	-	-	-	-	-		79.4	90.6	90.5	
Sorghum	91.6	92.5	92.5	92.5	92.5		-	-	-	
Soybean meal	5.8	-	-	-	-		12.8	1.0	1.1	
Wheat bran	-	-	-	-	-		4.5	4.5	4.5	
Nutrients (%)										
CP	12.0	12.0	12.0	12.0	12.0		12.0	8.0	8.0	
Lys	0.37	0.19	0.19	0.43	0.43		0.54	0.53	0.53	
Thr	0.34	0.22	0.34	0.22	0.34		0.41	0.31	0.45	
Thr:Lys	92%	114%	176%	52%	80%		76%	58%	85%	
Daily intake and retention										
Feed intake (kg/d)	2	2	2	2	2		1.98	1.98	1.98	
Nitrogen retention (g/d)	16.72	12.6	13.24	15.76	16.68	P<0.01	-	-	-	
IgG in sow plasma during gestation (mg/ml)										
Resp. d 70 or d 80	17.01	16.7	18.08	17.71	16.97	P<0.03	32.5	32.2	31.3	NS
Resp. d 103 or d 110	18.62	16.11	18.46	16.81	16.74	P<0.03	33.9	31.1	31.1	NS
Farrowing	18.48	14.27	17.84	14.55	18.09	P<0.03	21.3	17.2	16.9	NS
IgG in sow plasma during lactation (mg/ml)										
Lactation, d 7	-	-	-	-	-		31.6	29.4	29.5	NS
Lactation, d 21	-	-	-	-	-		22.8	25.1	22.9	NS
IgG in sow whey (mg/ml)										
Farrowing	51.08	48.48	53.77	53.88	56.43	ns	44.7	34.6	44.6	NS
Lactation, d 7							1.5	1.2	1.3	P<0.1
Lactation, d 21							1.1	1.0	0.9	NS
IgG in piglet plasma (mg/ml)										
Short after farrowing	12.87	12.29	12.11	13.5	13.32	ns	18.1	18.4	18.5	NS
d 7	-	-	-	-	-		17	18.2	18.6	NS
d 21	-	-	-	-	-		6.4	9.3	6.9	P<0.05

Li Defa *et al.* (1999) studied the impact of dietary threonine (4 Thr:Lys levels : 64, 75, 83 and 99%) on growing pigs (17-31 kg) challenged with either Bovine Serum Albumin (BSA) or Swine Fever Attenuated Vaccine (SFAV). On day 7 of the trial, all pigs were injected with the antigens. IgG levels and specific anti-BSA and anti-SFAV antibodies were recorded. IgG concentrations increased with dietary threonine. Furthermore, SFAV challenged pigs showed a significant increase in specific anti-SFAV antibodies (figure 15). The authors explained the absence of a similar reaction on BSA challenged pigs by the fact that BSA acts as a single antigen, while SFAV replicates in the host, producing several different antigenic viral proteins which stimulate the production of several antibodies.

fig. 15. Impact of dietary threonine on growing pigs immune humoral response (Li Defa et al.,1999).



These papers confirm the involvement of threonine in the immune response, the immunoglobulin synthesis being directly limited by the dietary threonine supply. This is another argument besides performance and the digestive function (see Info 2) to consider threonine in pig diets, even if this subject requires further investigation.

Info 5 Effect of amino acid evaluation systems on the Thr:Lys ratio

Threonine is generally less digestible than lysine (lower digestibility and higher contribution to endogenous losses, Info 2). Therefore, the digestible Thr:Lys ratio is lower than the total Thr:Lys ratio.

■ Quantifying the switch

The gap depends on the feedstuffs used in the mix, the lysine content and the amount of free amino acids. In particular, it increases when the feed is supplemented with L-Lysine (100% digestible), but not with L-Threonine.
Therefore, it is not possible to give a strict equivalency between Thr:Lys (digestible) and Thr:Lys (total), but a range: A 65% threonine to lysine ratio translates into a 67 to 69% ratio when expressed as total amino acids (table 12), whichever digestibility table is considered (AmiPig, 2000 or CVB, 2001).

tab.12. Effect of amino acid evaluation systems (standardised ileal digestibility vs. total) and feedstuff composition tables (AmiPig, 2000 vs. CVB, 2001) on amino acid levels in pig diets. Results of formulation studies (ranges reflect the sensitivity of the switch to feed protein level).

	Grower Diets				Finisher Diets			
Table	AmiPig (2000)		CVB (2001)		AmiPig (2000)		CVB (2001)	
System	Digestible	Total	Digestible	Total	Digestible	Total	Digestible	Total
	Barley - Wheat - Soybean meal							
Lys	0.90	0.99-1.00	0.88	0.97-0.98	0.70	0.79	0.68-0.69	0.77-0.78
Thr:Lys	65%	67-68%	66%	67-68%	65%	68-68.5%	66%	67-68%
M+C:Lys	60%	60%	59%	60-61%	60%	61%	59%	61%
Trp:Lys	18%	18%	17%	18.0%	19%	19%	17%	19%
	Barley - Wheat - Pea - Rapeseed meal - Soybean meal							
Lys	0.90	1.02	0.89	1.01-1.02	0.70	0.80-0.81	0.69	0.79-0.80
Thr:Lys	65%	68%	65%	67.5%	65%	68-68.5%	65%	67-68%
M+C:Lys	60%	60%	59%	60-61%	60%	61%	58%	60-61%
Trp:Lys	19%	19%	18%	19.5%	20%	20%	19%	20%
	Maize - Wheat - Soybean meal							
Lys	0.90	0.99	0.87	0.98-0.99	0.70	0.77	0.68	0.77
Thr:Lys	65%	68-69%	66%	68-69%	65%	69%	66%	69%
M+C:Lys	60%	60-61%	59%	60-61%	60%	61%	59%	61%
Trp:Lys	18%	18%	18%	18-19%	18%	18%	18%	19%

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