Developing Model Equation to Subdivide Threonine Requirements into Requirements for Growth and Maintenance in Pigs

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ABSTRACT : Purified diets containing 5 graded levels of threonine were fed to young, growing and finishing pigs to determine the threonine requirement for growth and maintenance. A model was developed to subdivide the threonine requirement for the maintenance from the requirement for growth. From this model, the threonine requirement for growth was 7.733, 10.968 and 11.235 g/kg live weight gain and the maintenance requirement was 0.118, 0.048 and 0.024 g per unit of metabolic body size at each stage of growth, respectively. In the young pigs, the threonine requirement for growth was 0.388 g/g N gain and the maintenance requirement was 0.122 g per unit of metabolic body size. The breakpoint of plasma threonine concentrations was 3.995, 7.933 and 7.738 g/d, respectively. Expected requirements obtained from these formulae were in general agreement with previous estimates. Based on the weight gain vs N gain equation, about 4.24% of the retained protein was comprised of threonine and compared to 3.81%, the mean threonine content of pig muscle CP.

(**Key words** : Threonine, Requirement, Maintenance, Growth, Body Composition, Plasma Concentration, Purified Diets, Pigs)

INTRODUCTION

The amino acid requirements of a growing pig include two portions, a requirement for maintenance and a requirement for tissue protein accretion. Threonine represents a significant proportion of the endogenous losses of essential amino acids from the gastrointestinal tract (Buraczewska et al., 1975; de Lange et al., 1989; Butts et al., 1993). The combination of higher oxidative losses with the significant losses from the gastrointestinal tract may explain why the threonine requirement for maintenance was 140% of the maintenance requirement for lysine (Fuller et al., 1989).

Direct estimates of the threonine requirement of pigs for maintenance were attempted by Baker et al. (1966). Other experiments were made to estimate separately the amino acid requirements of young and growing pigs for maintenance and for protein accretion by Fuller et al. (1989) and Chung and Baker (1992c). However, they did not provide adequate amino acid needs for maximum growth and protein accretion, and significant weight differences of subject animals existed between two studies.

The threonine requirement suggested by NRC (1988) was 0.56% for 10-20 kg, 0.48% for 20-50 kg and 0.40% for 50-110 kg. The threonine requirements determined by plasma urea N concentrations were 0.61% for 5-15 kg and 0.56% for 25-55 kg (Rosell and Zimmerman, 1985). The threonine requirement determined by plasma free threonine concentrations was 0.53-0.63% for 5-15 kg, 0.47% for 20 kg and 0.37% for 15 kg (Lewis and Peo, 1986; Sower and Meade, 1972a,b). The dietary threonine requirement for the accretion of 1 g body protein in the growing pig was 47 mg. In contrast, from the relationship between N retention and amino acid intake the daily threonine maintenance requirements for N equilibrium were estimated to be 53 mg per metabolic body size (Fuller et al., 1989). The maintenance requirements for threonine estimated in N balance studies were 39 mg/$W_{kg}^{0.75}$ per day in nongravid gilts averaging 145 kg weight by Baker et al. (1966).

The growth and maintenance requirements of threonine can vary with response criterion and mathematical models. Nutrient limitations, environmental conditions, or performance potentials influencing feed intake also should be considered as important factors to affect requirement.

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Therefore, it seems desirable to express amino acid requirements for maintenance, like energy requirements, on metabolic body size because daily N loss should be a result of surface and intestinal protein losses and, basal metabolic rate should be proportional to body weight. The objective of this study was to determine the threonine requirement for maintenance and growth, in young (10 kg), growing (40 kg) and finishing (70 kg) pigs, respectively.

MATERIALS AND METHODS

Animals and general procedures

Four-week-old, male weanling, pure bred (Landrace) pigs were used in all experiments. Individual pigs based on ancestry and weight were initially fed standard corn-soybean meal diets, which were followed by gradual introduction of a chemically defined, amino acid diets for 7 days as described in table 1 until they attained an average weight of 10 kg (experiment 1), 40 kg (experiment 2) and 70 kg (experiment 3). In all experiments, pigs were housed individually in 1.2 × 2.5 m pens (containing a self-feeder and nipple waterer) in an environmentally controlled room (20 to 24℃) in which a 24 h constant light schedule was maintained. Before the beginning and the end of experiment, the pigs were weighed after overnight fasting. All animals were meal-fed to satiation twice daily, once in the morning and once in the evening. Fresh (refrigerated) diet was provided at every feeding. Diets were fed dry without moistening. Feed intakes were monitored daily and body weights were recorded weekly.

Experimental diets

The composition of the basal diet for pigs of an average weight of 10 kg (experiment 1), 40 kg (experiment 2) and 70 kg (experiment 3), respectively, is shown in table 1. Experimental diets were formulated to contain either 25, 50, 75, 100 or 125% of threonine requirement suggested by NRC (1988); all amino acids except threonine were formulated to meet or exceed at 100% of NRC nutrient requirements (1988). To make the experimental diets isocaloric, L-theronine were substituted for L-glutamic acid in the basal diet. Methyl-donor compounds (choline, folate and vitamine B_{12}) were included to meet the requirement. Pigs had ad libitum access to water and their test diet, which were kept at −20℃ throughout the experimental period to prevent spoilage or any other change after mixing and during storage.

Table 1. Composition of the chemically defined amino acid diet (% of diet)

	Young	Growing	Finishing
Ingredients :			
Cornstarch	37.24	50.44	52.44
Amino acid mixture	18.00	15.00	13.00
Lactose	15.00	–	–
Sucrose	15.00	20.00	20.00
Mineral mixture[a]	5.28	5.28	5.28
Corn oil	5.00	5.00	5.00
Cellulose	3.00	3.00	3.00
$NaHCO_3$	1.20	1.00	1.00
Vitamin mixture[b]	0.04	0.04	0.04
Choline chloride	0.20	0.20	0.20
Antibiotic mixture[c]	0.03	0.03	0.03
DL-α-tocopheryl acetate	(20 mg/kg)	(20 mg/kg)	(20 mg/kg)
Ethoxyquin	(125 mg/kg)	(125 mg/kg)	(125 mg/kg)
Total	100.00	100.00	100.00
Amino acid mixture :			
L-Arginine	0.40	0.25	0.10
L-Histidine HCL H_2O	0.35	0.31	0.25
L-Isoleucine	0.53	0.46	0.38
L-Leucine	0.70	0.60	0.50
L-Lysine HCl	1.19	0.94	0.75
L-Methionine	0.24	0.21	0.17
L-Cystine	0.24	0.21	0.17
L-Phenylalanine	0.46	0.40	0.33
L-Tyrosine	0.31	0.26	0.22
L-Threonine	0.56	0.48	0.40
L-Tryptophan	0.14	0.12	0.10
L-Valine	0.56	0.48	0.40
L-Proline	0.40	0.33	0.29
L-Glycine	1.20	1.00	0.87
L-Glutamic acid	10.72	8.96	8.07
Total	18.00	15.00	13.00

[a] Mineral mixture provided per kilogram of diet: $CaCO_3$, 3 g; $Ca_3(PO_4)_2$, 28 g; K_2HPO_4, 9 g; NaCl, 8.8 g; $MgSO_4 \cdot H_2O$, 2.6 g; $MnSO_4 \cdot H_2O$, 0.65 g; $FeSO_4$, 0.5 g; $ZnCO_4$, 0.15 g; $CuSO_4 \cdot H_2O$, 15 mg; H_3BO_3 9 mg; $Na_2MoO_4 \cdot 2H_2O$, 9 mg; KI, 40.6 mg; $CoSO_4 \cdot 7H_2O$, 1 mg; Na_2SeO_3 0.66 mg.

[b] Vitamin mixture provided per kilogram of diet: thiamin HCl, 20 mg; niacin, 50 mg; riboflavin, 10 mg; D-calcium pantothenate, 30 mg; vitamin B_{12}, 0.04 mg; pyridoxine HCl, 6 mg; D-biotin, 0.6 mg; folic acid, 4 mg; menadione, 2 mg; ascorbic acid, 250 mg; retinyl acetate, 5,200 IU; cholecalciferol (200,000 IU per g), 600 IU.

[c] Antibiotic mixture provided per kilogram of diet: chlortetracycline, 110 mg; sulfamethazine, 110 mg; procaine penicillin, 55 mg.

Blood amino acid analysis

On the final day of the experiment, blood plasma samples were collected from three pigs in each treatment of all experiments. Samples were centrifuged at 3,000 rpm for 20 min to obtain plasma samples. The plasma was frozen in two aliquots. One aliquot was analyzed for plasma urea N and total plasma protein concentration by blood analyzer (Ciba-Corning Model, Express Plus, Ciba Corning Diagnostics Co.). The other aliquot was deproteinized with sulfosalicylic acid, and analysed for plasma free amino acid concentration with ion-exchange chromatography (Hitachi Model 835, Amino Acid Analyzer, Hitachi Ltd, Tokyo, Japan).

Preparation of carcass sample

In experiment 1, the pigs were weighed before they were transported to the Meat Laboratory. They were killed by hammer stunning, after which the blood was allowed to clot inside the body before evisceration. An incision through the abdominal wall was made between both hams to facilitate removal of the gastrointestinal tract, which was emptied of its contents and rinsed with a minimal amount of water. The intact whole carcass including head and all organs and the washed gastrointestinal tract were combined, weighed, packaged in a heavy-duty plastic bag and frozen at −20℃. The weight obtained before freezing was recorded as empty body weight.

After deep freezing, whole carcasses and gastrointestinal tract were cut while frozen into 2.5 × 2.5 × 5 cm shape and after mixing, ground two times through a 1 cm die and ground two times again through a 0.5 cm die, with hand mixing between grindings to obtain homogeneous samples. Subsamples (~4 kg) were taken and frozen again. After deep freezing, samples were sliced while frozen into 0.5 cm strips and ground through a 0.1 cm die until a homogeneous, finely minced paste was obtained. One subsample was taken and frozen at −20℃ for dry matter and ash determination. The other subsample was freeze-dried at −40℃ for 36 h and frozen at −20℃ until chemical analysis.

Analysis of body composition

Dry matter was obtained by drying wet samples for 24 h at 105℃. The dried samples were then extracted in ether for determination of whole-body lipid. For ash determination, wet carcass samples were dry-ashed for 24 h at 550℃. Whole-body nitrogen was analyzed on wet samples by the Kjeldahl procedure (AOAC, 1990).

Development of model equation and statistical analysis

The threonine requirement for growth and maintenance was calculated using a model based on metabolic body size ($W_{kg}^{0.75}$). The mathematical equation for this model was :

$$y = ax + b \quad \cdots\cdots (1)$$

where $y = R/W_{kg}^{0.75}$; $x = I/W_{kg}^{0.75}$; a = upslope to plateau; b = y intercept; I = amino acid intake in g/day; R = response(weight gain in kg/day or nitrogen gain in g/day). By incorporating these variables into equation (1), the following new model was generated.

$$I = 1/a \cdot (R - bW_{kg}^{0.75}) \quad \cdots\cdots (2)$$

$-b/aW_{kg}^{0.75}$ is the requirement of threonine (g/day) at maintenance. The upslope, 1/a, represents the growth requirement (g/day) per 1 kg live weight gain or 1 g nitrogen gain. Two linear regression equations, one for some of the upslope portion and the other one for upslope plus some plateau portion, were determined as intersecting at the point at which the residual sum of square is minimized by the nonlinear least square method (SAS, 1985). The data points covering the plateau portion beyond 125% of threonine requirement by NRC (1988) were excluded from the equations because, by definition, some nutrient or energy other than threonine was limiting response in that region.

All experimental data were subjected to ANOVA procedures appropriate for completely randomized design. Orthogonal single degree of freedom comparisons were made to test for linear and quadratic threonine effects and for other treatment differences of interest (Steel and Torrie, 1980).

RESULTS AND DISCUSSION

Growth responses of young pigs fed diets containing graded levels of threonine are shown in table 2. Weight gain and nitrogen gain increased proportionally up to 0.56 % threonine. Responses beyond 0.56% threonine were minorly decreased. Between 0.14 and 0.28% threonine in the diet was required to maintain both body weight and nitrogen content. Feed intake continued to increase up to 0.56%, but gain/feed ratio was similar from 0.42 to 0.70% threonine levels.

Performances of growing pigs fed diets containing graded levels of threonine are shown in table 3. Weight gain increased rapidly by supplementing up to 0.48% threonine. Responses beyond 0.36% dietary threonine were minor. Feed intake reached to the plateau at 0.36% but gain/feed ratio increased with continuous increase in threonine level up to 0.48%.

Responses of finishing pigs fed diets containing graded levels of threonine are shown in table 4. Weight

gain increased up to 0.40% dietary threonine. Responses beyond 0.30% were almost unchanged. Feed intake and gain/feed plateaued at 0.30% threonine.

Table 2. Responses of young pigs fed diets containing five graded levels of threonine for 14 days[1]

Threonine	Mean[2] $W^{0.75}$	Feed intake	Weight[3] gain	Threonine intake	Body nitrogen retention	Gain / Feed
(%)	(kg)	(kg/d)	(kg/d)	(g/d)	(g/d)	
0.14	5.62 ± 0.10	0.29 ± 0.00	−0.05 ± 0.02	0.40 ± 0.01	−1.25 ± 0.38	−0.18 ± 0.08
0.28	6.36 ± 0.25	0.66 ± 0.15	0.20 ± 0.07	1.85 ± 0.43	3.68 ± 0.31	0.29 ± 0.03
0.42	7.10 ± 0.18	0.80 ± 0.06	0.46 ± 0.03	3.36 ± 0.23	9.00 ± 0.46	0.57 ± 0.02
0.56	7.55 ± 0.30	0.98 ± 0.09	0.55 ± 0.04	5.49 ± 0.52	11.04 ± 0.49	0.57 ± 0.02
0.70	7.19 ± 0.28	0.87 ± 0.06	0.50 ± 0.06	6.09 ± 0.45	9.60 ± 0.85	0.57 ± 0.03

[1] Values are mean ± S.E. of 3 pigs of each treatment.
[2] $W^{0.75}$ is (initial weight + final weight)/2)$^{0.75}$.
[3] Average initial weight was 10.51 ± 0.85 kg.

Table 3. Responses of growing pigs fed diets containing five graded levels of threonine for 13 days[1]

Threonine	Mean[2] $W^{0.75}$	Feed intake	Weight[3] gain	Threonine intake	Gain / Feed
(%)	(kg)	(kg/d)	(kg/d)	(g/d)	
0.12	15.86 ± 0.27	1.10 ± 0.12	0.12 ± 0.12	1.32 ± 0.14	0.09 ± 0.11
0.24	17.35 ± 0.24	2.16 ± 0.10	0.89 ± 0.07	5.19 ± 0.24	0.41 ± 0.01
0.36	17.50 ± 0.28	2.41 ± 0.08	0.98 ± 0.08	8.67 ± 0.30	0.41 ± 0.03
0.48	17.95 ± 0.17	2.39 ± 0.11	1.09 ± 0.08	11.49 ± 0.53	0.45 ± 0.02
0.60	17.58 ± 0.09	2.29 ± 0.24	1.02 ± 0.11	13.76 ± 1.44	0.45 ± 0.04

[1] Values are mean ± S.E. of 3 pigs of each treatment.
[2] $W^{0.75}$ is (initial weight + final weight)/2)$^{0.75}$.
[3] Average initial weight was 39.25 ± 1.32 kg.

Table 4. Responses of finishing pigs fed diets containing five graded levels of threonine for 14 days[1]

Threonine	Mean[2] $W^{0.75}$	Feed intake	Weight[3] gain	Threonine intake	Gain / Feed
(%)	(kg)	(kg/d)	(kg/d)	(g/d)	
0.10	23.95 ± 0.14	1.87 ± 0.09	0.21 ± 0.05	1.87 ± 0.09	0.11 ± 0.02
0.20	24.69 ± 0.44	2.59 ± 0.15	0.68 ± 0.11	5.17 ± 0.31	0.27 ± 0.03
0.30	25.36 ± 0.28	2.88 ± 0.08	1.05 ± 0.03	8.63 ± 0.25	0.37 ± 0.00
0.40	25.67 ± 0.08	2.97 ± 0.38	1.08 ± 0.10	11.87 ± 1.49	0.36 ± 0.01
0.50	25.16 ± 0.26	2.78 ± 0.12	0.97 ± 0.03	13.90 ± 0.62	0.35 ± 0.03

[1] Values are mean ± S.E. of 3 pigs of each treatment.
[2] $W^{0.75}$ is (initial weight + final weight)/2)$^{0.75}$.
[3] Average initial weight was 67.36 ± 1.82 kg.

Weights of water and protein in carcasses increased as dietary threonine increased up to 0.56% as seen in table 5. However, the ratio of protein to water content decreased by increasing the threonine level up to 0.56%. This means that the ratio of protein to water content would be changed by deficiency or excess of threonine in the diet. Serious deficiency of threonine in the diet decreased water content of the pig carcass.

Table 5. Body composition of young pigs fed five graded levels of threonine for 14 days

Threo-nine	Live weight gain	Dry weight gain	Water gain	Protein gain	Protein gain / water gain
(%)	(kg/14 days)	(g/14 days)	(g/14 days)	(g/14 days)	
0.14	−0.72[c]	−0.10[c]	−0.62[c]	−0.11[c]	0.285[b]
0.28	2.77[b]	1.27[b]	1.49[b]	0.32[b]	0.241[a]
0.42	6.42[a]	2.68[a]	3.73[a]	0.79[a]	0.211[a]
0.56	7.75[a]	3.09[a]	4.67[a]	0.97[a]	0.209[a]
0.70	6.99[a]	2.95[a]	4.04[a]	0.84[a]	0.209[a]

[abc] Means in a column with different superscripts are different ($p < 0.05$).

Table 6 shows plasma amino acid, urea N and protein concentrations of young pigs fed five graded levels of threonine. Plasma threonine concentrations changed in a linear pattern as the dietary threonine level increased. Plasma urea N concentration showed a linear pattern with increasing threonine. The pattern was smilar to plasma urea N conentrations of pigs fed diets containing graded levels of lysine in the study by Coma et al. (1995).

Plasma amino acid, urea N and protein concentration of growing pigs fed five graded levels of threonine are presented in table 7. Plasma isoleucine, threonine, alanine and glycine concentrations changed in a linear pattern as dietary threonine increased. Urea N concentrations in plasma decreased in a linear pattern.

Table 6. Plasma amino acid concentrations of young pigs fed five graded levels of threonine (mg / 100 ml)

AA	Threonine (%)					Mean	SE
	0.14	0.28	0.42	0.56	0.70		
ARG	1.97	0.55	0.48	0.54	0.39	0.79	0.27
HIS	1.61	1.54	1.57	1.51	1.85	1.62	0.12
ILE	1.37	1.65	4.01	2.37	3.62	2.60	0.46
LEU	2.63	2.35	1.89	1.65	1.49	2.00	0.26
LYS	4.25	4.42	6.26	3.53	5.36	4.76	0.46
MET	0.50	0.28	0.53	0.36	0.58	0.45	0.06
PHE	2.17	1.92	2.50	2.32	2.54	2.29	0.19
THR[1]	1.94[b]	1.41[b]	1.79[b]	6.23[a]	8.30[a]	3.93	0.84
VAL	2.94	3.09	5.10	4.09	5.08	4.06	0.47
Total Ess.	19.39	17.20	24.13	22.59	29.20	22.50	1.97
ALA	8.03	7.94	13.42	13.02	15.58	11.60	1.45
ASP	1.20	0.30	0.32	0.47	1.09	0.67	0.20
CYS	0.18	0.17	0.20	0.32	0.33	0.24	0.04
GLU	8.87	7.85	13.58	10.33	13.47	10.82	1.27
GLY	9.03	8.16	12.91	9.25	16.17	11.10	1.32
PRO	3.44	2.45	4.36	2.94	3.25	3.29	0.32
SER	1.93	1.28	1.97	1.34	2.35	1.77	0.20
TYR	1.54	1.46	1.60	1.44	1.61	1.53	0.11
Total Noness.	34.22	29.61	48.36	39.12	53.84	41.03	4.30
Grand total	53.61	46.81	72.49	61.70	83.05	63.53	6.17
PUN (mg/dl)[1]	14.80[a]	10.93[b]	7.71[bc]	8.58[bc]	6.74[c]	9.75	0.88
Protein (g/dl)	3.27	2.67	2.90	3.23	3.17	3.05	0.24

[abc] Means in a row with different superscripts are different ($p < 0.05$).
[1] Linear relationship among treatment means ($p < 0.05$).

Table 8 represents plasma amino acid, urea N and protein concentrations of finishing pigs fed five graded levels of threonine. Isoleucine, threonine, valine, alanine, aspartic acid, cystine, glycine, proline, total nonessential amino acid, total essential amino acid and total amino acid concentrations changed in a linear shape as dietary

Table 7. Plasma amino acid concentrations of growing pigs fed five graded levels of threonine (mg / 100 ml)

AA	Threonine (%)					Mean	SE
	0.10	0.24	0.36	0.48	0.60		
ARG	0.99	0.92	0.74	0.68	0.93	0.85	0.12
HIS	0.95	1.26	1.82	1.17	1.98	1.44	0.19
ILE[1]	1.07^{c}	1.72^{bc}	2.42^{ab}	3.22^{a}	2.66^{ab}	2.22	0.25
LEU	1.02	1.60	1.70	1.98	1.79	1.62	0.15
LYS	1.76	1.91	3.51	3.03	2.20	2.48	0.33
MET	0.42	0.39	0.83	0.73	0.73	0.62	0.08
PHE	0.81	1.26	0.96	1.49	1.58	1.22	0.14
THR[1]	2.74^{b}	2.66^{b}	3.00^{b}	5.98^{a}	7.00^{a}	4.28	0.56
VAL	1.90	2.50	4.14	3.86	3.83	3.24	0.35
Total Ess.[1]	11.66^{c}	14.22^{bc}	19.12^{abc}	22.15^{ab}	22.71^{a}	17.92	1.48
ALA[1]	3.54^{c}	4.49^{bc}	7.54^{ab}	9.89^{a}	7.63^{ab}	6.62	0.76
ASP	0.27	0.28	0.13	0.15	0.15	0.20	0.04
CYS	0.15	0.17	0.19	0.22	0.25	0.20	0.02
GLU	3.40^{b}	4.03^{ab}	4.52^{a}	6.84^{ab}	3.91^{ab}	4.54	0.48
GLY[1]	4.25^{b}	4.89^{b}	10.05^{a}	10.53^{a}	8.74^{ab}	7.69	0.89
PRO	2.07	1.74	2.81	3.05	2.70	2.48	0.21
SER	0.72	0.90	1.12	1.19	1.20	1.03	0.09
TYR	0.69	0.96	1.01	1.00	1.03	0.94	0.07
Total Noness.[1]	15.07^{b}	17.47^{b}	27.38^{ab}	32.86^{a}	25.62^{ab}	23.68	2.34
Grand total[1]	26.73^{c}	31.69^{bc}	46.50^{abc}	55.01^{a}	48.34^{ab}	41.65	3.72
PUN (mg/dl)[1]	11.83^{a}	9.63^{ab}	7.83^{b}	7.17^{b}	6.73^{b}	8.64	0.63
Protein (g/dl)	2.67	2.30	3.13	3.20	3.57	2.97	0.29

^{abc} Means in a row with different superscripts are different ($p < 0.05$).
[1] Linear relationship among treatment means ($p < 0.05$).

threonine level increased, while phenylalanine concentrations formed a quadratic shape as threonine levels increased in the diet. Plasma urea N concentrations decreased in a linear pattern. However, protein concentrations in plasma were not affected by increases in dietary threonine level (table 6, 7, and 8).

The predicted equation for the threonine requirement of young pigs (10 kg of body weight) for maintenance and for growth is shown in figure 1. The estimated threonine requirement for growth was 7.733 g per unit of kg weight gain while the estimated requirement for maintenance was 0.118 g/d per unit of metabolic body size. The total threonine requirement is the sum of growth and maintenance requirements. For example, if a young pig weighing 15 kg and gaining at a rate of 0.45 kg per day, the growth requirement would be 3.480 g per day and the maintenance requirement would be 0.901 g per day. Thus, the total requirement for threonine needed by

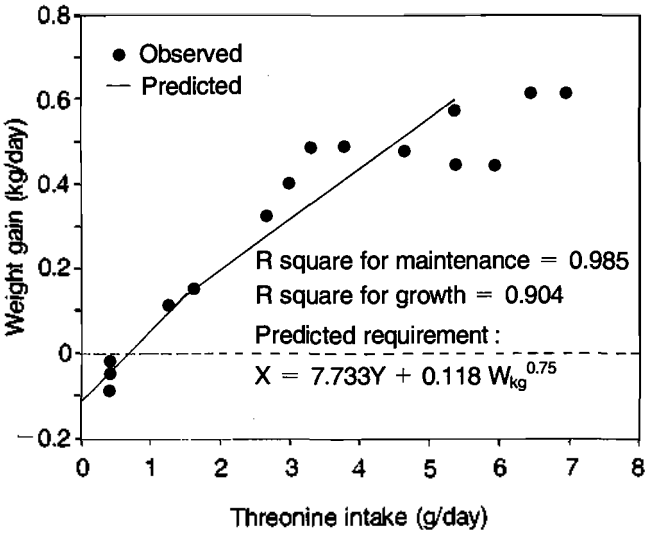

Figure 1. Weight gain response to graded threonine intake in young pigs.

Table 8. Plasma amino acid concentrations of finishing pigs fed five graded levels of threonine (mg / 100 ml)

AA	Threonine (%)					Mean	SE
	0.10	0.20	0.30	0.40	0.50		
ARG	1.18	0.67	0.92	1.23	0.93	0.98	0.10
HIS	1.44	1.95	2.04	2.28	2.02	1.95	0.13
ILE[l]	2.12^{b}	2.07^{b}	3.72^{a}	3.72^{a}	4.78^{a}	3.28	0.31
LEU	2.10^{bc}	1.45^{c}	2.92^{b}	2.62^{ab}	2.15^{bc}	2.25	0.16
LYS	4.44	3.10	4.25	3.41	3.58	3.76	0.33
MET[l]	0.61^{b}	0.47^{b}	1.22^{a}	0.93^{a}	1.22^{a}	0.89	0.09
PHE[q]	1.71^{ab}	1.56^{b}	2.30^{a}	2.17^{ab}	0.85^{c}	1.72	0.15
THR[l]	3.10^{b}	3.29^{b}	4.67^{b}	9.24^{a}	13.00^{a}	6.66	1.12
VAL[l]	3.74^{bc}	3.02^{c}	5.74^{ab}	4.57^{bc}	6.66^{a}	4.75	0.42
Total Ess.[l]	20.45^{c}	17.59^{c}	27.79^{b}	30.17^{ab}	35.21^{a}	26.24	1.88
ALA[l]	5.72^{b}	5.80^{b}	13.76^{a}	12.27^{a}	15.07^{a}	10.52	1.17
ASP[l]	0.23^{b}	0.33^{b}	0.44^{ab}	0.67^{a}	0.43^{ab}	0.42	0.05
CYS[l]	0.23^{ab}	0.20^{b}	0.29^{ab}	0.32^{a}	0.39^{a}	0.29	0.03
GLU	4.41^{b}	4.26^{b}	6.67^{b}	10.05^{a}	6.24^{b}	6.33	0.65
GLY[l]	7.08^{b}	6.64^{b}	14.18^{a}	12.13^{a}	14.48^{a}	10.90	1.03
PRO[l]	2.80^{b}	2.41^{b}	4.35^{a}	4.49^{a}	4.08^{a}	3.36	0.27
SER	1.58^{b}	1.35^{b}	1.89^{ab}	1.91^{ab}	2.26^{a}	1.80	0.11
TYR	1.68^{a}	1.14^{b}	1.97^{a}	1.86^{a}	1.70^{a}	1.67	0.09
Total Noness.[l]	23.72^{b}	22.13^{b}	43.55^{a}	43.70^{a}	44.65^{a}	35.55	3.03
Grand total[l]	44.16^{b}	39.72^{b}	71.34^{a}	73.87^{a}	79.86^{a}	61.79	4.78
PUN (mg/dl)[l]	14.70^{a}	14.07^{a}	8.57^{ab}	7.03^{b}	7.27^{b}	10.33	1.16
Protein (g/dl)	5.57	6.27	5.60	4.03	6.30	5.55	0.40

^{abc} Means in a row with different superscripts are different ($p < 0.05$).
[l] Linear relationship among treatment means ($p < 0.05$).
[q] Quadratic relationship among treatment means ($p < 0.05$).

this young pig would be 4.381 g per day. This means that about 26.06% of the total requirement would be utilized for maintenance. If feed intake is 0.95 kg per day, the dietary level of threonine required for growth would be 0.37%, for maintenance would be 0.09% and therefore, total requirement would be 0.46%. This value is similar to previously reported total threonine requirements of 0.53% (table 9).

The predicted equation for threonine requirement of growing pigs (40 kg body weight) for maintenance and for growth is shown in figure 2. The estimated threonine requirement for growth was 10.968 g per unit of kg weight gain while the estimated requirement for maintenance was 0.048 g/d per unit of metabolic body size. The gross requirement is the sum of growth and maintenance requirement. For example, if a growing pig weighs 45 kg and gains 0.7 kg per day, the growth

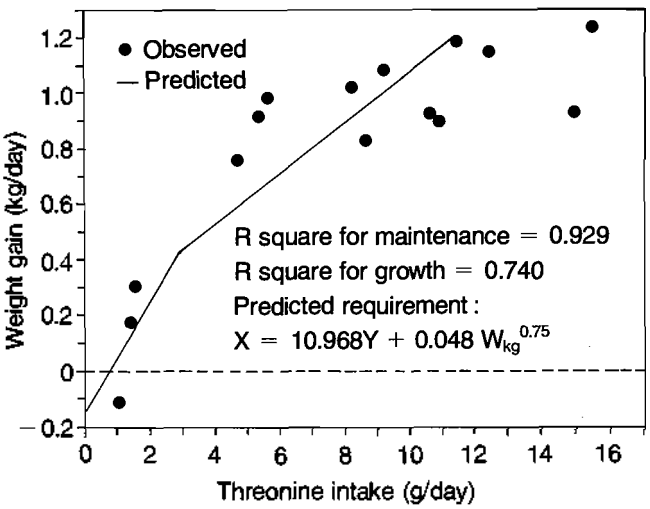

Figure 2. Weight gain response to graded threonine intake in growing pigs.

requirement would be 7.678 g per day and the maintenance requirement would be 0.838 g per day. Thus, the total requirement for threonine needed by this growing pig would be 8.516 g per day. This means that about 9.84 % of the total requirement would be utilized for maintenance. If feed intake is 1.9 kg per day, the dietary level of threonine required for growth would be 0.40% and for maintenance would be 0.04%. This value in total (0.44%) is slightly lower than the previously reported threonine requirements for total (0.49%) as shown in table 9.

Table 9. Previously published threonine requirements for young, growing and finishing pigs

Dietary threonine	Live weight	Response criterion	Threonine requirement	Sources
(%)	(kg)		(%)	
	10-20	Growth	0.56	NRC (1988)
0.55-0.75	5-15	Growth, PUN, PAA	0.61	Rosell and Zimmerman (1985)
0.53-0.83	5-15	Growth, PAA	0.61	Lewis and Pel (1986)
0.60-0.76	6-16	Growth	0.46 (D)	Saldana (1994)
0.49-0.69	6.4	Growth	0.54	Leibholz (1988)
0.50-0.78	8-21	Growth, N retention	0.63	Borg et al. (1987)
0.38-0.83	10	N balance	0.60	Mitchell et al. (1968)
0.24-0.59	15	Growth, PAA	0.37	Sowers & Meade (1972a)
0.27-0.63	20	Growth, PAA	0.47	Sowers & Meade (1972b)
0.30-0.50	25	Growth	0.50	Kaji et al. (1988)
Mean			0.53	
STD			0.08	
	20-50	Growth	0.48	NRC (1988)
0.42-0.62	17-45	Growth	0.52	Lougnan & Brette (1971)
0.60-0.79	17-50	Growth	0.44 (D)	Conway et al. (1990)
0.39-0.69	18-40	Growth	0.47	Cohen and Tankley (1977)
0.44-0.60	21-50	Growth	0.48	Henry & Rerat (1967)
0.45-0.75	45-65	Growth	0.47 (D)	Lenis et al. (1990)
0.56-0.74	20-40	Growth	0.57 (D)	Schutte et al. (1990)
Mean			0.49	
STD			0.05	
	50-110	Growth	0.40	NRC (1988)
0.30-0.50	58-96	Growth	0.28 (D)	Saldana (1994)
0.29-0.59	59-90	Growth	0.38	Cohen and Tankley (1977)
0.06-0.56	65-95	Growth	0.43 (D)	Lenis et al. (1990)
Mean			0.37	
STD			0.07	
Maintenance requirement				
	145	N balance	39 $mg/W_{kg}^{0.75}$	Baker (1966b)
	46	Growth	53 $mg/W_{kg}^{0.75}$	Fuller (1989)

PUN : plasma urea nitrogen, PAA : plasma amino acids, D : digestible requirement.

The predicted equation for threonine requirement of finishing pigs (70 kg of body weight) for maintenance and for growth is shown in figure 3. The estimated threonine requirement for growth was 11.235 g per unit of kg

weight gain while the estimated requirement for maintenance was 0.024 g/d per unit of metabolic body size. The total threonine requirement is the sum of growth and maintenance requirement. For example, if a finishing pig weighs 80 kg and gains 0.82 kg per day, the growth requirement would be 9.212 g per day and the maintenance requirement would be 0.640 g per day. Thus, the total requirement for threonine needed by this finishing pig would be 9.852 g per day. In this case, about 6.50% of the total requirement would be utilized for maintenance. If feed intake is 3.11 kg per day, the dietary level of threonine required for growth would be 0.30% and for maintenance would be 0.02%. This value in total (0.32%) is close to the previously reported threonine requirements (0.37%) for total (table 9). However, the difference between our estimate and previous requirements could be due to differences in digestibility between natural amino acids and synthetic amino acids.

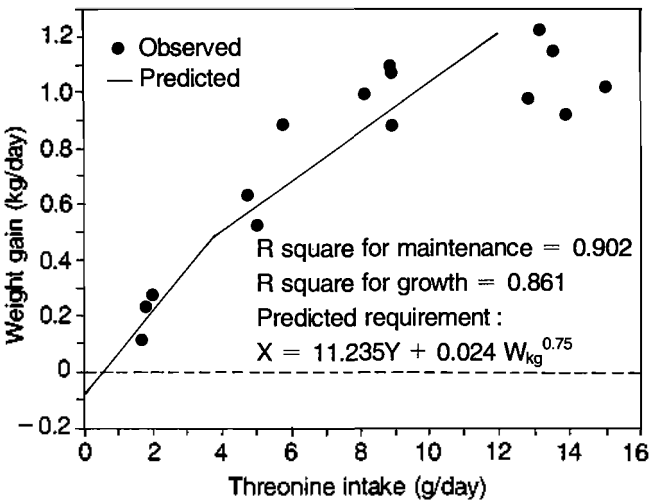

Figure 3. Weight gain response to graded threonine intake in finishing pigs.

Daily threonine intake of young pigs are plotted against daily nitrogen gains in figure 4; the prediction line and equation are also included. The estimated threonine requirement for growth was 0.388 g per g nitrogen gain and the estimated requirement for maintenance was 0.122 g per unit of metabolic body size. The total threonine requirement is the sum of growth and maintenance requirement. For instance, a pig weighing 15 kg and gaining N at a rate of 8.5 g N/day would require 3.297 g of threonine per day for growth. The maintenance requirement for threonine for this young pig would be 0.933 g per day. Thus, the total daily amount needed by this growing pig would be 4.230 g per day. This means that about 22.06% of the total requirement would be utilized for maintenance in young pigs. When total requirement expressed as daily intake basis is converted to the dietary percentage assuming a feed intake of 0.95 kg per day, the requirement would be 0.45%.

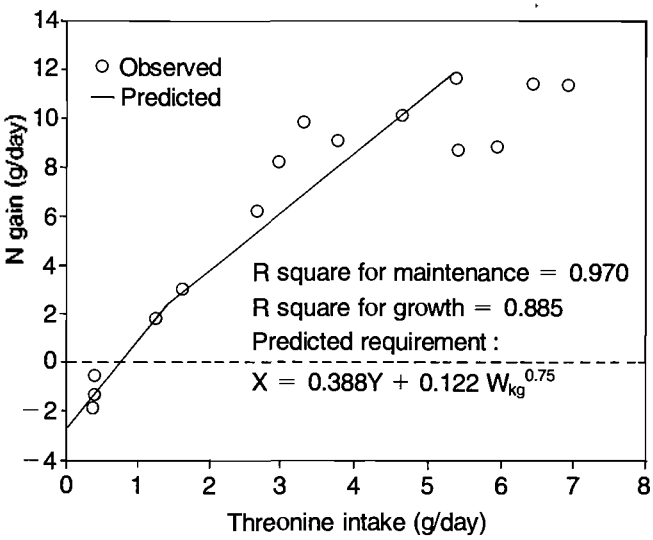

Figure 4. Nitrogen gain as influenced by threonine intake in young pigs.

Previously determined threonine requirement for the accretion of 1 g body N (protein × 6.25) in growing pigs (46 kg) was 0.394 g (47 mg × 6.25). In contrast, from the relationship between N retention and amino acid intake the daily threonine maintenance requirements for N equilibrium were estimated to be 0.053 $g/W_{kg}^{0.75}$ per day (Fuller et al., 1989). The maintenance requirements for threonine estimated in N balance studies were 0.039 $g/W_{kg}^{0.75}$ per day in nongravid gilts averaging 145 kg weight by Baker et al. (1966). These requirements from equation are generally close to requirements for growing pig (40 kg) values. The same predicted equation would underestimate maintenance and the accretion of 1 g body N in young pigs, while the same predicted equation would overestimate the threonine requirement for the maintenance and the accretion of 1 g body N in finishing pigs.

From the relationship of weight gain to N gain, the N percentage of retained body weight was 2.10% (5.555/265). Multiplied by 6.25, the protein content of weight gained was 13.10%. Based on N retention and weight gain responses, as a proportion of CP (N × 6.25) gained, threonine calculates to be 4.24%. This can be compared with mean threonine content of muscle protein in growing pig of 3.81% (Zhang et al., 1986) and 4.69% (Fuller et al., 1989).

The daily level of net protein synthesis increases in a curvilinear fashion until a genotypic maximum rate is obtained, and then it begins to decline (Tullis, 1980). As a result, dietary amino acid requirements for protein accretion also increase in a curvilinear fashion as metabolic body size increases. Dietary amino acid requirements for maintenance, in contrast, respond linearly with increases in metabolic body size until mature body weight is achieved (Hahn and Baker, 1995).

Plasma threonine concentrations of young pigs fed diets containing these 5 graded levels of threonine are presented in figure 5. Plasma threonine content remained constant up to the inflection point and then rose up abruptly. The inflection point (3.995 g/d intake) could be regarded as threonine requirement for growth. If the threonine intake at that inflection point is converted to a dietary percentage assuming that feed intake is 0.95 kg per day, the requirement is 0.42% of diet. This value is slightly below previous estimates 0.53 ± 0.08% as shown in table 9, but again plasma was sampled at the end of the young pig experiment, not at the midpoint. Plasma amino acid concentrations to 5 graded levels of threonine are presented in table 6. Plasma threonine concentration changed in the linear fashion as dietary threonine supply was elevated.

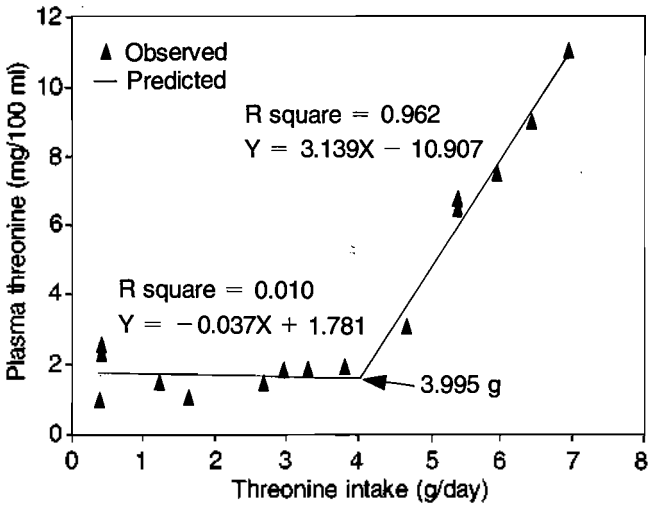

Figure 5. Plasma threonine concentration as influenced by threonine intake in young pigs.

Plasma threonine concentrations of growing pigs fed diets containing these 5 graded levels of threonine are presented in figure 6. Plasma threonine content showed the same trend as shown with young pigs. The inflection point (7.933 g/d intake) could be regarded as threonine requirement for growth. If the threonine intake at that inflection point is converted to a dietary percentage assuming that feed intake is 1.9 kg per day, the requirement is 0.42% of diet. This value is slightly below the values previously estimated 0.50 ± 0.05% as shown in table 9. Plasma amino acid concentrations to 5 graded levels of threonine are presented in table 7. Plasma threonine concentration changed in the linear fashion as dietary threonine supply was elevated.

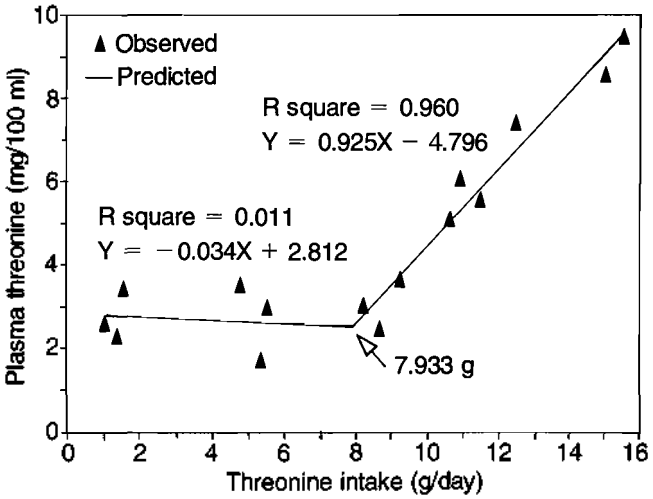

Figure 6. Plasma threonine concentration as influenced by threonine intake in growing pigs.

Plasma threonine responses of growing pigs fed diets containing these 5 graded levels of threonine are presented in figure 7. Plasma threonine content remained constant up to the inflection point and then rose up abruptly. The inflection point (7.738 g/d intake) could be regarded as threonine requirement for growth. If the threonine intake at that inflection point is converted to a dietary percentage

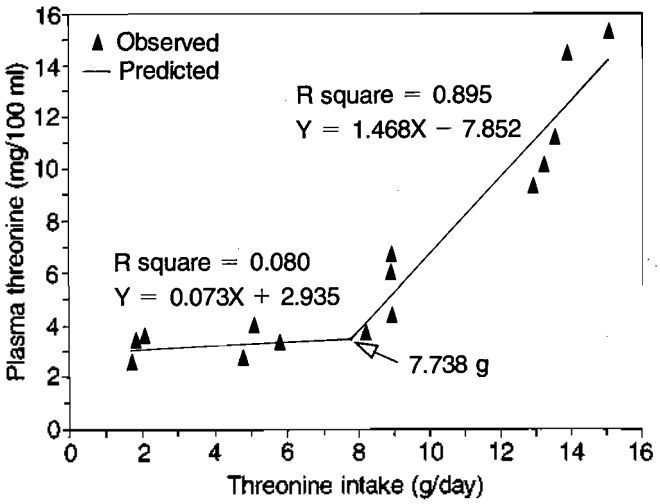

Figure 7. Plasma threonine concentration as influenced by threonine intake in finishing pigs.

assuming that feed intake is 3.11 kg per day, the requirement is 0.25% of diet. This value is slightly lower than previous estimates (0.37 ± 0.07%) as shown in table 9. Plasma amino acid concentrations with 5 graded levels of dietary threonine are presented in table 8. Plasma threonine concentrations of finishing pigs fed 5 graded level of threonine changed in the linear fashion as dietary threonine supply was elevated.

Table 10 shows the estimated requirement of threonine based on model equations for respective 10, 40, 70 kg pigs and lists of threonine requirements calculated from NRC (1988) nutrient requirements for each corresponding pigs. Total threonine requirements summing growth and maintenance are slightly lower than NRC (1988) requirements. The proportion of threonine needs for maintenance were greater for young and growing pigs than for finishing pig.

Table 10. Threonine requirement estimates derived from model equations for 10, 40 and 70 kg pigs

Body weight	Weight gain	Feed intake	Requirement		Total needs	NRC needs	Maintenance/ Total
			Growth	Maintenance			
(kg)	(kg/d)	(kg/d)	(g/d)	(g/d)	(g/d)	(g/d)	(%)
3.0	0.20	0.25	1.547	0.269	1.816	2.000	14.8
7.5	0.25	0.46	1.933	0.535	2.468	3.100	21.7
15.0	0.45	0.95	3.480	0.899	4.379	5.300	20.5
45.0	0.70	1.90	7.678	0.834	8.512	9.100	9.8
80.0	0.82	3.11	9.213	0.642	9.855	12.400	6.5

IMPLICATIONS

Based upon growth rate, the threonine requirement for young pigs weighing 15 kg and gaining 0.45 kg/d is 0.46 % of the diet. From the data of N gain, the requirement was estimated to be 0.45% of the diet. Similar requirement (0.42%) for threonine was obtained from the plasma threonine breakpoint. About 20 to 21% of these requirements were utilized for maintenance.

Based upon growth rate, the threonine requirement for growing pigs weighing 45 kg and gaining 0.70 kg/d is 0.44% of the diet. Similar requirement (0.41%) for threonine was obtained from the plasma threonine breakpoint. About 9 to 10% of these requirements were utilized for maintenance.

Based upon growth rate, the threonine requirement for finishing pigs weighing 80 kg and gaining 0.82 kg/d is 0.32% of the diet. Similar requirement (0.25%) for threonine was obtained from plasma threonine breakpoint. Approximately 6 to 7% of these requirements were utilized for maintenance.

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