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Factors affecting the requirement of dietary sulphur-containing amino acids of young pigs

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Abstract

Three experiments with young pigs were performed to study the factors affecting the requirement for dietary sulphur-containing amino acids (SAA). In the first experiment, the requirement for total and faecal digestible SAA was determined using 240 pigs in the weight range of 14 to 40 kg. Different quantities of synthetic methionine were added to a less digestible experimental diet, supplemented with all essential amino acids except methionine. A more practical diet was used as a positive control diet. At similar levels of faecal digestible SAA, no differences in performance between the experimental diet and the positive control diet were found, showing that optimum performance can be obtained with a less digestible diet supplemented with essential amino acids. Optimum performance was found at a faecal digestible SAA content of 0.52 % in the diet, corresponding with approximately 0.65 % total SAA. A second experiment, involving 360 pigs in the weight range of 14 to 40 kg, was performed to study the SAA requirement at sub-optimal (0.60 %) and optimal (0.70 %) dietary threonine levels. Increasing the threonine level from 0.60 % to 0.70 %, significantly ($P < 0.05$) improved performance. At a dietary threonine level of 0.60 %, SAA requirement was found to be 0.60 %, whereas at the 0.70 % threonine level, performance improved up to the highest dietary SAA level of 0.64 %. In the third experiment, the replacement value of cystine for methionine was studied in 324 pigs in the weight range of 20 to 50 kg, using diets with 0.50, 0.55 and 0.60 % dietary SAA. The results of this experiment suggest that minimal 50 % of the requirement of SAA should be fulfilled by methionine.

Key words: pigs, sulphur containing amino acids, amino acid requirement

Introduction

The nutritive value of feed protein depends on the amino acid composition and the digestibility and availability of the individual amino acids. In the last few years, a lot of work has been done to define the ideal dietary amino acid pattern for growing pigs (Cole et al., 1980; Fuller et al., 1989; Wang & Fuller, 1989). In the ideal protein concept, requirements for the essential amino acids are given as a percentage of dietary lysine.

The requirement for the sulphur-containing amino acids (SAA), methionine and cystine, is mostly given as one figure for total SAA, because in the body cystine can be synthesised from methionine, though not vice versa. When there is a deficiency of cystine, requirement for methionine is increased.

For young pigs, requirement figures found in literature for SAA vary from 0.50-0.65 % of the diet (Berende & Bertram, 1983). In the ideal protein concept, SAA requirement as a percentage of the dietary lysine requirement of 50 % (ARC, 1981), 63 % (Wang & Fuller, 1989), 59 % (Fuller et al., 1989) and 61 % (Wang & Fuller, 1990) are given.

Literature data on the proportion of SAA that can be supplied by cystine vary between 70 % (Mitchell et al., 1968) and 40 % (Becker et al., 1955).

The experiments reported herein were conducted to get more information about dietary factors affecting the SAA requirement of young pigs. The objectives studied were: (1) the requirement for total SAA and faecal digestible SAA, (2) the influence of a sub-optimal level of threonine on the requirement figures for total SAA, and (3) the replacement value of cystine for methionine.

Materials and methods

Experimental design

Experiment 1. This experiment was conducted to determine the requirement of young pigs for total SAA and faecal digestible SAA. Two hundred and forty crossbred (Large White × Dutch Landrace) pigs of about 6 weeks of age, were given a 7 day acclimatization period. During this period, the pigs were gradually changed over from their original diet to a mixture (50:50) of the basal diets A and B (Table 1). After the acclimatization period, at an average weight of 13 kg, the animals were allotted to 6 experimental treatments by weight, sex and parentage. The pigs were housed in an artificially lighted and ventilated pig unit. Four replicates of 10 pigs each, two pens with barrows and two pens with gilts, were assigned to each of the experimental treatments. The basal diets were adequately supplemented with all essential amino acids except methionine.

Control diet A consisted of highly digestible ingredients, whereas basal diet B consisted of less digestible ingredients (Table 1). Before starting this growth trial, the apparent faecal digestibility of diet A and basal diet B was determined with four pigs of approximately 30 kg body weight per diet. Faeces were collected quantitatively for 5 × 24 h using special bags attached to the piglets around the anus which were changed every 12 h. The faeces were stored at −25 °C till further analysis.

Control diet A and basal diet B were composed to have equal calculated contents of digestible protein, net energy and digestible lysine, threonine, tryptophan, isoleucine, leucine and histidine. Control diet A contained 0.63 % total SAA by analysis (faecal digestible 0.52 %), a level assumed to be sufficient for optimal performance. Basal diet B was low in these amino acids, and analysed to contain 0.51 % total SAA corresponding with approximately 0.37 % faecal digestible SAA.

The contents of dietary (analysed) and faecal digestible amino acids are given in Table 1. The experimental treatments are given in Table 2.

The animals were fed twice a day according to a restricted feeding scheme (approximately 90 % of ad libitum), based on live weight and expected weight gain. A slop feeding system was applied, with a water:meal ratio of 1:1. Additional water was available ad libitum.

Table 1. Composition (%) and analysed or calculated contents (%) of crude protein and total amino acids, and the calculated contents (%) of faecal digestible amino acids of diet A and basal diet B used in Experiment 1.

	Diet A		Basal diet B	
Ingredients (%)				
Barley	23		20.3	
Corn	32		15	
Tapioca	10		21.2	
Vicia faba beans	–		20	
Soyabean meal	24.9		7.9	
Meat meal	–		10.1	
Skimmilk powder	5		–	
Soya oil	1		3.2	
Vit/Min mixture[1]	1.6		1.6	
Ground limestone	0.84		–	
Dicalcium phosphate	1.36		–	
Salt	0.3		0.21	
L-lysine	0.06		0.12	
L-threonine	–		0.07	
L-tryptophan	–		0.04	
L-isoleucine	–		0.11	
L-leucine	–		0.14	
L-histidine	–		0.04	
Contents (%)	total	faecal[2] digestible	total	faecal[2] digestible
Crude protein (analysed)	17.1	14.2	18.4	14.1
Net energy (kcal kg^{-1}, calc.)	2240		2240	
Meth. + cystine (SAA, analysed)	0.63	0.52	0.51	0.37
Lysine (analysed)	1.04	0.85	1.10	0.84
Tryptophan (calculated)	0.19	0.16	0.20	0.16
Threonine (analysed)	0.69	0.56	0.73	0.54
Isoleucine (analysed)	0.73	0.60	0.80	0.59
Leucine (analysed)	1.49	1.27	1.54	1.20
Ca (analysed)	0.83		0.84	
P (analysed)	0.62		0.64	

[1] The vitamin mineral mixture supplied per 1 kg diet: 9000 I.U. vitamin A, 1800 I.U. vitamin D_3, 37 mg vitamin E, 6 mg riboflavin, 30 mg niacin, 15 mg d-pantothenic acid, 120 mg choline chloride, 45 μg vitamin B_{12}, 3 mg vitamin K, 100 mg $CuSO_4 \cdot 5H_2O$, 200 mg $ZnSO_4 \cdot H_2O$, 70 mg MnO_2, 410 mg $FeSO_4 \cdot 7H_2O$, 0.8 mg $CoSO_4 \cdot 7H_2O$ and 20 mg Virginiamycin.

[2] Calculated using the digestibility coefficients as determined in the digestibility trial.

Table 2. Experimental design of Experiment 1.

Group	Diet	Dietary levels (%)			
		total[1]		faecal digestible[2]	
		Meth	SAA	Meth	SAA
I	A	0.32	0.63	0.26	0.52
II	B	0.24	0.51	0.17	0.37
III	B + 0.05 % DL-methionine	0.29	0.56	0.22	0.42
IV	B + 0.10 % DL-methionine	0.34	0.61	0.27	0.47
V	B + 0.15 % DL-methionine	0.39	0.66	0.32	0.52
VI	B + 0.20 % DL-methionine	0.44	0.71	0.37	0.57

[1] The contents of methionine and SAA in the diets of groups III to VI were calculated on basis of the analysed values in basal diet B.
[2] Derived from the digestibility values as determined in the digestibility trial. Faecal digestibility of DL-methionine was assumed to be 100%.

Table 3. Composition and contents (%) of the basal diet used in Experiment 2.

Ingredients (%)	Barley	30.00
	Corn	16.64
	Tapioca	21.80
	Soyabean meal (50 % cp)	13.00
	Cornglutenmeal	3.25
	Herringmeal	0.40
	Skimmilk powder	3.00
	Wheypowder (delact.)	1.00
	Soyabean oil	2.35
	Alfalfa meal	2.00
	Vit/Min premix[1]	1.00
	Molasses	2.00
	Monocalciumphosphate	1.65
	Salt	0.30
	Calcium formate (Cafo)	1.00
	L-lysine HCl	0.47
	L-isoleucine	0.05
	L-tryptophan	0.04
	L-histidine	0.05
Contents (%)	Crude protein (analysed)	16.5
	NE (calculated, kcal kg^{-1})	2300
	Lysine (analysed)	1.10
	Methionine (analysed)	0.27
	Cystine (analysed)	0.27
	Threonine (analysed)	0.60
	Tryptophan (analysed)	0.22
	Ca (analysed)	0.82
	P (analysed)	0.68

[1] The vitamin mineral mixture supplied per 1 kg diet: 9000 I.U. vitamin A, 1800 I.U. vitamin D_3, 40 mg vitamin E, 5 mg riboflavin, 30 mg niacin, 12 mg d-pantothenic acid, 150 mg choline chloride, 40 μg vitamin B_{12}, 3 mg vitamin K, 50 mg vitamin C, 650 mg $CuSO_4 \cdot 5H_2O$, 200 mg $ZnSO_4 \cdot H_2O$, 70 mg MnO_2, 400 mg $FeSO_4 \cdot 7H_2O$, 2.5 mg $CoSO_4 \cdot 7H_2O$, 0.2 mg $Na_2SeO_3 \cdot 5H_2O$, 0.5 mg KI and 40 mg Tylosine.

Body weight gain was determined individually after 8 weeks, at the end of the experimental period. Feed comsumption as well as feed conversion efficiency, calculated as kg feed consumed per kg weight gain, were recorded per replicate of ten animals.

Experiment 2. The second experiment was designed to study the effect of increasing supplementations of DL-methionine to a diet deficient in SAA, with a sub-optimal (0.60 %) and an optimal (0.70 %) level of dietary threonine (Schutte et al., 1990). Three hundred and sixty crossbred (Large White × Dutch Landrace) pigs of about 5 weeks of age, were given a 14 day acclimatization period. During this period, the pigs were gradually changed over from their original diet to a basal experimental diet supplemented with 0.05 % DL-methionine and 0.05 % threonine. After the acclimatization period, at an average weight of 14 kg, the animals were allotted to 10 experimental treatments by weight, sex and parentage. The pigs were housed in an artificially lighted and ventilated pig unit. Four replicates of 9 pigs each, two pens with barrows and two pens with gilts, were assigned to each of the experimental treatments. The basal diet (Table 3) was adequately supplemented with all essential amino acids except methionine and threonine, and analysed for the contents of methionine, cystine, lysine, threonine and tryptophan.

In Table 4, the experimental design is given. Two dietary levels of threonine (0.60 % and 0.70 %) each, were combined with 5 levels of methionine (0.28 % to 0.38 %).

The diets were fed ad libitum as pellets. The animals had free access to water.

At the end of the experimental period, after 6 weeks, body weight gain was determined individually, while feed consumption and feed conversion efficiency were recorded per replicate of 9 animals.

Table 4. Experimental design of Experiment 2.

Group	Additions (%) to basal diet		Dietary levels (%)				
			total[1]			faecal digestibile[2]	
	DL-Meth	L-Thre	Meth	SAA	Thre	SAA	Thre
I	0.0	0.0	0.27	0.54	0.60	0.49	0.52
II	0.025	0.0	0.295	0.565	0.60	0.515	0.52
III	0.050	0.0	0.32	0.59	0.60	0.54	0.52
IV	0.075	0.0	0.345	0.615	0.60	0.565	0.52
V	0.100	0.0	0.37	0.64	0.60	0.59	0.52
VI	0.0	0.10	0.27	0.54	0.70	0.49	0.62
VII	0.025	0.10	0.295	0.565	0.70	0.515	0.62
VIII	0.050	0.10	0.32	0.59	0.70	0.54	0.62
IX	0.075	0.10	0.345	0.615	0.70	0.565	0.62
X	0.100	0.10	0.37	0.64	0.70	0.59	0.62

[1] Calculated on basis of the analysed contents of methionine, SAA and threonine in the basal diet (= Group I).
[2] Derived from the figures given by CVB (1988).

Experiment 3. The objective of this experiment was to determine the replacement value of cystine for methionine. Three hundred and twenty four crossbred (Large White × Dutch Landrace) pigs of about 7 weeks of age, were given an acclimatization period of 11 days. During this period, the animals were gradually changed over from their original diet to a mixture (50:50) of basal diets A and B (Table 5), containing 0.65 % SAA and 0.33 % methionine. After the acclimatization period, the

Table 5. Composition and analysed or calculated contents (%) of crude protein and amino acids of the two basal diets used in Experiment 3.

		Basal diet A	Basal diet B
Ingredients (%)	Barley	30	30
	Corn	16	16
	Tapioca	27.25	27.03
	Cornglutenmeal (55 % cp)	2.50	0.45
	Soyabean oilmeal (49 % cp)	7.10	9.40
	Fishmeal (70 % cp)	3.00	0.45
	Feathermeal hydr. (85 % cp)	0.40	2.45
	Wheypowder (delactosed)	4.00	4.00
	Soya oil	1.40	1.72
	Alfalfameal	2.00	2.00
	Vit/Min premix[1]	1.00	1.00
	Molasses	2.00	2.00
	Ground limestone	0.75	0.77
	Monocalcium phosphate	1.30	1.45
	Salt	0.30	0.30
	L-lysine HCl	0.50	0.57
	L-isoleucine	0.13	0.11
	L-tryptophan	0.05	0.05
	L-valine	0.06	–
	L-histidine	0.09	0.12
	L-threonine	0.14	0.12
Contents (%)	Crude protein (analysed)	15.3	15.4
	NE (kcal kg^{-1}, calculated)	2275	2275
	Methionine (analysed)	0.27	0.21
	Cystine (analysed)	0.25	0.28
	Lysine (analysed)	1.11	1.09
	Threonine (analysed)	0.73	0.71
	Arginine (analysed)	0.78	0.81
	Valine (analysed)	0.84	0.79
	Isoleucine (analysed)	0.78	0.74
	Leucine (analysed)	1.30	1.15
	Tryptophan (calculated)	0.20	0.20
	Ca (analysed)	0.84	0.83
	P (analysed)	0.65	0.62

[1] The vitamin mineral mixture supplied per 1 kg diet: 9000 I.U. vitamin A, 1800 I.U. vitamin D_3, 40 mg vitamin E, 5 mg riboflavin, 30 mg niacin, 12 mg d-pantothenic acid, 150 mg choline chloride, 40 μg vitamin B_{12}, 3 mg vitamin K, 50 mg vitamin C, 650 mg $CuSO_4 \cdot 5H_2O$, 200 mg $ZnSO_4 \cdot H_2O$, 70 mg MnO_2, 400 mg $FeSO_4 \cdot 7H_2O$, 2.5 mg $CoSO_4 \cdot 7H_2O$, 0.2 mg $Na_2SeO_3 \cdot 5H_2O$, 0.5 mg KI and 40 mg Tylosine.

Table 6. Experimental design of Experiment 3.

Group	Basal diet	Addition of DL-Meth (%)	Calculated dietary levels (%)			Methionine (% of SAA)
			Meth	Cystine	SAA	
I	A	0.0	0.25	0.25	0.50	50
II	B	0.0	0.20	0.30	0.50	40
III	A	0.05	0.30	0.25	0.55	55
IV	B	0.05	0.25	0.30	0.55	45
V	A	0.10	0.35	0.25	0.60	58
VI	B	0.10	0.30	0.30	0.60	50

animals were allotted to 6 experimental treatments by weight, sex and parentage. The pigs were housed in an artificially lighted and ventilated pig unit. Six replicates of 9 pigs each, three pens with barrows and three pens with gilts, were assigned to each of the experimental treatments. The basal diets were adequately supplemented with all essential amino acids except methionine.

Two basal diets A and B (Table 5) were composed with calculated cystine contents of 0.25 % and 0.30 % and calculated methionine contents of 0.25 % and 0.20 %, respectively. The experimental design, three methionine additions (0, 0.05 and 0.10 %) to both basal diets, is given in Table 6. As the calculated contents of methionine and cystine agreed well with the analysed ones (Table 5), for the clarity the former values were used in calculating the contents of methionine and cystine in the experimental diets.

The diets were fed as pellets ad libitum. Water was available ad libitum.

At the end of the experimental period, after 6 weeks, body weight gain was determined individually, whereas feed consumption and feed conversion efficiency were determined per replicate of 9 animals.

Statistical analysis

Weight gain and feed conversion efficiency, at the end of the experimental periods, were analysed statistically using the ANOVA procedure of the SPSSPC+ statistical package (SPSS, 1988). The Least Significance Difference test was used to identify significant differences among treatment means (Snedecor & Cochran, 1980).

Results

Experiment 1. The ratio of (faecal) digestible to total SAA was different for the two basal diets; in basal diet A, 83 % of the total SAA was digestible, whereas in basal diet B the digestible SAA only accounted for 73 % of the total SAA. To obtain equal contents of faecal digestible SAA (0.52 %), basal diet B should contain 0.66 % total SAA and basal diet A 0.63 %.

The results for weight gain and for feed conversion efficiency (kg feed per kg gain) are given in Table 7. At similar dietary levels of faecal digestible SAA, no

Table 7. Experiment 1. Results for weight gain and feed conversion efficiency (kg feed per kg gain) at 8 weeks experimental period.

Group	Diet	Dietary level of SAA		Weight gain[1] (g day^{-1})	Feed/ gain[1] (kg kg^{-1})	Feed intake (g day^{-1})
		total (%)	digestible (%)			
II	B	0.51	0.37	326a	2.86a	932
III	B	0.56	0.42	394b	2.57b	1013
IV	B	0.61	0.47	417bc	2.44bc	1017
V	B	0.66	0.52	440cd	2.30c	1012
VI	B	0.71	0.57	453d	2.28c	1033
I	A	0.63	0.52	450cd	2.32c	1044

[1] Values within columns not having one letter in common, differ significantly ($P < 0.05$).

appreciable differences in performance were found for the experimental and the control diet, showing that optimum performance can be obtained with a less digestible diet supplemented with essential amino acids. Optimum performance of pigs fed on basal diet B was found at a faecal digestible SAA content of about 0.52 %. This value corresponded with 0.66 % total dietary SAA for basal diet B.

Experiment 2. The results for weight gain and feed conversion efficiency after 6 weeks experimental period are given in Table 8. When the dietary threonine level

Table 8. Experiment 2. Mean results for weight gain and feed conversion efficiency (feed/gain) at 6 weeks experimental period.

Group	Dietary level of		Weight gain[1] (g day^{-1})	Feed/ gain[1] (kg kg^{-1})	Feed intake (g day^{-1})
	SAA (%)	Threon (%)			
I	0.54	0.60	536a	2.08a	1115
II	0.565	0.60	577a	2.04a	1177
III	0.59	0.60	564a	2.01a	1134
IV	0.615	0.60	562a	2.02a	1135
V	0.64	0.60	568a	2.02a	1147
VI	0.54	0.70	552a	2.02a	1115
VII	0.565	0.70	574ab	1.96ab	1125
VIII	0.59	0.70	628ab	1.93bc	1212
IX	0.615	0.70	619ab	1.88c	1164
X	0.64	0.70	642b	1.87c	1200
Composite data threonine effect					
Groups I-V		0.60	561a	2.03a	1141
Groups VI-X		0.70	603b	1.93b	1163

[1] Values within groups with equal levels of dietary threonine not having one letter in common, differ significantly ($P < 0.05$).

was increased from 0.60 to 0.70 %, weight gain was significantly ($P < 0.05$) improved with 7.5 % and feed conversion efficiency was significantly ($P < 0.05$) improved with 5 %, indicating that the basal diet was clearly deficient in threonine.

At 0.60 % threonine, small and non significant effects of methionine supplementation were found. At 0.70 % threonine level, however, a significant linear effect ($r = 0.93$) of an addition of methionine to the basal diet on weight gain was found. Feed conversion efficiency was improved upto a methionine supplementation of 0.075 % to the 0.70 % threonine diet, resulting in a dietary SAA level of approximately 0.62 %. Upto this dietary SAA level the improvement in feed conversion was significantly linear ($r = 0.99$).

Experiment 3. In Table 9 the mean results for weight gain and feed conversion efficiency at 6 weeks experimental period are given. At equal dietary levels of methionine almost similar performance on both basal diets was achieved (Group I vs Group IV and Group III vs Group VI). Thus it can be justified to assume that the differences in pig performance on both basal diets are the result of the dietary methionine and cystine treatments. At dietary SAA levels of 0.50 %, significantly ($P < 0.05$) better results for weight gain and feed conversion efficiency were achieved with a methionine: cystine ratio of 50:50 than with a ratio of 40:60 between these amino acids (Group I vs Group II). Supplementation of the diets of Groups I and II with 0.05 % methionine, resulting in dietary SAA levels of 0.55 % and methionine: cystine ratio's of 55:45 and 45:55, respectively, did improve weight gain significantly ($P < 0.05$) and feed conversion efficiency markedly. However, at a methionine: cystine ratio of 55:45 (Group III) significantly ($P < 0.05$) better performance was achieved than at a ratio of 45:55 (Group IV), the results of the latter group being almost similar to those of Group I. When methionine contributed 58 and 50 % of the total SAA, respectively, almost similar results for weight gain and feed conversion efficiency were obtained (Groups V and VI).

Table 9. Experiment 3. Mean results for weight gain and feed conversion efficiency (feed/gain) at 6 weeks experimental period.

Group	Dietary level of			Methionine as % of SAA	Weight gain[1] (g day^{-1})	Feed/ gain[1] kg kg^{-1})	Feed intake (g day^{-1})
	Meth (%)	Cyst (%)	SAA (%)				
A I	0.25	0.25	0.50	50	693a	2.24ab	1552
B II	0.20	0.30	0.50	40	610c	2.38d	1452
A III	0.30	0.25	0.55	55	736b	2.14bc	1575
B IV	0.25	0.30	0.55	45	686a	2.26a	1550
A V	0.35	0.25	0.60	58	738b	2.09c	1542
B VI	0.30	0.30	0.60	50	729b	2.16abc	1575

[1] Values within columns not having one letter in common, differ significantly ($P < 0.05$).

A comparison of Groups I, III and V with methionine levels increasing from 0.25 till 0.35 % and cystine contents of <50 % of SAA shows that weight gain was maximized at 0.30 % methionine (SAA 0.55 %); feed conversion improved as the methionine levels were increased, the difference between 0.25 % and 0.35 % methionine levels being significant.

Discussion

A review of the literature by Bach Knudsen & Jørgensen (1986) pointed out that the utilization of synthetic amino acids was reported to be less than protein-bound amino acids by some investigators and equal or better by others. From these studies, they concluded that the utilization of synthetic amino acids most likely depends on the buffering capacity of the body's metabolic pool of amino acids, as the absorption of synthetic amino acids is more rapid than that of protein-bound amino acids. In this connection the frequency of feeding and/or the amounts of synthetic amino acids included in the diet would also influence the utilization of synthetic amino acids. In a lot of experiments discussed in literature, in which diets supplemented with free synthetic amino acids did not give the same performance as diets with only protein-bound amino acids, it is also possible that one of the other amino acids was limiting performance. This can also be seen with the threonine-deficient diet of Experiment 2, which did not give the same performance as the diet adequately supplemented with threonine, despite the adequate supplementation with methionine.

Requirement figures for methionine + cystine found in literature vary considerably. Taylor et al. (1983) suggested a SAA requirement of 0.45 % of the diet for pigs in the weight range of 25-55 kg. For slightly heavier pigs (30-60 kg), Roth & Kirchgessner (1987) advised a dietary SAA content of 0.57 %. The results from Experiment 1 as well as Experiment 2 suggest a SAA requirement of approximately 0.65 % of the diet for pigs in the weight range of 15 to 40 kg, slightly higher than the 0.60 % reported by Berende & Bertram (1983). As a percentage of the dietary lysine content, our experiments suggest a SAA content of 59 %, comparable to the 61 % recommended by Wang & Fuller (1990).

When a diet is deficient in one or more essential amino acids, determination of the requirement for another essential amino acid will result in an underestimation of this requirement. This is shown in Experiment 2, in which the basal diet was clearly deficient in threonine. The lower SAA requirements as determined by Taylor et al. (1983) are probably due to a shortage of threonine (0.57 % in the diet) and tryptophan (0.16 % in the diet).

The extent to which cystine can be used to meet the requirement for total SAA ranges in literature from 40 % (Becker et al., 1955) to 70 % (Mitchell et al., 1968). Recently, Roth & Kirchgessner (1987) reported that considerable losses in performance occur if the proportion of cystine exceeds 55 % of the requirement for SAA.

The results of Experiment 3 suggest that cystine should not contribute more than 50 % of the total requirement for SAA, which is close to the findings of Roth & Kirchgessner (1987). The 50 % replacement value of cystine in pigs agrees well with those found in layer diets (Schutte et al., 1984).

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