



## Effect of Lysine to Digestible Energy Ratio on Growth Performance and Carcass Characteristics in Finishing Pigs

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**ABSTRACT:** This experiment was performed to investigate the effects of lysine (Lys) to DE ratio on growth performance, and carcass characteristics in finishing barrows. Ninety six cross-bred finishing barrows ((Landrace×Yorkshire)×Duroc, average BW 58.25±0.48 kg) were assigned as a randomized complete block design by 2 energy levels and 4 Lys:DE ratios on the basis of BW to one of 8 treatments with 3 replications with 4 animals per pen. The levels of DE and Lys:DE ratio for each treatment were i) DE 3.35 Mcal/kg, 1.5 g Lys/Mcal DE, ii) DE 3.35 Mcal/kg, 1.8 g Lys/Mcal DE, iii) DE 3.35 Mcal/kg, 2.1 g Lys/Mcal DE, iv) DE 3.35 Mcal/kg, 2.4 g Lys/Mcal DE, v) DE 3.60 Mcal/kg, 1.5 g Lys/Mcal DE, vi) DE 3.60 Mcal/kg, 1.8 g Lys/Mcal DE, vii) DE 3.60 Mcal/kg, 2.1 g Lys/Mcal DE, viii) DE 3.60 Mcal/kg, 2.4 g Lys/Mcal DE. During finishing period from 58 kg to 103 kg of BW, increased energy density in the diet increased ( $p<0.05$ ) ADG and gain:feed ratio, but did not influence ADFI. As Lys:DE ratio was increased, ADG, ADFI and gain:feed ratio were improved in finishing barrows ( $p<0.05$ ). There were positive interactions ( $p<0.05$ ) between carcass weight, grade, and backfat thickness and energy density and Lys level ( $p<0.05$ ). In conclusion, data from our current study suggest that maximum yields including ADG, gain:feed ratio, carcass weight and grade can be achieved by administering finishing pigs with an ideal Lys:DE ratio, Lys 2.1 g/DE Mcal. (**Key Words:** Barrows, Backfat, Lysine:DE Ratio, Carcass Characteristics)

### INTRODUCTION

Lysine (Lys) is considered as a reference of other indispensable amino acids due to the fact that Lys is the limiting amino acid in cereal-soybean meal diets for growing pigs (Southern, 1991; Kerr, 1993). Furthermore, Lys plays an important role in protein accretion and growth performance. Although a large amount of data for estimating Lys requirements is available, there are considerable variations due to numerous factors including genotype (Stahly, 1991), gender (Stuewe et al., 1992), balances with other limiting- (Schutte and Van Weerden, 1985; Yen et al., 1986a,b; Wang and Fuller, 1989) and non-limiting amino acids (Henry et al., 1992).

Many trials have been conducted to examine the effects of various levels of Lys:energy ratios on the growth performance. Increase in Lys:energy ratio in diet leads to

significant improvements in ADG and gain:feed ratio (Batterham et al., 1985; Rao and McCracken, 1990; Chiba et al., 1991). When the Lys:energy ratio was increased from 1.35 to 2.59 g Lys/Mcal DE, growth rate and lean content are improved but there is a concomitant reduction in marbling and backfat thickness (Castell et al., 1994). In a trial conducted with barley-based diets, Campbell et al. (1988) observed maximum growth when gilts were fed with diet containing 2.97 g Lys/Mcal DE. Van Lunen and Cole (1996) showed that increase in the Lys:energy ratio decreased back-fat thickness in high-lean-growth pigs without affecting the growth rate. However, Wahlstrom and Libal (1983) did not observe differences in carcass traits at 100 kg in pigs fed protein-deficient diets during the first 4 wk of growth period.

Amino acid:energy ratio determines the rate of protein and lipid deposition in the pig's body. Castell et al. (1994) and Blanchard et al. (1999) demonstrated that administration of pigs with feed containing low amino acid:energy ratio improved carcass and intramuscular fat

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level. Others reported that marginal efficiency of Lys utilization was decreased as the Lys intake approached to the amount required for maximum growth performance (Heger and Frydrieh; 1985; Batterham et al., 1990; Gahl et al., 1991; 1995). This discrepancy might be attributed to animal variation. Due to inter-animal variation, the mean efficiency of nutrient utilization determined in groups of animals would be lower than that in individual animal, especially when nutrient intake level approached to the requirements of maximum performance (Baker, 1986).

Therefore, the objective of this experiment was to determine the optimum energy density and Lys:DE ratio for growth performance by analyzing carcass characteristics in finishing barrows.

## MATERIALS AND METHODS

### Animal and experimental design

Ninety six cross-bred finishing barrows (Landrace×Yorkshire)×Duroc) with an average of 58.25±0.48 kg of BW were assigned as a randomized complete block (RCB) design by 2×4 factorial arrangement. Barrows were allotted to 1 of 8 dietary treatments with low and high DE and 4 levels of Lys:DE according to a 2×4 factorial arrangement, with 3 replicates for each dietary treatment. Piglets were blocked on the basis of BW. The levels of DE and Lys:DE ratio for each treatments were i)

DE 3.35 Mcal/kg, 1.5 g Lys/Mcal DE, ii) DE 3.35 Mcal/kg, 1.8 g Lys/Mcal DE, iii) DE 3.35 Mcal/kg, 2.1 g Lys/Mcal DE, iv) DE 3.35 Mcal/kg, 2.4 g Lys/Mcal DE, v) DE 3.60 Mcal/kg, 1.5 g Lys/Mcal DE, vi) DE 3.60 Mcal/kg, 1.8 g Lys/Mcal DE, vii) DE 3.60 Mcal/kg, 2.1 g Lys/Mcal DE, viii) DE 3.60 Mcal/kg, 2.4 g Lys/Mcal DE. The formula and calculated nutritional values of experimental diets were presented in Table 1. Pigs were housed in partially slotted concrete floored pen, equipped with a feeder and nipple waterer and allowed to freely access to water throughout the experiment. Pigs were fed twice daily at 08:00 and 16:00.

### Growth performance

Body weight was measured 2 wk interval and body weight gain was calculated by the difference between the initial body weight and final body weight. Body weight was measured individually. Feed efficiency was calculated by dividing corresponding body weight gain with total amount of feed consumed.

### Carcass characteristics

Backfat thickness during growing period was measured 2 wk interval using Lean-Meater (Renco Corp., Minneapolis, MN, USA). All pigs were slaughtered when they reached to an average body weight of 110 kg. After slaughter, backfat thickness was measured at the 5 to 8 cm off midline between 10th to 11th rib. After 24 h of

**Table 1.** Formula and chemical composition of the experimental diets

DE level G of lys/Mcal of DE	3.35 Mcal of DE/kg				3.6 Mcal of DE/kg			
	1.5	1.8	2.1	2.4	1.5	1.8	2.1	2.4
<b>Ingredients</b>								
Corn	85.60	81.26	75.92	70.19	86.16	80.35	73.89	69.90
Corn gluten feed	7.99	8.37	8.5	8.75	3.95	4.25	4.66	4.65
Soybean meal (44%)	0.48	4.54	9.82	15.39	3.58	7.19	15.37	19.40
Molasses	3.50	3.50	3.5	3.5	-	-	-	-
Tallow	-	-	-	-	4.00	4.00	4.00	4.00
Limestone	0.51	0.78	0.70	0.67	0.60	0.66	0.72	0.76
Tricalcium phosphate	0.93	0.58	0.63	0.61	0.75	0.63	0.50	0.42
NaCl	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
L-lys·HCl	0.22	0.21	0.17	0.12	0.19	0.15	0.09	0.10
Mineral mixture <sup>1</sup>	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Vitamin mixture <sup>2</sup>	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
<b>Chemical composition<sup>3</sup></b>								
DE (kcal/kg)	3,350	3,350	3,350	3,350	3,600	3,600	3,600	3,600
Crude protein (%)	9.4	10.9	12.8	14.8	9.8	11.8	14.0	15.5
Lys (%)	0.50	0.60	0.70	0.80	0.54	0.65	0.76	0.87
Methionine (%)	0.18	0.19	0.21	0.23	0.18	0.20	0.22	0.24
Ca (%)	0.55	0.55	0.55	0.55	0.50	0.50	0.50	0.50
Total P (%)	0.50	0.45	0.48	0.50	0.45	0.45	0.45	0.45

<sup>1</sup> Provided the following per kilogram of diet: choline chloride 700 mg, selenium 0.15 mg, manganese 0.03 g, zinc 0.1 g, iron 0.1 g, iodine 0.5 mg, magnesium 0.1 g.

<sup>2</sup> Provided the following per kilogram of diet: vitamin A 5,500 IU, vitamin D<sub>3</sub> 550 IU, vitamin E 27 IU, menadione sodium bisulfate 2.5 mg, pantothenic acid 27 mg, niacin 33 mg, riboflavin 5.5 mg, vitamin B<sub>12</sub> 0.04 mg, thiamin 5 mg, pyridoxine 3 mg, biotin 0.24 mg, folic acid 1.5 mg. <sup>3</sup> Calculated value.

postmortem, loin muscles between the 10th and 11th ribs were harvested, vacuum packed and stored at 5°C until chemical analysis.

Meat samples were mixed and homogenized with distilled water at a 1:10 (wt/vol) ratio and pH was measured using an Orion Research 601A Ionalyzer (Orion Research Inc., USA). Color values were analyzed by a chroma meter (Minolta Co. CR 301) for lightness (L), redness (a) and yellowness (b) of CIE (Commission Internationale de l'éclairage) and Hunter. The purge loss was measured based upon the amounts of drip loss during vacuum packing. Filter papers (diameter 150 mm; Whatman NO. 1, Japan) were used to absorb water on the meat surface. Proximate analysis for carcass samples was analyzed according to the methods of AOAC (1995).

### Statistical analysis

For statistical analyses, pigs were blocked by DE and body weight and carcass characteristics were compared by means using Duncan's multiple range test by GLM procedure of SAS (1985) program. The pen was considered as the experimental unit for performance data.

## RESULTS AND DISCUSSION

### Growth performance

Table 2 shows the effect of dietary Lys:DE ratio on the growth performance in pigs. Increase in energy density improved ( $p < 0.05$ ) ADG and gain:feed ratio, but ADFI was not affected. Similarly, Lee et al. (2002) reported that finishing barrows fed with high energy diet containing 3.5 Mcal of DE/kg increased both ADG and gain:feed ratio but decreased feed intake. Smith et al. (1999) demonstrated that increased dietary energy density improved ADG and gain:feed ratio, but ADFI was decreased in gilts from 29.5 to 72.6 kg. For barrows weighed from 44.5 to 104 kg, ADG was not changed but ADFI was decreased resulting in improved gain:feed ratio. Other studies have also shown increased growth performance when pigs were administered with diets with increased Lys content (Yen et

al., 1986a; Rao and McCracken, 1990; Hansen and Lewis, 1993). Friesen et al. (1994) showed improved ADG, FE and ADFI with increased Lys:DE ratio in growing pigs (34 to 72 kg) fed with digestible Lys levels ranging from 0.54 to 1.04% (2.14 to 3.65 g Lys/Mcal ME). Pigs fed with diets containing low Lys level (1.88 to 3.33 g Lys/Mcal DE) showed decreased growth rate (Chiba, 1994).

TMV (Technical Model for Pig Nutrition, 1994) model predicted 794, 734 and 658 g daily gain with 358, 332 and 299 g/kg feed efficiency in pigs fed with high, medium, and low Lys:DE diets, respectively. Witte et al. (2000) demonstrated that the high Lys diet improved gain:feed ratio, but did not affect feed intake and ADG in finishing pigs (90 to 120 kg BW). King et al. (2000) found that ADG increased but feed intake and gain:feed ratio decreased exponentially as Lys level increased from 4.8 to 9.7 g Lys/kg feed (1.38 to 2.80 g Lys/Mcal DE) in pigs from 80 to 120 kg BW, and anticipated the optimal level of Lys to energy ratio was at approximately 1.67 g Lys/Mcal DE. Smith et al. (1999) observed that increase in Lys:DE ratio did not affect gain:feed ratio but increased ADG and ADFI in gilts from 29.5 to 72.6 kg. Bae et al. (1998) showed the optimal growth rates occurred at 3.18 g Lys/Mcal for gilts and at 3.62 g Lys/Mcal for boars. Jung et al. (1999) suggested that optimal growth could be achieved when growing pigs fed diets with 3.5 g Lys/Mcal DE. Chang et al. (2000) reported that the optimal Lys:DE ratios was 3.2 and 3.8 g Lys/Mcal DE for barrows and gilts of 16 to 57 kg BW, respectively. Szabó et al. (2001) reported that ADG and gain:feed ratio were increased ( $p < 0.05$ ) by higher apparent ileally digestible Lys (0.42 g Lys/MJ DE) vs lower (Lys 0.30 g Lys/MJ DE) from 60 to 105 kg BW.

Therefore, based on the previous studies (Yen et al., 1986a; Cromwell et al., 1993; Hahn et al., 1995) and the present study, ADG, ADFI and gain:feed ratio in swine could be affected by gender, age, energy density and Lys level. Our current study shows that the optimum Lys:DE ratio for growth of finishing barrows was 2.4 g Lys/Mcal DE. This value is slightly higher than estimated Lys:DE ratio suggested by NRC (1998) for 50 to 80 kg barrows

**Table 2.** Effects of dietary energy level and lys:DE ratio on growth performance of finishing barrows

DE level g of lys/Mcal of DE	3.35 Mcal of DE/kg				3.60 Mcal of DE/kg				MSE <sup>1</sup>
	1.5	1.8	2.1	2.4	1.5	1.8	2.1	2.4	
ADG (kg/d)	0.26	0.50	0.70	0.77	0.52	0.71	0.78	0.79	0.02
ADFI (kg/d)	1.70	2.20	2.61	2.71	2.07	2.36	2.42	2.46	0.03
Gain:feed ratio	0.15	0.23	0.27	0.28	0.25	0.30	0.32	0.32	0.01
	ADG				ADFI				G/F
Probability (%)									
DE level	<0.01				0.45				<0.01
Lys level	<0.01				<0.01				<0.01
DE×Lys	<0.01				<0.01				0.16

<sup>1</sup> Mean standard error.

**Table 3.** Effects of dietary energy level and lys:DE ratio on carcass characteristics of finishing barrows

DE level		3.35 Mcal of DE/kg				3.60 Mcal of DE/kg				MSE <sup>1</sup>		
g of lys/Mcal of DE		1.5	1.8	2.1	2.4	1.5	1.8	2.1	2.4			
CWT (kg)		56.42	70.85	83.25	86.87	72.47	84.15	88.56	89.80	1.37		
Carcass grade <sup>2</sup>		3.83	2.75	1.91	1.75	2.41	2.41	1.91	2.00	0.12		
Backfat thickness (mm)		14.66	19.16	20.83	21.16	18.66	20.00	21.41	21.91	0.55		
Shear value (kg)		3.40	3.38	3.86	3.73	3.90	3.58	3.61	4.07	0.11		
Carcass loss (%)		30.96	28.01	28.58	28.12	30.42	28.90	27.48	28.34	0.36		
WHC (%)		58.76	62.35	61.18	61.66	59.66	60.67	62.73	61.56	0.47		
pH		5.49	5.63	5.66	5.68	5.76	5.65	5.59	5.57	0.03		
Chemical analysis (%)												
Moisture		73.98	73.45	73.04	73.03	74.58	73.12	73.45	73.34	0.15		
Crude fat		2.38	2.46	2.05	1.98	2.17	2.40	1.61	1.32	0.15		
Crude protein		21.33	21.70	22.61	22.24	21.02	22.00	22.43	22.86	0.13		
Crude ash		1.09	1.09	1.09	1.26	1.06	1.11	1.13	1.10	0.01		
Probability (%)												
DE level		CWT <sup>3</sup>	Grade	BF	Shear	CL	WHC <sup>4</sup>	pH	MO	CF	CP	CA
Lys level		<0.01	<0.01	<0.01	0.63	0.03	0.17	0.99	0.04	0.28	<0.01	0.28
DE×lys		<0.01	0.03	0.58	0.69	0.77	0.68	0.17	0.70	0.91	0.45	0.59

<sup>1</sup> Mean standard error. <sup>2</sup> Based on a scale with 1 = grade A, 2 = grade B, 3 = grade C, 4 = grade D.

<sup>3</sup> CWT = Carcass weight; <sup>4</sup> WHC = Water holding capacity.

with lean growth rates of 325 g/d of carcass fat-free lean (2.1 g Lys/Mcal DE).

**Carcass characteristics**

Table 3 showed the results of carcass quality of pigs administered with different Lys:DE ratio in diets. Carcass weight was significantly influenced by energy concentration and Lys level resulting in significant interaction response. Carcass grade and backfat thickness were positively correlated with concentration of Lys and energy level and showed interactive effects (p<0.05, Table 3).

Lean body mass rate is negatively correlated with backfat thickness in response to dietary energy density (Smith et al., 1999). Backfat thickness at slaughter was decreased by low energy and Lys levels which are contributed to reduced final weight. Chiba et al. (1999) found that backfat thickness at 10th rib was decreased but

lean accretion rate was increased as dietary Lys content increased from 1.76 to 2.96 g/Mcal DE. These results clearly showed that the lowest energy and Lys level were not sufficient for maximal lean deposition rate of barrows. The Lys:energy ratio is the primary determinants of protein and lipid deposition rate in pigs.

Crude fat content in loin eye area was not affected by DE level. However, intramuscular fat content was increased but carcass lean content was decreased by feeding pigs with diets containing low Lys:DE ratio (Castell et al., 1994; Kerr et al., 1995; Cisneros et al., 1996; Blanchard et al., 1999; King et al., 2000; Witte et al., 2000; Szabó et al., 2001). Cisneros et al. (1996) showed increased intramuscular fat content in longissimus muscle of pigs fed with Lys-deficient diets for 3 or 5 wks before slaughter. Therefore, these data suggest that intramuscular fat content and carcass lean content is determined by interactive effect of Lys:DE ratio

**Table 4.** Effects of dietary energy level and lys:DE ratio on pork color of finishing barrows

DE level:		3.35 Mcal of DE/kg				3.60 Mcal of DE/kg				MSE <sup>1</sup>	
g of lys/Mcal of DE		1.5	1.8	2.1	2.4	1.5	1.8	2.1	2.4		
Color	L	56.16	54.91	52.93	53.56	55.58	54.55	52.99	54.36	0.62	
	a	6.24	6.80	6.36	5.81	6.89	6.43	6.31	6.97	0.21	
	b	3.80	3.72	3.12	2.98	3.68	3.59	3.15	3.89	0.18	
Hunter	L	49.15	47.83	45.92	46.46	48.73	47.54	45.88	47.31	0.62	
	a	5.26	5.69	5.28	4.85	5.75	5.37	5.22	5.85	0.17	
	b	3.05	2.98	2.48	2.37	2.93	2.88	2.49	3.10	0.14	
Probability (%)											
DE level		Color L	Color a	Color b	Hunter L	Hunter a	Hunter b				
Lys level		0.97	0.44	0.61	0.95	0.46	0.63				
DE×lys		0.42	0.96	0.64	0.39	0.94	0.61				
		0.98	0.63	0.72	0.98	0.63	0.72				

<sup>1</sup> Mean standard error.

but not by DE level.

The appropriate lightness and color of lean meat represented important criteria for the consumer. Meat color was not affected by treatments ( $p>0.05$ , Table 4). Other researchers also reported that neither the lightness nor hue values were affected by Lys:DE treatments (Witte et al., 2000; Szabó et al., 2001).

In conclusion, data from our current study suggest that inadequate dietary Lys inhibits protein synthesis but increases available energy for fat deposition. Furthermore, maximum yields including ADG, gain:feed ratio, carcass weight and grade can be achieved when finishing barrows are administered with diet containing Lys 2.1 g/DE Mcal.

## REFERENCES

- Ahima, R. S., C. B. Saper, J. S. Flier and J. K. Elmquist. 2000. Leptin regulation of neuroendocrine systems. *Front Neuroendocrinol.* 21:263-307.
- Almeida, F. R. C. L., J. Mao, S. Novak, J. R. Cosgrove and G. R. Foxcroft. 2001. Effects of different patterns of feed restriction and insulin treatment during the luteal phase on reproductive, metabolic, and endocrine parameters in cyclic gilts. *J. Anim. Sci.* 79:200-212.
- AOAC. 1995. Official methods of analysis. 16th ed. Association of Official Analytical Chemists, Arlington, VA, USA.
- Bae, S. H., J. Jin, J. H. Kim, W. T. Cho, Z. N. Xuan, M. K. Kim and In K. Han. 1998. Effects of dietary lysine levels on growth Performance and nutrient digestibility of boar and gilt. *Kor. J. Anim. Nutr. Feed.* 22:157.
- Baker, D. H. 1986. Problems and pitfalls in animal experiments designed to establish dietary requirements for essential nutrients. *J. Nutr.* 116:2339-2348.
- Barb, C. R. 1999. The brain-adipocyte axis: role of leptin in modulating neuroendocrine function. *J. Anim. Sci.* 77:1249-1257.
- Batterham, E. S., L. M. Anderson, D. R. Baigant and E. White. 1990. Utilization of ileal digestible amino acids by growing pigs: effect of dietary lysine concentration on efficiency of lysine retention. *Br. J. Nutr.* 64:81-92.
- Batterham, E. S., L. R. Giles and E. B. Dettmann. 1985. Amino acid and energy interactions in growing pigs. 1. Effects of food intake, sex and live weight on the responses of growing pigs to lysine concentration. *Anim. Prod.* 40:331-343.
- Blanchard, P. J., M. Ellis, C. C. Warkup, B. Hardy, J. P. Chadwick and G. A. Deans. 1999. The influence of rate of lean and fat tissue development of pork eating quality. *J. Anim. Sci.* 68:477-485.
- Campbell, R. G., M. R. Taverner and D. M. Curic. 1988. The effects of sex and live weight on the growing pig's response to dietary protein. *Anim. Prod.* 46:123-130.
- Castell, A. G., R. L. Cliplef, L. M. Poste-Flynn and G. Butler. 1994. Performance, carcass and pork characteristics of castrates and gilts self-fed diets differing in protein content and lysine:energy ratio. *Can. J. Anim. Sci.* 74:519-528.
- Chang, W. H., J. D. Kim, Z. N. Xuan, W. T. Cho, In K. Han, B. J. Chae and In K. Paik. 2000. Optimal Lysine:DE ratio for growing pigs of different sexes. *Asian-Aust. J. Anim. Sci.* 13:31-38.
- Chiba, L. I. 1994. Effects of dietary amino acid content between 20 and 50 kg and 50 and 100 kg live weight on the subsequent and overall performance of pigs. *Livest. Prod. Sci.* 39:213-221.
- Chiba, L. I., A. J. Lewis and E. R. Peo, Jr. 1991. Amino acid and energy interrelationships in pigs weighing 20 to 50 kilograms: I. Rate and efficiency of weight gain. *J. Anim. Sci.* 69:694-707.
- Chiba, L. I., H. W. Ivey, K. A. Cummins and B. E. Gamble. 1999. Growth performance and carcass traits of pigs subjected to marginal dietary restrictions during the grower phase. *J. Anim. Sci.* 77:1769-1776.
- Cisneros, F., M. Ellis, D. H. Baker, R. A. Easter and F. K. McKeith. 1996. The influence of short-term feeding of amino-acid deficient diets and high dietary leucine levels on the intramuscular fat content of pig muscle. *Anim. Sci.* 63:517-522.
- Clapper, J. A. and T. M. Clark. 1999. Serum concentrations of IGF-I and relative amounts of IGF binding proteins (IGFBPs) in growing boars, barrows and gilts. *J. Anim. Sci.* 77(Suppl. 1):97(Abstr.).
- Clapper, J. A., T. M. Clark and L. A. Rempel. 2000. Serum concentrations of IGF-I, estradiol-17 $\beta$ , testosterone, and relative amounts of IGF binding Proteins (IGFBP) in growing boars, barrows, and gilts. *J. Anim. Sci.* 78:2581-2588.
- Cromwell, G. L., T. R. Cline, J. D. Crenshaw, T. D. Crenshaw, R. C. Ewan, C. R. Hamilton, A. J. Lewis, D. C. Mahan, E. R. Miller, J. E. Pettigrew, L. F. Tribble and T. L. Veum. 1993. The dietary protein and (or) lysine requirements of barrows and gilts. *J. Anim. Sci.* 71:1510.
- Friesen, K. G., J. L. Nelssen, R. D. Goodband, M. D. Tokach, J. A. Unruh, D. H. Kropf and B. J. Kerr. 1994. Influence of dietary lysine on growth and carcass composition of high-lean-growth gilts fed from 34 to 72 kilograms. *J. Anim. Sci.* 72:1761-1770.
- Gahl, M. J., M. D. Finke, T. D. Crenshaw and N. J. Benevenga. 1991. Use of a four-parameter logistic equation to evaluate the response of growing rats to ten levels of each indispensable amino acid. *J. Nutr.* 121:1720-1729.
- Gahl, M. J., T. D. Crenshaw and N. J. Benevenga. 1994. Diminishing returns in weight, nitrogen, and lysine gain of pigs fed six levels of lysine from three supplemental sources. *J. Anim. Sci.* 72:3177-3187.
- Hahn, J. D., R. R. Biehl and D. H. Baker. 1995. Ideal digestible lysine level for early- and late- finishing swine. *J. Anim. Sci.* 73:773-784.
- Hansen, B. C. and A. J. Lewis. 1993. Effects of dietary protein concentration (corn:soybean meal ratio) on the performance and carcass characteristics of growing boars, barrows, and gilts: Mathematical descriptions. *J. Anim. Sci.* 71:2122-2132.
- Heger, J. and Z. Frydrieh. 1985. Efficiency of utilization of essential amino acids in growing rats at different levels of intake. *Br. J. Nutr.* 54:499-508.
- Henry, Y., B. Seve, Y. Colleaux, P. Ganier, C. Saligaut and P. Jego. 1992. Interactive effects of dietary levels of tryptophan and protein on voluntary feed intake and growth performance in pigs, in relation to plasma free amino acids and hypothalamic serotonin. *J. Anim. Sci.* 70:1873-1887.
- Jung, H. J., J. H. Kim, K. S. Sohn and In K. Han. 1999. Effects of lysine:DE ratio on growth performance and nutrients digestibilities in growing pigs Korean. *J. Anim. Sci.* 41:435.
- Kerr, B. J. 1993. Optimizing lean tissue deposition in Swine. BioKoyowa Tech.

- Kerr, B. J., F. K. McKeith and R. A. Easter. 1995. Effect on performance and carcass characteristics of nursery to finisher pigs fed reduced crude protein, amino acid-supplemented diets. *J. Anim. Sci.* 73:433-440.
- King, R. H., R. G. Campbell, R. J. Smits, W. C. Morley, K. Ronnfeldt, K. Butler and F. R. Dunshea. 2000. Interrelationships between dietary lysine, sex, and performance and porcine somatotropin administration on growth Performance and Protein deposition in Pigs between 80 and 120 kg live weight. *J. Anim. Sci.* 78:2639-2651.
- Langlois, A. and F. Minvielle. 1989. Comparisons of three-way and backcross swine: I. Growth performance and commercial assessment of the carcass. *J. Anim. Sci.* 67:2018-2024.
- NRC. 1998. Nutrient requirements of swine. 10th ed. National Academy Press, Washington, DC, USA.
- Owens, P. C., K. L. Gatford, P. E. Walton, W. Morley and R. G. Campbell. 1999. The relationship between endogenous insulin-like growth factors and growth in pigs. *J. Anim. Sci.* 77:2098-2103.
- Rao, D. S. and K. J. McCracken. 1990. Effect of protein intake on energy and nitrogen balance and chemical composition of gain in growing boars of high genetic potential. *Anim. Prod.* 51:389-397.
- SAS. 1985. SAS user's guide. SAS Inst. Inc., Cary, NC, USA.
- Schutte, J. B. and E. J. Van Weeden. 1985. Interaction between lysine and sulphur amino acids. threonine and tryptophan in pigs in the live weight period of 10-30 kg. ILOB Rep. p. 552.
- Southern, L. L. 1991. Digestible amino acids and digestible amino acid requirements for swine. BioKyowa Technical Review-2. Chester field, MO: Nutri-Quest, Inc.
- Stahly, T. S. 1991. Amino acids in growing, finishing and breeding swine. In: Proceedings of Natl. Feed Ingredient Assoc. Nutrition Institute, Chicago, IL, USA.
- Stuewe, S. R., J. A. Unruh, K. G. Friesen, J. L. Nelsson, R. D. Goodband and M. D. Tokach. 1992. The influence of genotype, sex, and dietary lysine on carcass quality characteristics of 230 and 280 lb finishing pigs. Swine Day 1992. Kansas State University. pp. 102-105.
- Szabó, C. A., J. M. Jansman, L. Babinszky, E. Kanis and M. W. A. Verstegen. 2001. Effect of dietary protein source and lysine:DE ratio on growth performance, meat quality, and body composition of growing-finishing pigs. *J. Anim. Sci.* 79:2857-2865.
- TMV. 1994. Proefstation voor de Varkenshouderij. Technical Model Pig Nutrition; in Dutch. Rosmalen, The Netherlands.
- Van Lunen, T. A. and D. J. A. Cole. 1996. The effect of lysine/digestible energy ratio on growth performance and nitrogen deposition of hybrid boars, gilts and castrated male pigs. *Anim. Sci.* 63:465-475.
- Wahlstrom, R. D. and G. W. Libal. 1983. Compensatory responses of swine following protein insufficiency in grower diets. *J. Anim. Sci.* 56:118-124.
- Wang, T. C. and M. F. Fuller. 1989. The optimum dietary amino acid pattern for growing pigs. 1. Experiments by amino acid deletion. *Br. J. Nutr.* 62:77-89.
- Witte, D. P., M. Ellis, F. K. McKeith and E. R. Wilson. 2000. Effect of lysine and environmental temperature during the finishing phase on the intramuscular fat content of pork. *J. Anim. Sci.* 78:1272-1276.
- Yen, H. T., D. J. A. Cole and D. Lewis. 1986a. Amino acid requirements of growing pigs. 7. The response of pigs from 25 to 55 kg live weight to dietary ideal protein. *Anim. Prod.* 43:141-154.
- Yen, H. T., D. J. A. Cole and D. Lewis. 1986b. Amino acid requirements of growing pigs. 8. The response of pigs from 50 to 90 kg live weight to dietary ideal protein. *Anim. Prod.* 43:155-165.