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L. I. Chiba
Auburn University

A. J. Lewis
University of Nebraska-Lincoln, alewis2@unl.edu

E. R. Peo, Jr.
University of Nebraska-Lincoln

AMINO ACID AND ENERGY INTERRELATIONSHIPS IN PIGS WEIGHING 20 TO 50 KILOGRAMS: II. RATE AND EFFICIENCY OF PROTEIN AND FAT DEPOSITION[1,2]

L. I. Chiba[3], A. J. Lewis[4] and E. R. Peo, Jr.

University of Nebraska[5], Lincoln 68583-0908

ABSTRACT

Two experiments were conducted to investigate the relationships between amino acids and DE for pigs weighing 20 to 50 kg. In Exp. 1, there were three dietary lysine levels that were either adjusted (1.50, 2.35 and 3.20 g/Mcal DE) for five DE levels (3.00 to 4.00 Mcal/kg) or unadjusted (.45, .71 and .96% of the diet) for three DE levels (3.50 to 4.00 Mcal/kg). In Exp. 2, diets containing six lysine:DE ratios (1.90 to 3.90 g/Mcal) at two DE levels (3.25 and 3.75 Mcal/kg) were fed. Pigs were housed individually, and could eat and drink ad libitum. When pigs weighed 50 kg, their empty body composition was determined by the urea dilution technique in Exp. 1 and by prediction equations based on backfat in Exp. 2. For the adjusted diets in Exp. 1, protein deposition and protein deposition:DE intake increased ($P < .01$) slightly as DE levels increased. These criteria decreased linearly ($P < .001$), and fat deposition increased ($P = .11$) as DE increased when lysine:DE ratios were not maintained. As lysine levels increased, protein deposition and protein deposition: DE intake increased ($P < .001$) in both the adjusted and unadjusted diets. In Exp. 2, there was no effect of DE on either the rate or efficiency of protein deposition. Both protein deposition and protein deposition:DE intake increased ($P < .001$) and fat deposition decreased as lysine:DE ratios increased up to 3.00 g lysine/Mcal DE. Protein deposition: lysine intake decreased ($P < .01$) progressively as the lysine:DE ratio increased. Regression analyses indicated that protein deposition increased up to 3.00 g lysine/Mcal DE. The results demonstrate the need to adjust lysine according to energy levels and indicate that the optimum ratio for protein deposition was approximately 3.00 g lysine/Mcal DE (or 49 g of balanced protein/Mcal DE).

Key Words: Pigs, Lysine, Digestible Energy, Protein, Fat, Deposition

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Introduction

The amino acid concentrations of swine diets should bear some relationship to energy concentrations if the diets are to be used efficiently (Chiba et al., 1990a). However, investigations of the need to adjust amino acids in concert with the DE content of the diet have yielded inconsistent results (Clawson et al., 1962; Greeley et al., 1964a,b; Allee and Hines, 1972; Tribble et al., 1979; Prince, 1987). Although there are numerous possibilities for the inconsistencies, a primary cause may be changes in body composition of the pigs.

The concept of expressing amino acid requirements relative to energy concentrations is valid only if the relationship between energy intake and rate of protein deposition is linear (SCA, 1987). Linear, linear/plateau and curvi-

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[3]Present address: Anim. and Dairy Sci. Dept., Auburn Univ., Auburn, AL 36849-5415.

[4]To whom reprint requests should be addressed.

[5]Dept. of Anim. Sci.

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TABLE 1. REGRESSON MODELS USED TO PREDICT EMPTY BODY COMPOSITION (EXP. 1 AND 2)

Empty body component, kg	Regression coefficients[a]					$S_{y \cdot x}$[b]	R^2
	b_0	b_1	b_2	b_3	b_4		
Exp. 1							
Protein	−3.082	.169	.122	−.003	−.270	.36	.81
Fat	3.588	−.717	.429	.055	1.138	1.49	.79
Exp. 2							
Protein	9.189	−.218	.089	−.025	−.169	.33	.85
Fat	−10.417	.986	−.124	.121	.001	1.53	.83

[a]Model was $Y = b_0 + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_4$, where Y = empty body components (kg), X_1 = either urea space (kg; Exp. 1) or backfat thickness (mm; Exp. 2), X_2 = live BW (kg), X_3 = age (d) and X_4 = sex (assigned 1 for gilts and 2 for barrows).

[b]Standard error of estimate for the regression model.

linear relationships have been postulated (Williams, 1980; ARC, 1981), but the relationship seems to be linear for pigs weighing ≤ 50 kg (Close and Mount, 1976; Campbell and Dunkin, 1983; Campbell et al., 1983, 1985a). Thus, for growing pigs, feeding a fixed proportion of amino acids:energy at various DE concentrations should result in the same rate of lean deposition.

Two experiments were conducted to elucidate amino acid and energy interrelationships in pigs weighing 20 to 50 kg based on the rate and efficiency of protein and fat deposition. Growth data have been presented in a companion paper (Chiba et al., 1991).

Experimental Procedures

General. This research consisted of two experiments. The general features, such as experimental designs, composition of diets, animals, housing, management practices and statistical methods, have been described previously (Chiba et al., 1991).

Six gilts and six barrows weighing approximately 20 kg were killed by injection of 40 ml of Na pentobarbital[6], and the contents of gastrointestinal tracts and bladder were removed. Pigs had consumed a corn-soybean meal diet (16% CP) for 1 to 2 wk before euthanasia. The total empty body of each pig was analyzed for DM, CP (N × 6.25) and fat as described previously (Chiba et al., 1990). Ash content was determined by the procedures described by AOAC (1984). The body composition of these 12 pigs was assumed to be representative of the body composition at 20 kg of the other pigs used in this research.

Empty body composition of pigs weighing 50 kg was estimated from prediction equations based on urea space (Exp. 1) or backfat (Exp. 2). These equations are presented in Table 1. Although some values for live BW (six pigs in Exp. 1), age (seven pigs in Exp. 2) and backfat (six pigs in Exp. 2) were outside the range of the data used to derive the prediction equations (Chiba et al., 1990), the empty body components of all pigs were estimated.

Experiment 1. This experiment consisted of three trials in which the dietary lysine concentration was either adjusted or unadjusted for differences in DE concentration. Dietary treatments consisted of three lysine:DE ratios (1.50, 2.35 and 3.20 g/Mcal) at five DE levels (3.00, 3.25, 3.50, 3.75 and 4.00 Mcal/kg) for the adjusted diets and three lysine levels (.45, .71 and .96%) at three DE levels (3.50, 3.75 and 4.00 Mcal/kg) for the unadjusted diets. Empty body composition was estimated by the urea dilution technique (Chiba et al., 1990) when pigs weighed 50 kg. Urea space, live BW, age and sex (gilts and barrows) were used as the independent variables to predict empty body composition.

Experiment 2. In this experiment there were two trials with diets containing six lysine:DE ratios (1.90, 2.50, 3.00, 3.40, 3.70 and 3.90 g/Mcal) at two DE levels (3.25 and 3.75 Mcal/kg). Backfat thickness was measured when pigs weighed 50 kg. Measurements were made

[6]Anthony Products Co., Arcadia, CA.
[7]Lean-Meater, Renco Corp., Minneapolis, MN.

with an ultrasonic instrument[7] 4 to 5 cm from the midline on the right side at the third rib, last rib and last lumbar vertebra. Empty body composition was estimated by prediction equations as in Exp. 1, except that urea space was replaced with the mean of backfat measured at the three positions.

Regression Analyses. Quadratic regressions of protein deposition on DE concentrations and(or) lysine:DE ratios were developed. In Exp. 2, a complete quadratic regression analysis, involving both DE concentrations and lysine:DE ratios, was not possible because only two levels of DE were fed. Quadratic regressions also were developed to describe the relationships between protein deposition and DE and(or) lysine intakes. In addition, quadratic regressions of weight gain on DE and(or) lysine intakes were developed. All regressions were developed within each experiment and sex, and the homogeneity of regression coefficients for the independent variables were tested using experiment and sex as class variables.

Results and Discussion

The empty body composition of pigs weighing approximately 20 kg is presented in Table 2. The values for the body water, protein and ash were slightly lower but in general agreement with those reported by others (Shields et al., 1983; Tess et al., 1986; Smits et al., 1988). Body fat contents (15.19 and 14.93% for gilts and barrows, respectively) were somewhat higher than those reported by Shields et al. (1983) and Tess et al. (1986). There was no difference ($P > .05$) between gilts and barrows for any of the components. Therefore, means from the combined data were used to estimate initial body composition of pigs in both Exp. 1 and 2.

Experiment 1

General. Analyses for homogeneity revealed that the variances of response criteria were homogeneous ($P > .05$) in both the adjusted and unadjusted data sets; thus, results from the three trials were combined.

Rates of Protein and Fat Deposition. The rate of empty-body protein deposition increased slightly (linear, $P < .05$) toward high-energy diets in the adjusted diets (Table 3). In contrast, protein deposition rates decreased linearly ($P < .001$) as DE increased when lysine concentrations were not adjusted (Table 4). The effects of DE, however, became increasingly diminutive as lysine concentrations increased from .45 to .96% in the unadjusted diets (linear × linear and linear × quadratic, $P < .05$). The rate of fat deposition was unaffected by DE ($P > .05$) in the adjusted diets but seemed to increase ($P = .11$) as DE increased in the unadjusted diets.

Protein deposition increased curvilinearly as lysine:DE ratio or lysine content of the diets increased in both the adjusted (linear and quadratic, $P < .001$) and unadjusted diets. Pigs deposited progressively less fat (linear, $P < .001$) as lysine:DE ratios increased in the adjusted diets, whereas lysine concentration had no effect ($P > .05$) on fat deposition in the unadjusted diets.

The results reflected the daily consumption of lysine (and other amino acids) and energy (Chiba et al., 1991), emphasizing the importance of daily intakes of these nutrients. When pigs consume the same amounts of amino acids and energy at various dietary energy concentrations, the rate of lean (protein and its associated water) deposition is maintained. The lysine × DE interaction observed in the unadjusted data set indicates, however, that the need to adjust amino acids in concert with changes in DE may depend on the levels of amino acid in the basal diet. When dietary

TABLE 2. EMPTY BODY COMPOSITION OF PIGS WEIGHING APPROXIMATELY 20 KILOGRAMS[a]

Item	Gilts	Barrows	Combined	CV
Live BW, kg	20.7	20.5	20.6	–
Empty BW, kg	19.6	19.2	19.4	–
Empty body component, %				
Water	66.67	67.30	66.98	3.07
Protein	15.19	15.53	15.36	3.47
Fat	15.19	14.93	15.06	15.53
Ash	2.53	2.42	2.47	6.19

[a]Data represent means of six gilts and six barrows with the contents of gastrointestinal tracts and bladder removed.

lysine concentrations were high, pigs fed diets high in DE may have been able to consume adequate amounts of amino acids even though feed intake was reduced.

Nevertheless, the results of Exp. 1 emphasize the need to adjust amino acid concentrations with changes in DE, especially at low lysine levels. Without such adjustment, the rate of lean deposition is likely to decease, and fat deposition rate may increase, although in our data the latter effect was not statistically significant.

Efficiency of Protein Deposition. As for protein deposition rate, there was a slight, yet consistent, increase (linear, $P < .001$) in the efficiency of DE utilization for protein deposition in the adjusted diets but a decrease (linear, $P < .001$) as DE increased in the unadjusted diets. Protein deposition to DE intake increased with increases in lysine:DE ratio (linear, $P < .001$; quadratic, $P < .01$) and lysine concentration (linear, $P < .001$). The efficiency of lysine utilization for protein deposition improved as DE increased in both the adjusted (linear, $P < .001$) and unadjusted diets (linear, $P < .05$). Dietary energy, however, seemed to have less influence as lysine:DE ratios increased from 1.50 to 3.20 g/Mcal in the adjusted diets (linear × linear, $P < .05$). Although lysine was utilized less efficiently (linear, $P < .001$; quadratic, $P < .05$) for protein deposition in the adjusted diets as

TABLE 3. EFFECT OF VARIOUS LYSINE TO DIGESTIBLE ENERGY RATIOS AND DIGESTIBLE ENERGY LEVELS ON PROTEIN AND FAT DEPOSITION IN PIGS WEIGHING 20 TO 50 KILOGRAMS (EXP. 1: ADJUSTED)[ab]

		Least squares means[c]					
Lys:DE, g/Mcal	DE, Mcal/kg	PD, g/d	FD, g/d	PD:DEI, g/Mcal	PD:LysI, g/g	FD:DEI, g/Mcal	FD:LysI, g/g
1.50	3.00	63.5	250.3	8.9	6.0	35.4	23.6
	3.25[d]	66.5	216.0	9.6	6.4	31.8	21.5
	3.50	74.8	252.2	10.6	7.1	35.7	23.8
	3.75	72.2	255.2	11.5	7.7	40.9	27.2
	4.00	68.0	255.3	10.8	7.3	41.4	27.6
2.35	3.00	93.7	213.8	14.9	6.3	33.6	14.3
	3.25	104.7	217.8	15.2	6.5	31.9	13.6
	3.50	102.7	220.5	15.4	6.6	33.0	14.0
	3.75	97.0	225.3	15.8	6.7	36.8	15.7
	4.00	108.8	234.7	16.7	7.1	35.7	15.2
3.20	3.00	112.2	205.8	18.4	5.8	34.1	10.7
	3.25	112.7	192.5	18.3	5.7	31.2	9.7
	3.50	120.7	208.7	18.8	5.9	32.3	10.1
	3.75	122.2	216.5	18.8	5.9	33.3	10.4
	4.00	117.2	190.3	19.8	6.2	32.4	10.1
		P-values[e]					
Lys:DE							
Lin		.001	.001	.001	.001	.001	.001
Quad		.001	–	.003	.048	–	.001
DE							
Lin		.014	–	.001	.001	.007	.001
Cub		–	–	–	–	.015	.004
Lys:DE × DE		–	–	–	–	–	.017
Lys:DE × trial		–	–	–	–	–	.028
CV, %		14.55	16.51	11.18	11.41	13.50	16.46

[a]Lys:DE = lysine to digestible energy ratio, PD = protein deposition, FD = fat deposition, DEI = digestible energy intake and LysI = lysine intake.

[b]Ranges of initial weights were 19.9 to 21.7, 20.5 to 21.1 and 20.6 to 21.4 kg for Lys:DE ratios of 1.50, 2.35 and 3.20 g/Mcal, respectively; ranges of final weights were 49.2 to 51.3, 48.8 to 51.0 and 49.0 to 51.0 kg for Lys:DE ratios of 1.50, 2.35 and 3.20 g/Mcal, respectively.

[c]Each mean represents six individually fed pigs.

[d]One pig died from an unknown cause in Trial 2.

[e]*P*-values ≤ .05 are reported; Lin = linear, Quad = quadratic and Cub = cubic.

lysine:DE ratio increased, the increases in lysine concentration had no effect ($P > .05$) in the unadjusted diets.

Efficiency of Fat Deposition. Fat deposition to DE intake increased slightly as DE increased at 1.50 and 2.35 g lysine/Mcal DE, but it was relatively constant at 3.20 g lysine/Mcal DE in the adjusted diets (linear × linear, $P < .01$). In the unadjusted diets, pigs utilized energy more efficiently (linear, $P < .01$) for fat deposition as energy content of the diets increased, but lysine concentration had no effect ($P > .05$). Although there were lysine levels × trial interactions ($P < .05$) in both the adjusted and unadjusted diets, fat deposition to lysine intake decreased ($P < .001$) as lysine contents increased in all three trials. Fat deposition to lysine intake increased concomitantly with increases in DE, but the effect of DE seemed to diminish as lysine contents increased in both sets of diets.

Discussion. Considering the effect of DE on feed intake and the effect of energy intake on protein deposition (ARC, 1981; SCA, 1987), it seems logical to express amino acid requirements in terms of DE. However, the concept of expressing amino acid levels relative to energy is valid only if the relationship between energy intake and the rate of protein deposition is linear (SCA, 1987). This relationship was reported to be linear for young pigs (Campbell and Dunkin, 1983) and growing pigs (Close and Mount, 1976; Campbell et al., 1983; Campbell et al., 1985a), but not for finishing pigs (Dunkin et al., 1984; Campbell et al., 1985b). In addition, the relationship between the rate of lean deposition and BW of pigs seems to be linear up to approximately 50 kg

TABLE 4. EFFECT OF VARIOUS LYSINE AND DIGESTIBLE ENERGY LEVELS ON PROTEIN AND FAT DEPOSITION IN PIGS WEIGHING 20 TO 50 KILOGRAMS (EXP. 1: UNADJUSTED)[ab]

		Least squares means[c]					
Lys, %	DE, Mcal/kg	PD, g/d	FD, g/d	PD:DEI, g/Mcal	PD:LysI, g/g	FD:DEI, g/Mcal	FD:LysI, g/g
.45	3.00	63.5	250.3	8.9	6.0	35.4	23.6
	3.50	56.8	204.8	9.4	7.3	34.7	27.0
	3.75	54.5	243.5	8.1	6.7	36.8	30.7
	4.00	37.0	227.7	6.6	5.9	39.4	35.0
.71	3.00	93.7	213.8	14.9	6.3	33.6	14.3
	3.50	89.2	258.0	13.2	6.6	38.3	19.0
	3.75	89.8	255.8	13.1	6.9	37.9	20.1
	4.00	73.5	279.5	11.5	6.5	43.3	24.6
.96	3.00	112.2	205.8	18.4	5.8	34.1	10.7
	3.50	102.2	236.5	16.0	5.8	36.2	13.2
	3.75	106.8	224.5	16.8	6.6	35.0	13.7
	4.00[d]	109.1	238.5	16.7	7.0	36.5	15.2
		P-values[e]					
Lys							
Lin		.001	–	.001	–	–	.001
Quad		.018	–	–	–	–	.004
DE							
Lin		.001	–	.001	.047	.006	.001
Quad		–	–	–	–	–	.046
Lys × DE		–	–	–	–	–	.010
Lys × trial		–	–	–	–	–	.019
CV, %		14.31	16.17	11.92	12.67	13.24	12.81

[a]Lys = lysine, PD = protein deposition, FD = fat deposition, DEI = digestible energy intake and LysI = lysine intake.

[b]Ranges of initial weights were 19.9 to 21.6, 20.6 to 21.8 and 20.6 to 22.0 kg for Lys levels of .45, .71 and .96%, respectively; ranges of final weights were 47.7 to 49.5, 49.5 to 50.5 and 49.0 to 50.4 kg for Lys levels of .45, .71 and .96%, respectively.

[c]Each mean represents six individually fed pigs.

[d]One pig in Trial 3 was not catheterized; thus, body composition was not estimated.

[e]*P*-values ≤ .05 are reported; Lin = linear and Quad = quadratic.

(Just, 1984). These results and the relatively constant protein deposition rate observed at various DE contents (Table 3) indicate that the concept of expressing amino acid levels relative to energy is appropriate for growing pigs.

Although there was a diminishing response in protein deposition, pigs responded to increases in lysine:DE ratios up to the highest level fed. Furthermore, fat deposition decreased linearly with increases in lysine:DE ratio. Therefore, the effects of higher lysine: DE ratios were investigated in the second experiment.

Experiment 2

The variances for the response criteria were homogeneous ($P > .05$), thus data from the two trials were combined.

There was no effect ($P > .05$) of DE on the rate of protein deposition when lysine:DE ratios were maintained (Table 5). The rate of protein deposition increased quadratically (linear, $P < .001$; quadratic, $P < .05$) as lysine: DE ratio increased, reaching a maximum at 3.40 g/Mcal.

For fat deposition, there was a three-way interaction ($P < .05$) that seemed to be caused by the high feed intake of pigs fed one diet (3.40 g lysine/Mcal DE at 3.75 Mcal/kg) in Trial 1 (Chiba et al., 1991). The increased feed intake (and consequently higher DE intake) may have resulted in higher backfat thickness of those pigs (16.3 and 13.9 mm for Trials 1 and 2, respectively), which in turn increased the estimated empty-body fat content. The combined data indicated that the rate of fat deposition was higher in pigs fed the diets containing 3.75 Mcal DE/kg. This observation

TABLE 5. EFFECT OF VARIOUS LYSINE TO DIGESTIBLE ENERGY RATIOS AND TWO DIGESTIBLE ENERGY LEVELS ON PROTEIN AND FAT DEPOSITION IN PIGS WEIGHING 20 TO 50 KILOGRAMS (EXP. 2)[ab]

		Least squares means[c]					
Lys:DE, g/Mcal	DE, Mcal/kg	PD, g/d	FD, g/d	PD:DEI, g/Mcal	PD:LysI, g/g	FD:DEI, g/Mcal	FD:LysI, g/g
1.90	3.25	89.3	222.6	13.7	7.2	33.9	17.8
	3.75	90.8	261.5	13.7	7.2	39.4	20.7
2.50	3.25	106.9	200.5	17.2	6.9	32.0	12.8
	3.75	114.5	235.1	17.8	7.1	36.5	14.6
3.00	3.25	128.9	177.9	20.6	6.9	28.1	9.4
	3.75	125.9	201.3	20.1	6.7	32.3	10.8
3.40	3.25	137.9	143.5	21.9	6.5	22.7	6.6
	3.75	131.5	209.3	19.9	5.9	30.9	9.1
3.70	3.25	137.5	163.8	21.4	5.8	24.8	6.7
	3.75	131.8	187.6	20.7	5.6	29.6	8.0
3.90	3.25	126.8	165.8	20.6	5.3	26.9	6.9
	3.75	131.4	175.3	21.5	5.5	28.4	7.3
		P-values[d]					
Lys:DE							
Lin		.001	.009	.001	.003	.005	.001
Quad		.019	–	–	–	–	.009
DE		–	.044	–	–	.022	.017
Lys:DE × DE × trial		–	.047	.048	–	–	–
CV, %		13.68	19.62	12.84	12.20	19.81	21.07

[a]Lys:DE = lysine to digestible energy ratio, PD = protein deposition, FD = fat deposition, DEI = digestible energy intake and LysI = lysine intake.

[b]Initial weights were 21.6 and 21.7, 20.9 and 21.2 21.5 and 21.1, 21.7 and 21.2, 22.1 and 21.4 and 21.5 and 21.3 kg for Lys:DE ratios of 1.90, 2.50, 3.00, 3.40, 3.70 and 3.90 g/Mcal, respectively; final weights were 51.0 and 49.7, 50.1 and 51.1, 49.6 and 50.7, 51.3 and 50.6, 49.5 and 49.9 and 51.0 and 49.9 kg for Lys:DE ratios of 1.90, 2.50 3.00, 3.40, 3.70 and 3.90 g/Mcal, respectively.

[c]Each mean represents eight individually fed pigs.

[d]*P*-values ≤ .05 are reported; Lin = linear and Quad = quadratic.

supports the contention that the difference observed in weight gain was due to changes in fat deposition in pigs fed the diets containing two levels of DE (Chiba et al., 1991). The rate of fat deposition decreased (linear, $P < .01$) up to 3.40 g lysine/Mcal DE and changed little with further increases.

Although the three-way interaction observed in feed (and energy) intake just mentioned was reflected in the efficiency of DE utilization for protein deposition, there seemed to be no effect of DE on this criterion. Similarly, there was no effect ($P > .05$) of DE on the efficiency of lysine utilization. The efficiency of DE utilization for protein deposition increased linearly up to 3.00 g lysine/Mcal DE and improved slightly with further increases. Pigs used lysine less efficiently (linear, $P < .01$) for protein deposition as lysine:DE ratio increased.

Fat deposition to both DE and lysine intakes were higher ($P < .05$) in pigs fed the diets containing 3.75 Mcal DE/kg than in those fed the diets containing 3.25 Mcal DE/kg. Conversely, fat deposition to DE (linear, $P < .01$) and lysine (linear, $P < .001$; quadratic, $P < .01$) intakes decreased consistently with increases in lysine:DE ratio.

Although pigs responded positively to increases in lysine:DE ratio up to 3.40 g/Mcal, their response in protein deposition was small when lysine:DE ratio increased from 3.00 to 3.40 g/Mcal. The efficiency of DE utilization for protein deposition improved up to 3.00 g lysine/Mcal DE. For fat deposition, the response to lysine:DE ratios was obscure because of the three-way interaction, but it decreased sharply up to 3.00 g/Mcal and changed little with further increases. These results indicate that the performance of pigs was optimized at 3.00 g lysine/Mcal DE.

Regression Analysis

General. Equations based on urea space (Exp. 1) and backfat thickness (Exp. 2) seemed to estimate empty body composition differently. Therefore, quadratic regression analyses were conducted within each experiment. The linear ($P < .001$) and quadratic ($P < .001$; $P < .05$ for barrows in Exp. 1) terms of both lysine: DE ratio and lysine intake were significant variables for predicting the rate of protein deposition, with the exception of the regression based on lysine intake for gilts in Exp. 2. The inclusion of DE concentration in Exp. 1 or DE intake in both Exp. 1 and 2 failed to improve the regression models based on either lysine: DE ratio or lysine intake. The initial and final weights ($P < .001$) were included in the models as covariates. After testing the homogeneity of regression coefficients between gilts and barrows, the quadratic regressions were developed and presented accordingly. Regression coefficients, standard errors of estimates

TABLE 6. THE RELATIONSHIPS BETWEEN PROTEIN DEPOSITION AND LYSINE TO DIGESTIBLE ENERGY RATIOS, AND BETWEEN PROTEIN DEPOSITION AND LYSINE INTAKE IN PIGS WEIGHING 20 TO 50 KILOGRAMS (EXP. 1 AND 2)

Exp.	Sex	N	Regression coefficients[a]					$S_{y \cdot x}$[b]	R^2
			b_0	b_1	b_{11}	b_2	b_3		
Based on lysine:DE									
1	Gilts	71	−187.818	110.656	−17.540	1.323	2.005	11.81	.82
1	Barrows	71	−148.148	67.277	−8.333	1.072	2.267	12.03	.79
2[c]	Combined	96	−122.253	116.888	−16.480	4.313	−.885	14.89	.58
Based on lysine intake									
1	Gilts	71	−66.718	13.397	−.289	.240	.556	9.44	.88
1	Barrows	71	−33.281	8.193	−.115	−.482	.834	10.42	.84
2	Gilts	48	−11.256	3.758	.008	3.999	−.553	14.23	.67
2	Barrows	48	−141.282	22.515	−.498	3.713	−1.115	14.36	.58

[a]Model was $Y = b_0 + b_1X_1 + b_{11}X_1^2 + b_2X_2 + b_3X_3$ where Y = protein deposition (g/d), X_1 = lysine:DE (g/Mcal) or lysine intake (g/d), X_2 = initial weight (kg) and X_3 = final weight (kg); initial weight and final weight were included in the model as covariates. (See Figures 1 and 2 for graphic presentations.)

[b]Standard error of estimate for the regression model.

[c]Regression coefficients for independent variables between gilts and barrows were homogeneous ($P > .05$); thus, only the regression derived from the pooled data is presented.

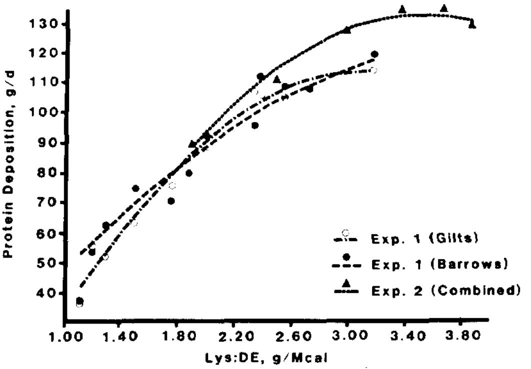

Figure 1. The relationship between the rate of protein deposition and lysine (Lys) to digestible energy (DE) ratios (Lys:DE) in pigs weighing 20 to 50 kg. The model was $Y = b_0 + b_1X_1 + b_{11}X_1^2 + b_2X_2 + b_3X_3$, where Y = protein deposition (g/d), X_1 = Lys:DE (g/Mcal), X_2 = initial weight (kg) and X_3 = final weight (kg) (see Table 6 for regression coefficients). Both initial and final weights were included in the model as covariates, and means were used for the regression lines. Regression coefficients for the independent variables between gilts and barrows were homogenous in Exp. 2; thus, the regression derived from the pooled data is presented.

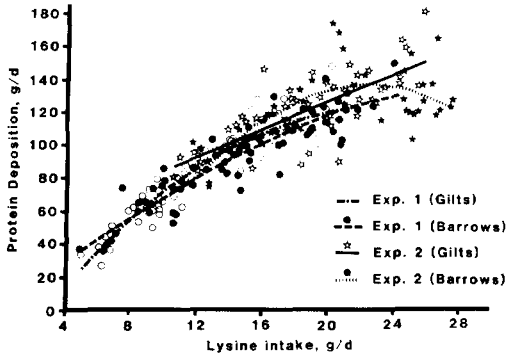

Figure 2. The relationship between the rate of protein deposition and lysine intake in pigs weighing 20 to 50 kg. The model was $Y = b_0 + b_1X_1 + b_{11}X_1^2 + b_2X_2 + b_3X_3$, where Y = protein deposition (g/d), X_1 = lysine intake (g/d), X_2 = initial weight (kg) and X_3 = final weight (kg) (see Table 6 for regression coefficients). Both initial and final weights were included in the model as covariates, and means were used for the regression lines. The methods of estimating body composition in Exp. 1 and 2 were different, and regression coefficients for the independent variables between gilts and barrows were not homogeneous ($P < .05$) in both Exp. 1 and 2. Therefore, regressions are presented accordingly.

and coefficients of determination for prediction equations are presented in Table 6.

For the prediction of weight gain, the linear, quadratic and interaction terms of lysine and DE intakes were significant variables ($P < .001$). The initial and final weights ($P = .07$ and $P < .01$, respectively) were also included in the regression model as covariates. There were no differences ($P > .05$) in regression coefficients between Exp. 1 and 2, or between gilts and barrows; thus, a common regression was developed from the pooled data.

Protein Deposition and Lysine:DE Ratios. Although regression coefficients for the independent variable between sexes were different ($P < .05$) in Exp. 1, both gilts and barrows responded to increases in lysine:DE ratio up to the highest ratio fed (3.20 g/Mcal; Figure 1). In Exp. 2, protein deposition was maximized at 3.40 g/Mcal, but the response was small when lysine:DE ratio increased from 3.00 to 3.40 g/Mcal.

Campbell et al. (1985a) reported that a lysine concentration of 3.39 g/Mcal was required to maximize protein deposition in boars weighing 20 to 45 kg. These values are greater than the NRC (1988) requirement for pigs weighing 20 to 50 kg (2.21 g/Mcal DE or .75% of the diet) but are less than that recommended by the ARC (1981) for pigs weighing 15 to 50 kg (3.51 g/Mcal DE).

Protein Deposition and Lysine Intake. Although there were differences in response to lysine intake between experiments and between sexes (Figure 2), pigs responded to increases in lysine intake up to at least 20 to 22 g/d (this is equivalent to 325 to 360 g/d of balanced protein). The limited number of observations beyond this range precludes a definite conclusion, but there was little response to further increases in lysine intake.

The ARC (1981) suggested that growing pigs need a minimum of 16 g lysine/d for maximal weight gain. Similar daily lysine intakes for optimum growth performance of gilts and barrows have been reported by Yen et al. (1986) and Giles et al. (1987). The NRC (1988) listed the daily lysine requirement of 20 to 50 kg pigs as 14.3 g. Even though it is generally assumed that higher amino acid levels are required for maximum lean deposition than for weight gain (Asche et al., 1985; NRC, 1988), gilts and barrows used in our experiments responded to higher lysine intakes (20 to 22 g/d) than those aforementioned. Some of the differences between our results and those of others may have been caused by differences in amino acid digestibility. The

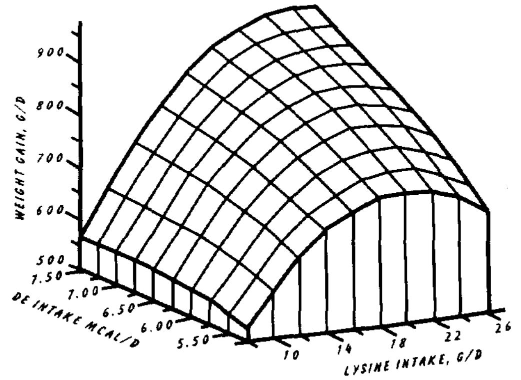

Figure 3. The relationship between weight gain and lysine intake and digestible energy intake in pigs weighing 20 to 50 kg. The equation was $WG = -708.6 + 33.8(LysI) + 159.8(DEI) - 1.5(LysI)^2 + 5.1(LysI \times DEI) - 14.3(DEI)^2 + 4.6(IWT) + 6.1(FWT)$ (n = 239; $S_{y.x} + 58.5$; $R^2 = .82$), where WG = weight gain (g/d), LysI = lysine intake (g/d), DEI = digestible energy intake (Mcal/d), IWT = initial weight (kg) and FWT = final weight (kg). Both IWT and FWT were included in the model as covariates, and means were used for the predicted values. Regression coefficients for the independent variables between Exp. 1 and Exp. 2, and also between gilts and barrows, were homogeneous ($P > .05$); thus, the regression from the pooled data is presented.

quadratic regression of weight gain on lysine intake from the pooled data ($R^2 = .74$; $P < .001$; not shown) indicated that pigs responded to increases in lysine intake up to 20 to 22 g/d, followed by little or no increase in weight gain at higher lysine intakes.

Weight Gain and Lysine and DE Intakes. Weight gain of pigs is determined primarily by lean and fatty tissue accretion, which are determined, to a large extent, by amino acid and energy intakes. Figure 3 demonstrates the interdependence of lysine and DE intakes on weight gain of pigs. At low lysine intakes, increases in DE intake had little or no effect on weight gain. However, as the intake of lysine (and other amino acids) became greater, pigs responded to an increase in DE intakes. When energy intake was low, there was an initial increase in weight gain in response to the additional lysine intakes, followed by a plateau and then a slight reduction. However, when DE intake was increased, pigs showed a greater response to increased lysine intake, and there was little or no reduction in weight gain associated with the high lysine intakes.

When amino acid intake is inadequate, an increase in energy intake has little beneficial effect on protein metabolism (Campbell et al., 1985a; SCA, 1987). As amino acid intake increased in our experiments, there was a concomitant increase in protein deposition (Figure 2). Although sufficient energy intake is necessary for a full utilization of additional amino acids consumed (Campbell et al., 1985a; SCA, 1987), energy intake did not seem to limit protein deposition in the present research. An energy intake in excess of that needed for maximum protein deposition results in a sharp rise in fat to protein ratio (Just, 1984; Whittemore, 1985). Therefore, the greater response to increased DE intake in pigs with high lysine intakes (Figure 3) may have been a reflection of increased rate of fat deposition without a change in the rate of protein deposition.

The reductions in weight gain associated with high lysine intakes (Figure 3) may indicate a reduction in energy available for fat deposition (Just, 1984; Whittemore, 1985). As amino acid intake increases, total ME intake would be reduced (Morgan et al., 1975). In addition, the efficiency of deaminated amino acid for ATP production (Schultz, 1975) or energy deposition (Just, 1982) has been shown to be lower than that of carbohydrates or lipids. Fat deposition rate was lower in pigs fed the diets with a high amino acid level (and consequently a high amino acid intake; r = .94, $P < .001$) in the present experiments.

An increase in heat loss (Tess et al., 1984) due to a higher visceral organ mass (Noblet et al., 1987) and increased rate of protein turnover (Reeds et al., 1981), both of which are associated with high protein intakes, are likely to reduce energy status of pigs further. A suppressing effect of high protein on the rate of lipogenesis in pigs has also been reported (O'Hea et al., 1970; Allee et al., 1971). These effects imply that the leanness of pigs can be improved by increasing dietary protein above the requirement, but a reduction of weight gain might be an inevitable consequence (Whittemore, 1985). Thus, the low weight gain when lysine consumption was low was caused by reductions in the rate of lean tissue deposition, whereas the reduced gain of pigs with high lysine intakes was caused by decreased fat deposition with little or no effect on lean tissue accretion.

Implications

The results demonstrate the need to adjust amino acid concentrations according to increases in energy content of the diets, without which protein deposition rates are likely to decrease and fat deposition rates may increase. However, the need to adjust dietary amino acids may depend on levels of amino acid in the basal diet; adjustment is less crucial when basal levels are high. The results also indicate that the pigs used in the present experiments responded to increases in lysine to digestible energy ratio and lysine intake beyond the current NRC (1988) requirements.

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