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Partitioning of dietary nitrogen between body components and waste in young growing pigs

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Abstract

Two experiments were conducted to determine the effect of protein and energy intake on (1) protein deposition and nitrogen utilization, (2) partitioning of body protein between edible products and offal, and (3) weights of metabolically active organs. In the first experiment, 90 female pigs were fed at two energy intake levels and 15 protein intakes from 20 to 45 kg. Protein deposition increased linearly with increasing protein intake until a plateau in deposition was reached at 106 and 126 g d^{-1} at the low and high energy level respectively. Marginal efficiency of utilization of ileal digestible lysine was 0.74 for the two energy levels. In a second experiment, 24 female pigs were fed a protein- adequate diet at six levels of energy intake ranging from 1.7 times maintenance to *ad libitum*. Protein deposition increased from 70 to 172 g d^{-1} with increasing feed intake. The proportion of body protein deposited as lean tissue decreased from 0.62 to 0.55 with increasing feed intake. Consequences of these results for a more sustainable animal production are discussed.

Keywords: pig, energy, protein, lysine, deposition, partitioning, excretion, organs

Introduction

In practical pig husbandry, dietary protein is deposited in body tissue with an efficiency of about 30%. Consequently 70% is lost to the environment (Coppoolse et al., 1990). Nutritional research can contribute to increase this efficiency and reduce excretion considerably by improving protein digestibility, protein quality (amino acid pattern) and utilization of absorbed amino acids. On the basis of two experiments this paper discusses various aspects of efficiency of utilization of dietary amino acids, i.e. the effect of protein and energy intake on protein utilization and excretion, on protein partitioning in the body and on individual organs.

The objectives of Exp. 1 were to determine (1) the relationship between intake and deposition of ileal digestible protein and lysine respectively, (2) the utilization of ileal digestible protein and lysine, and (3) the separate effects of protein and energy intake on protein and lysine utilization.

The aims of Exp. 2 were to determine the relationship between energy intake and

protein deposition and the effect of energy intake on partitioning of protein in the body. The design and results of these experiments are reported briefly and some consequences for developing feeding strategies with regard to a more sustainable animal production are discussed.

Materials and methods

Animals and experimental design

Ninety-five female pigs of a commercial hybrid (VOC Nieuw Dalland) were used in Exp. 1. At an average live weight of 20 kg, 90 animals were allocated on the basis of live weight to 30 treatments in a 2 * 15 factorial arrangement with three pigs per treatment. The respective treatments were energy intake level, equivalent to 2.5 (2.5*M) and 3.0 (3.0*M) times energy required for maintenance, and protein intake ranging from 127 to 350 $g.d^{-1}$ in 15 graduated steps. The remaining five pigs were used to determine initial body composition. In Exp. 2, 24 female pigs of similar genotype were allocated at 20 kg to six feeding levels, ranging from 1.7 times energy for maintenance to *ad libitum*.

Diets and feeding

Exp. 1

In order to obtain the 15 protein intake steps at the lower energy intake level, the animals were fed rations with a calculated lysine content ranging from 0.44 to 1.24 g MJ^{-1} digestible energy (DE). To ensure a constant dietary amino acid pattern, a protein-rich diet (Diet 1) and a protein-free diet (Diet 2) were formulated. Lysine was the first limiting amino acid in Diet 1. At the low energy intake level (2.5*M), animals received on average 15.8 MJ DE per day. To determine the effect of non-protein energy on protein deposition and N utilization independent of protein intake, at each of the 15 protein intake levels a second group of three animals received the same diet with in addition an extra amount of protein-free energy (Diet 2) of 3.0 MJ d^{-1}. Consequently lysine/energy ratios at the high intake level were 83% of the ratios at the low intake level and ranged from 0.37 to 1.03 g MJ^{-1} DE.

Exp. 2

In this experiment a cereal-based diet was used, designed to be adequate in protein and amino acids, with 0.64 g ileal digestible lysine MJ^{-1} DE.

In both experiments the animals were weighed twice a week and feed allowances were adjusted according to a scale based on metabolic live weight. Maintenance requirements were taken as 0.475 MJ DE $kg^{-0.75}$ (ARC, 1981).

Management and carcass analysis

The pigs were housed individually in pens with half-slatted floors in an insulated shed. They were fed equal rations twice daily at 08.00 and 16.00. Water was avail-

able *ad libitum*. At 45 kg the animals were humanely killed and their bodies were divided into carcass and organ fractions which were stored at –20°C. In addition carcasses of animals from treatments 2.2*M and 3.7*M in Exp. 2 were dissected into lean tissue and other carcass parts according to the Dutch standard method (Bergström & Kroeske, 1968). In a later-stage carcass, organ and lean fractions were homogenized and sampled for chemical analyses.

Statistical analysis

The effect of energy and protein intake in Exp. 1 and feed intake in Exp. 2 on deposition and utilization parameters was analysed with regression analysis. To describe a linear-plateau relationship the following model, based on Koops & Grossman (1993), was used:

$$y = A - b * p * \ln (1 + e^{(c-x)/p}) \quad (1)$$

This equation represents a linear-plateau model in which: y is the dependent variable, x is the independent variable, A is the level of the dependent variable when a plateau (second phase) is reached, b is the slope of the linear (first) phase, c is the level of the independent variable at the point of transition from the first to the second phase, and p is a parameter regulating the smoothness of transition.

Results

Production parameters

Exp. 1

Gain in live weight increased with increasing protein intake ($P < 0.001$) from 425 g d^{-1} to a plateau of 600 g d^{-1} at the low energy intake level and from 480 to 770 g d^{-1} at the high energy intake level. Gain to feed ratio (GFR) increased with increasing protein intake ($P < 0.001$) from 400 g kg^{-1} to a plateau of 560 and 600 g kg^{-1} at the low and high energy intake level respectively. Consequently extra energy intake improved both gain ($P < 0.01$) and GFR ($P < 0.01$) at adequate protein intake.

Exp. 2

Live weight gain increased linearly ($P < 0.001$) with increasing feed intake from 350 g d^{-1} at 1.7*M to 1075 g d^{-1} for the animals fed *ad libitum*. GFR increased ($P < 0.01$) from 480 g kg^{-1} at 1.7*M to 600 g kg^{-1} at 3.2*M and remained constant thereafter.

Protein and lysine deposition

Exp. 1

Protein and lysine deposition increased ($P < 0.001$) with increasing protein intake. This relationship was described accurately with the linear-plateau model with

r^2=0.91 and r^2=0.83 for protein (Figure 1 a) and lysine deposition respectively. Protein deposition reached a maximum of 106 and 126 g.d^{-1} at the low and high energy level respectively. Lysine deposition increased with increasing protein intake up to a maximum of 7.8 and 9.4 g.d^{-1} at the two energy levels respectively.

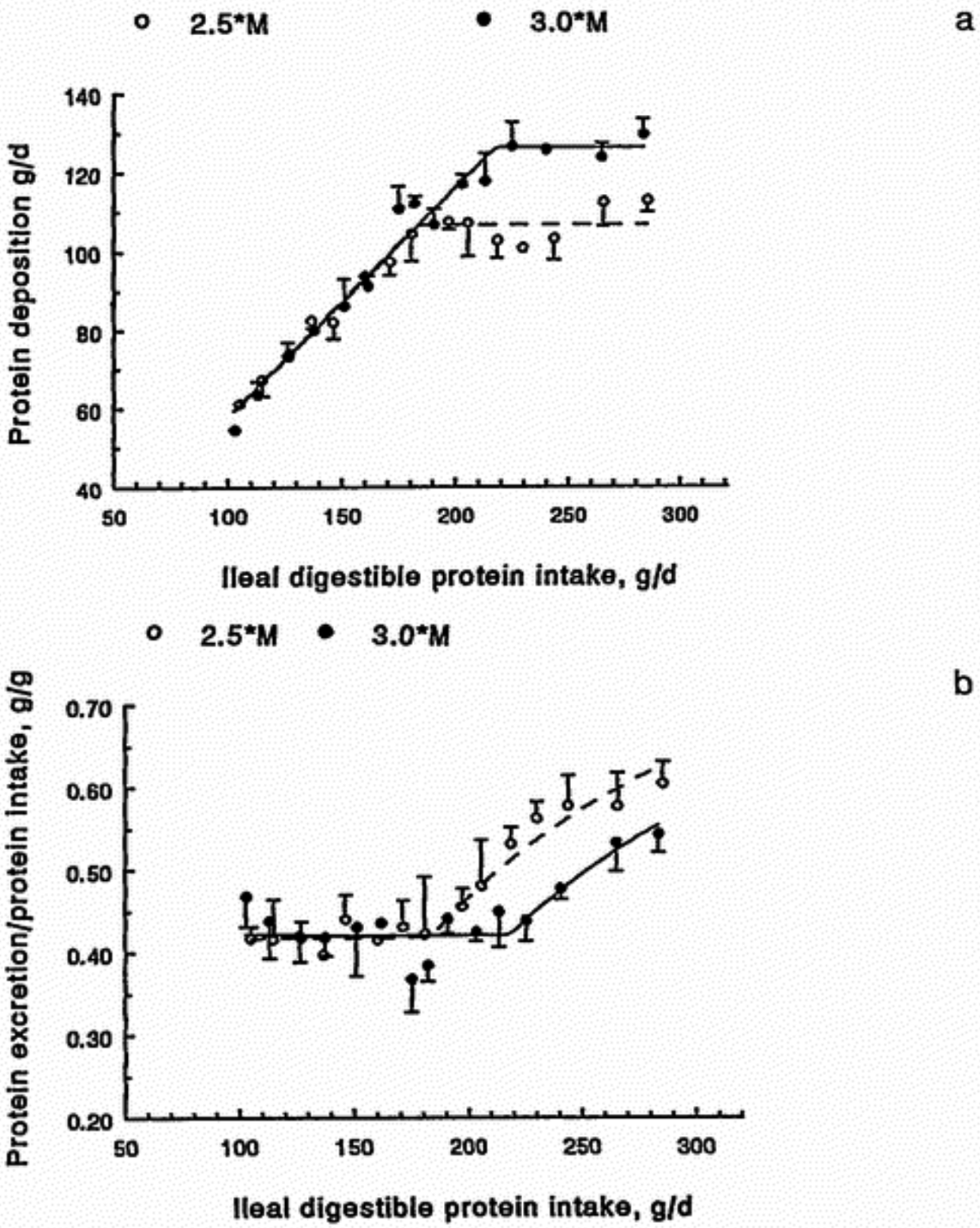

Figure 1. Relationship between protein intake and protein deposition (mean + se)(1a) and between protein intake and protein excretion (1b) at two energy intake levels.

Exp. 2

Protein deposition increased with increasing feed intake ($P < 0.001$) from 70 g d^{-1} at 1.7*M until a maximum of 172 g d^{-1} at an intake level close to *ad libitum*.

Protein and lysine utilization

Exp. 1

Gross efficiency of protein and lysine utilization was calculated as deposition divided by ileal digestible protein and lysine intake. These efficiencies were 0.58 and 0.75 for protein and lysine respectively in the protein-dependent phase and they were not affected ($P > 0.1$) by protein intake until a plateau in protein and lysine deposition was reached. The efficiencies declined rapidly after these plateaus had been reached. As a consequence excretion of protein and lysine relative to the intake was 0.42 and 0.25 respectively in the first phase and increased when maximum deposition rates were reached. This is illustrated in Figure 1(b) for the excretion of protein.

Marginal efficiency of protein utilization was defined as the increase in protein deposition per unit increase in protein intake. This marginal efficiency is represented by the slope of the relationship between protein intake and protein deposition. Marginal efficiencies of utilization of ileal digestible protein and lysine were 0.58 and 0.74 respectively in the protein-dependent phase.

Partitioning of protein

From results of Exp. 1 it was concluded that energy intake affected the partitioning of protein between carcass and organs ($P < 0.001$), whereas protein intake had no effect ($P > 0.1$). The relative amount of protein deposited in the organ fraction was 0.127 and 0.142 at the low and high energy level respectively. Such an effect of energy intake was also found in Exp. 2 where the relative amount of protein deposited in the organs increased from 0.114 at 1.7*M to 0.174 for the animals fed *ad libitum* ($P < 0.01$). Results of the dissection of the carcasses of animals at 2.2*M and 3.7*M showed a decrease in lean tissue from 63.7% to 58.5% of carcass weight. As a consequence of these effects of energy intake, the relative amount of empty body protein deposited as lean tissue decreased from 0.62 at 2.2*M to 0.55 at 3.7*M.

Organs

Both protein and energy intake affected the weights of several organs involved in nutrient uptake and metabolism. The most important results are summarized in Table 1. From these results it was concluded that an increase in protein intake increased the relative weight of liver, kidneys, pancreas and large intestine, whereas energy intake increased the weight of liver, small and large intestine. Results of Exp. 2 supported these effects but it was not possible to relate them to protein or energy intake separately because feed intake (both energy and protein) was increased in this experiment.

Table 1. Weight of individual organs at 45 kg as affected by protein, energy and feed intake[a]

Organ	Experiment 1					Experiment 2		
	weight (g)			effects[d]		weight (g)		effects[d]
	2.5*M[b]	3.0*M[b]	SEM[c]	energy	protein	mean	SEM[c]	feed
Liver	891	965	10.1	***	*	912	44.6	***
Kidneys	187	190	2.2	NS	***	185	5.9	***
Pancreas	68.8	75.2	3.2	NS	***	91.7	9.3	*
Small intestine	980	1081	18.8	***	NS	1031	59.6	***
Large intestine	670	705	13.3	*	*	759	52.5	*

[a] Linear regression was used to determine effects of protein and energy intake.
[b] First and second column: intake levels 2.5 and 3.0 times energy for maintenance respectively.
[c] Pooled standard error for the two and six energy intake levels respectively.
[d] NS, not significant, $P > 0.05$; *, $P < 0.05$; **, $P < 0.01$; ***, $P < 0.001$.

Discussion

The linear-plateau relationship between protein intake and protein deposition respectively is in agreement with Campbell et al. (1985) for pigs from 20 to 45 kg. The present study showed that this model is also suitable to describe the relationship between lysine intake and lysine deposition. Maximum protein and lysine deposition rates were higher at the high energy level than at the low energy level, which means that at adequate levels of protein intake, energy intake limited the protein and lysine deposition. In the linear phase, protein and lysine deposition were limited by protein intake and not by energy intake. These results support the concept of separate protein- and energy-dependent phases in protein and lysine deposition. The point of transition between the linear and the plateau phase increased with increasing energy intake ($P < 0.01$), which implies that if energy intake is increased, protein intake must also be increased to reach maximum protein deposition.

It has been suggested that maximum protein deposition can only be reached with a decline in nitrogen utilization (ARC, 1981). Because of the linear phase in the relationship between protein intake and protein deposition, and thus a constant marginal efficiency, this assumption was not supported by the results of the present experiment. Moreover, as illustrated in Figure 1(b), gross efficiency of protein utilization was constant until a plateau in protein deposition was reached. Consequently, feeding the animals well below their protein requirements will not improve protein utilization whereas carcass fatness will be increased. On the other hand, feeding the animals above their protein requirements will not result in any further increase in protein deposition and as a consequence nitrogen excretion will increase rapidly.

The distinction between protein- and energy-dependent phases has to be taken into consideration when measures to reduce nitrogen excretion are proposed or evaluated. If a measure improves protein deposition, and consequently protein utilization, in the energy-dependent phase, this can simply imply that the control animals received too much protein. This is illustrated in Exp. 1 by the fact that extra non-protein energy

increased protein deposition and utilization in the energy-dependent phase but did not improve protein utilization when protein intake (just) limited protein deposition, further called "potential protein utilization". A number of measures have been proposed to improve protein utilization whereas evidence that these can improve potential protein utilization is limited. Among these measures are the fattening of entire males instead of castrates, the use of metabolic modifiers such as recombinant porcine somatotropin and beta-agonists, and the improvement of the gain-to-feed ratio (Schutte & Tamminga, 1992). The validity of the statement that these measures improve protein utilization seems largely restricted to situations where dietary protein is available in abundance.

Both marginal and maximum gross efficiency of utilization of ileal digestible lysine, being the first limiting amino acid, were approximately 0.75. Batterham et al. (1990) determined marginal and maximum gross efficiencies for ileal digestible lysine of 0.86 and 0.73. Other workers determined or calculated values for marginal or maximum gross efficiencies of the first limiting amino acid or digestible ideal protein between 0.70 and 0.85 for pigs above 20 kg live weight (Noblet et al., 1987; Rao & McCracken, 1990; Kyriazakis & Emmans, 1992). These results indicate that marginal efficiency of utilization of ileal digestible ideal protein probably does not exceed 0.75-0.85.

These values seem low in comparison with studies in which oxidation of amino acids was measured. Several authors found that oxidation rate of a limiting amino acid was low until the requirements for that amino acid were met (Simon, 1989). An explanation for these differences is found in the processes of protein synthesis and breakdown in growing animals. Simon (1989) concluded that on average in growing animals the total protein synthesis is about five times the deposition rate. Furthermore, reutilization of a limiting amino acid might increase to 95% (Simon, 1989). If we assume that absorbed dietary lysine is used for protein synthesis with similar efficiency, the following calculation can be made. For an animal in Exp. 1 depositing 6.6 g lysine per day (100 g protein with 6.6 g lysine per 16 g N) this reflects a protein synthesis of 500 g d^{-1} (5*100), a degradation of 400 g d^{-1} and a requirement of 526 g d^{-1} (500/0.95) for synthesis. Consequently the dietary requirement is 126 g d^{-1} (526-400) which equals 8.4 g lysine. Thus the efficiency of utilization of dietary lysine for deposition is 0.79 (6.6/8.4). This calculation illustrates that protein presumably will be deposited with a lowered efficiency owing to a high ratio between protein synthesis and deposition.

Results of the present experiment showed that weights of different visceral organs increased with increasing protein intake or energy intake or both. Those increased weights presumably reflect an increased activity of these organs, in accordance with Koong et al. (1983), who reported a high positive correlation between fasting heat production and weights of metabolically active organs. This effect might be partially explained by the high fractional turnover rate of these organs as reported by Simon (1989). Consequently an increased protein or energy intake can be expected to cause an increased maintenance heat loss.

In Exp. 2 the combined effects of feed intake on protein deposited in the organs and on lean percentage in the carcass resulted in a decrease in the relative amount of

protein deposited as lean tissue from 0.62 at 2.2*M to 0.55 at 3.7*M. Because it is the aim of animal production to valorize edible products of high quality (i.e. lean meat), these effects should be taken into account when measures or feeding strategies are developed or evaluated.

Based on protein and lean tissue deposition at 2.2*M and 3.7*M the nitrogen excretion in the urine per kg deposited lean tissue was calculated, assuming a constant lean tissue composition. Protein deposition rates were 98 and 160 g d^{-1} and lean tissue deposition rates were 280 and 403 g d^{-1} at the low and high energy level respectively. Efficiency of utilization of ileal digestible protein was 0.64, which resulted in an excretion in urine of 31.5 and 35.7 g nitrogen per kg lean tissue at the low and high energy level respectively. If the utilization could be raised to 0.75 by improving the dietary amino acid pattern, this would result in an excretion of 18.7 and 21.2 g N in urine per kg lean tissue. Combined with a value for digestibility of dietary protein of 0.80, this would result in a minimum excretion of nitrogen between 37 and 42 g per kg lean tissue deposition in pigs between 20 and 45 kg.

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