Marginal Efficiency of Free or Protected Crystalline L-Tryptophan for Tryptophan and Protein Accretion in Early-Weaned Pigs[1]

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ABSTRACT: We conducted an experiment to determine the efficiency of dietary tryptophan (Trp) for protein and Trp accretion in 4-kg (live weight) pigs. Five Trp-deficient diets were fed for 18 d after weaning. The basal diet contained 23.4% protein and .14% Trp. The four other diets were similar to the basal diet but were supplemented with .06 or .12% free or protected crystalline Trp. No differences were found between the two crystalline Trp forms for all variables under study. Equal amounts of all diets were fed by intragastric tube feeding. Daily weight gain ($P < .10$), gain:feed ($P < .05$), and daily protein retention ($P < .01$) increased linearly as dietary Trp increased. Similarly, retention and gross efficiency (retained: intake) of almost all amino acids increased. Tryptophan retention also increased linearly ($P < .05$),but gross efficiency was maximal (40.1%) with protein-bound Trp from the basal diet, and it decreased linearly as dietary Trp increased. This important reduction was the result of a low marginal efficiency for crystalline (13.6 ± 3.3%) free or protected Trp.

Key Words: Pigs, Tryptophan, Growth Rate, Protein Retention, Efficiency

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Introduction

The efficiency of dietary protein utilization depends on the balance of amino acids composing the protein (ARC, 1981) and upon the availability and the efficiency of the primary limiting amino acid in this protein. The ratio of daily body protein retention to the amount of ingested protein or amino acids is a measurement of their gross efficiency (Heger and Frydrych, 1975). Direct measurement of daily body retention of the limiting amino acid provides better estimates of the efficiency or availability of this amino acid (Wilson and Leibholz, 1981; Batterham et al., 1994). A linear response is generally assumed when amino acid supply is not too close to the requirement for maximal growth, as shown by Bikker et al. (1994). Then, marginal efficiency, measured as the slope of the linear response, becomes the most relevant measurement of amino acid efficiency. On the basis of the sensitivity of Trp to acidic conditions (Sato et al., 1984), it is thought that Trp availability may be impaired in the gastric contents. In addition, the greater rate of absorption of the free crystalline amino acids compared with protein-bound amino acids might affect its metabolic efficiency (Batterham, 1979).

In the present work, we compared Trp in a protected form that was believed to improve its utilization for growth (Piva et al., 1993) and the regular industrial free L-Trp on the basis of their marginal efficiencies in early-weaned pigs.

Materials and Methods

Animals and Diets. The study was performed at the Veterinary Faculty of Bologna and involved 40 pigs (4 kg live weight, 12 to 14 d of age). Eight pigs were selected from five Large-White × Duroc litters. The heaviest and the lightest pigs within each litter group were immediately slaughtered to estimate initial body composition. Then, two blocks of three pigs were formed in each litter on the basis of live weight, without consideration of sex. Pigs from the same block were individually housed in adjoining metabolism cages in which temperature was maintained at 28°C by means of infrared lights. Pigs within blocks were randomly assigned to three of five diets according to a balanced incomplete block design, type III (Cochran

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and Cox, 1957) involving comparisons of five treatments within 10 blocks providing six replicates per treatment. A Trp-deficient basal diet (Table 1) was formulated to provide 23.4% protein, .14% Trp (.080 g/MJ DE), 1.64% lysine (.94 g/MJ DE) and a ratio to lysine of all essential amino acids (except Trp) equal to or greater than in the ideal protein as proposed by Wang and Fuller (1989). Four experimental diets were formulated in the same way; two were fortified with .06 or .12% free crystalline Trp and two were fortified with .06 or .12% protected crystalline Trp. Therefore, each of these forms of supplement was tested in diets providing .20 and .26% total dietary Trp, and both levels of Trp were supposed to be limiting (tryptophan:lysine < .18). The protection was microencapsulation with stearic (64%) and palmitic acids (31%) with minor quantities of miristic (3%) and oleic acids (1%; Eurema, Cavriago, Reggio Emilia, Italia).

Feeding and Slaughtering Procedures. On the first day of the experiment, each pig underwent a surgical operation in which a polyurethane catheter was fitted into the stomach via the esophagus as described by Cortamira et al. (1991). This catheter was used for three daily force-fed meals (0830, 1230, and 1730) performed by mixing the feed with water, to a final dry matter content of 217 g/kg. Daily allowances were increased up to 60 g dry feed /$BW^{.75}$ according to the feeding schedule in Table 2. Pigs were weighed at 3-d intervals, and their body weight was estimated each day on the basis of the same standard gain:feed regardless of diet. After 18 d of feeding, unfed experimental pigs were slaughtered on the morning of d 19. All pigs, including the 10 initial control pigs, were separated into five compartments, which were weighed and frozen at –20°C. These compartments were the empty entrails (i.e., stomach, intestines, and bladder), the blood and organs (i.e., heart together with the lungs and trachea, the genital organs, pancreas, spleen, and kidneys), the liver together with the head, the tail and the feet, and the carcass. After each compartment was ground, homogenized, and freeze-dried, aliquots were taken to reconstitute a representative sample of each pig for body composition analysis. The experimental protocol was approved by the ethics committee of the University of Bologna.

Laboratory Analyses. Pig body and diet samples were analyzed for nitrogen and dry matter according to standard procedures (AOAC, 1975). Tryptophan was analyzed after alkaline hydrolysis. A sample containing approximately 20 mg of N was weighed into a 20-mL Pyrex tube. Barium hydroxide (6.4 *M*, $Ba(OH)_2{\cdot}8H_2O$) and deionized water (10 mL) were added to get a 2 mol/L final concentration. The charged tube was immersed 10 min in boiling water. After 10 min of chilling in a refrigerator at 4°C and 3 min flushing with nitrogen, the tube was hermetically closed and heated in an air oven at 110°C for 22 h.

Table 1. Composition and chemical analyses of basal diet

Ingredient, %		Chemical analysis, continued	
Dried skimmed milk	7.00	Amino acids, %	
SFPC[a]	13.0	Lysine	1.64
Maize-gluten meal	24.2	Threonine	1.24
Maltodextrin	42.6	Tryptophan[c]	.14
Maize oil	6.00	Methionine	.48
Vitamin-mineral premix[b]	1.10	Cystine	.53
Dicalcium phosphate	4.60	Met + Cys	1.01
Calcium carbonate	.80	Isoleucine	1.06
Sodium chloride	.10	Leucine	2.76
L-Lysine HCl	.45	Valine	1.22
L-Threonine	.15	Phenylalanine	1.30
		Tyrosine	.36
		Phe + Tyr	1.65
Chemical analysis, as-fed basis		Histidine	1.20
		Arginine	.95
Dry matter, %	93.8	Aspartic acid	1.78
Crude protein, %	23.4	Glutamic acid	3.86
Gross energy, MJ/kg	18.8	Glycine	.93
Digestible energy, MJ/kg[d]	17.4	Alanine	.08
		Serine	1.16
		Proline	.83

[a]Solubilized fish protein concentrate.

[b]Contained the following elements and biologically active vitamins (mg/kg of diet): Fe 100, Cu 20, Mn 40, Zn 100, I 1, Co 2, Se 1, retinol 1.5, cholecalciferol .05, phytylmenoquinone 1.1, nicotinamide 50, calcium *d*-pantothenate 40, cyanocobalamin .05, choline 500, thiamin 10, pyridoxine 10, folic acid .2, ascorbic acid 20, α-tocopheryl acetate 20, riboflavin 20.

[c]Four additional diets were formulated in the same way; two were fortified with .06 or .12% free crystalline tryptophan, and two were fortified with .06 or .12% protected crystalline tryptophan.

[d]From tables (INRA, 1989).

Table 2. Daily feed allowances

Day of experiment	Daily feed,[a] g/kg $BW^{.75}$
1	17
2	20
3	24
4	27
5	32
6	40
7–9	48
10–12	55
13–18	60

[a]Air-dry feed mixed in water (.217 g/g) and given in three tube-fed meals per day.

Sulfuric acid (2.5 *M*) was used to adjust the hydrolysate pH to 3 to 4. After centrifugation, the precipitate was washed with deionized water. The combined supernatant and washing fluids were evaporated, and the residue was dissolved in sodium citrate buffer (.1 *M*, pH 2.2). Then, Trp was separated by HPLC and detected by fluorescence (Series 4, Perkin Elmer, Norwalk, CT). For the other amino acids, the samples were submitted to acid hydrolysis (6 mol/L HCl) after performic acid preoxidation for sulfur amino acids, according to previously described procedures (Mariscal-Landin et al., 1995). Chromatographic separation and ninhydrin colorimetric detection were performed on a Carlo Erba analyzer (Fisons Instruments, Milan, Italy) in Bologna or on a Biotronik LC 5001 analyzer (Biotronik, Pusheim, Germany) in St-Gilles.

Calculations and Statistical Analyses. For nitrogen and amino acid balance determinations, the initial contents of the 30 experimental pigs were calculated from regression equations of contents on live weight established using data from the initial control pigs. Diet effects were tested within litters, with analysis of variance using the GLM procedure of SAS (1990). The linear effect of Trp, and the deviation from linearity, were determined using polynomial contrasts. The results were presented as least-square means with their standard errors (SEM). Differences were considered significant at $P < .10$.

Results

There was a significant linear effect of dietary Trp without any significant deviation from linearity on the variables shown in Tables 3 and 5. Moreover, no difference was found between the two crystalline forms of Trp for these variables.

Growth Performance and Nitrogen Retention. The force-feeding procedure equalized feed intake of pigs receiving different diets (Table 3). In contrast, daily weight gain increased linearly ($P < .10$) according to dietary Trp and, consequently, a similar linear response ($P < .05$) of gain:feed ratio was obtained. Daily protein gain and the percentage of protein in daily weight gain both increased linearly ($P < .01$) as dietary Trp level increased. From the basal diet to the highest level of Trp, daily protein gain increased by 43% and the percentage of protein in daily weight gain increased by 24%.

Amino Acid Composition of Body Protein and of Body Protein Gain. As a whole, the amino acid profile of body protein was in general not significantly modified with the addition of Trp to the basal diet (Table 4). However, branched-chain amino acids (i.e., isoleucine, leucine, and valine) and proline contents significantly decreased with Trp addition to the basal diet. The decrease in contents of the same amino acids in protein gain was more accentuated (3.85 to 3.11%, $P < .10$ for isoleucine; 7.70 to 6.88%, $P < .01$ for leucine; 5.07 to 4.14%, $P < .05$ for valine; and 7.60 to 5.83%, $P < .05$ for proline) . The mean Trp contents in body protein from the initial controls and from the experimental pigs were .72% and .71%, respectively. The mean Trp content in protein gain was estimated to be .68%.

Daily Amino Acid Retention. Increasing dietary Trp concentration caused a linear increase in amino acid retention with the exception of isoleucine, valine, and tyrosine (Table 5). From .14% to .26% dietary Trp, the increase in daily retentions of sulfur amino acids (cystine + methionine), threonine, lysine, and arginine were greater than 30%. The increase was 30% for Trp and less than 30% for leucine. Glycine, alanine,

Table 3. Effect of tryptophan supplementation on growth performance and nitrogen retention in pigs

Item	Basal diet (B)	B + .06% Trp		B + .12% Trp		SEM[a]	Statistical significance[b]
		Free	Protected	Free	Protected		
Initial live weight, kg	4.27	4.37	4.01	4.11	4.21	.09	
Feed intake, g/d	126	129	125	127	129	2.36	
Live weight gain, g/d	90	103	100	102	106	4.64	L†
Gain/feed	.72	.79	.80	.80	.82	.02	L*
Protein retention							
g/d	9.2	11.3	11.5	12.9	13.5	.73	L**
% live weight gain	10.5	11.2	11.8	12.9	13.2	.54	L**

[a]Data are means of six pigs.
[b]L = linear effect of Trp; †$P < .10$; *$P < .05$; **$P < .01$.

Table 4. Effect of tryptophan supplementation on body protein amino acid composition (g/16 g N)

			Final pigs[b]						
				B + .06% Trp		B + .12% Trp			
Amino acid	Initial pigs[a]	SEM	Basal diet (B)	Free	Protected	Free	Protected	SEM	Statistical significance
Lysine	6.70	.09	6.83	6.81	6.76	6.78	6.79	.18	
Threonine	3.95	.07	4.07	4.00	4.09	4.09	4.14	.08	
Tryptophan	.72	.02	0.72	0.71	0.71	0.70	0.69	.02	
Methionine	1.57	.03	1.58	1.58	1.62	1.61	1.63	.04	
Cystine	1.22	.02	1.24	1.27	1.32	1.31	1.30	.03	
Met + Cys	2.79	.06	2.82	2.85	2.94	2.91	2.93	.06	
Isoleucine	3.20	.08	3.36	3.28	3.30	3.16	3.21	.10	L†
Leucine	6.70	.15	6.92	6.78	6.76	6.72	6.65	.03	L†
Valine	4.68	.14	4.79	4.75	4.71	4.49	4.59	.10	L†
Phenylalanine	3.19	.08	3.23	3.21	3.23	3.16	3.18	.08	
Tyrosine	1.05	.04	1.18	1.15	1.07	1.11	1.19	.06	
Phe + Tyr	4.23	.10	4.46	4.31	4.31	4.24	4.33	.11	
Histidine	4.50	.06	4.36	4.49	4.44	4.47	4.44	.14	
Arginine	5.50	.08	5.48	5.97	5.70	5.65	5.69	.24	
Aspartic acid	6.90	.18	7.14	7.26	6.88	6.97	7.12	.22	
Glutamic acid	10.30	.25	10.64	10.65	10.92	10.33	10.52	.40	
Glycine	9.70	.09	9.97	9.73	9.78	9.71	9.68	.23	
Alanine	5.68	.10	5.47	5.77	5.61	5.61	5.77	.17	
Serine	4.22	.10	4.27	4.25	4.10	4.28	4.19	.13	
Proline	7.40	.16	7.38	7.14	7.36	6.85	6.78	.24	L†

[a]Data are means of 10 (initial) pigs.
[b]Data are means of six pigs. L = linear effect of Trp; †$P < .10$; *$P < .05$; **$P < .01$.

and serine were the nonessential amino acids (results not shown) with the highest increase in daily body deposition (>20%). Proline and glutamic acid daily deposition were increased less due to the lack of response to the second level of Trp supplementation.

Efficiency of Protein and Amino Acid Utilization. Gross efficiencies of protein and individual amino acids, defined as the ratio of retention to intake, are shown on Table 6. The highest values were found for lysine and arginine, and the lowest values were found for aromatic amino acids (i.e., phenylalanine and tyrosine), branched-chain amino acids (i.e., isoleucine, leucine, and valine), and sulfur amino acids. Protein efficiency increased by 3.4 percentage points between the basal diet and the first level of supplemental Trp, and by 7.4 percentage points from the basal to the highest level of Trp. With the exception of Trp, gross efficiency increased linearly in response to dietary Trp, but in a different way according to the amino acid. Between the basal and the highest Trp

Table 5. Effect of tryptophan supplementation on daily amino acid retention (g) in pigs[a]

		B + .06% Trp		B + .12% Trp			
Amino acid	Basal diet (B)	Free	Protected	Free	Protected	SEM[b]	Statistical significance
Lysine	.68	.80	.80	.88	.92	.08	L*
Threonine	.41	.47	.51	.56	.60	.04	
Tryptophan	.065	.075	.075	.084	.086	.006	L*
Methionine	.15	.19	.20	.22	.24	.01	L**
Cystine	.12	.16	.18	.19	.19	.02	L**
Met + Cys	.27	.35	.37	.41	.43	.03	L**
Isoleucine	.36	.39	.41	.39	.43	.05	
Leucine	.71	.79	.79	.86	.86	.06	L*
Valine	.47	.56	.56	.52	.59	.05	
Phenylalanine	.30	.37	.38	.39	.42	.03	L*
Tyrosine	.14	.19	.15	.20	.19	.03	
Phe + Tyr	.44	.55	.54	.58	.61	.05	L*
Histidine	.38	.54	.54	.60	.59	.05	L**
Arginine	.45	.79	.70	.77	.81	.08	L**

[a]For protein retention, see Table 3.
[b]Data are means of six pigs.
[c]L = linear effect of Trp; †$P < .10$; *$P < .05$; **$P < .01$.

Table 6. Effect of tryptophan supplementation on the gross efficiency (retained/ingested of amino acid in pigs)

Item	Basal diet (B)	B + .06% Trp		B + .12% Trp		SEM[a]	Statistical significance
		Free	Protected	Free	Protected		
Protein	35.5	37.5	40.3	40.3	45.4	2.18	L**
Lysine	33.7	38.5	39.8	43.3	44.8	3.49	L*
Threonine	26.9	29.5	33.7	36.1	38.2	2.74	L**
Tryptophan	40.1	30.6	32.4	26.5	26.2	2.32	L**
Methionine	25.5	29.9	34.8	36.0	38.9	2.24	L**
Cystine	18.6	23.6	27.5	28.7	28.7	2.40	L**
Met + Cys	21.9	26.6	31.0	32.2	33.5	2.12	L**
Isoleucine	28.0	29.1	31.3	29.6	31.9	3.30	
Leucine	20.8	22.3	23.5	24.9	24.7	1.46	L*
Valine	31.7	35.6	36.9	33.9	37.7	2.98	
Phenylalanine	19.2	22.2	23.8	24.3	25.4	3.01	L*
Tyrosine	31.2	41.7	35.0	44.6	40.6	6.64	
Phe + Tyr	21.8	26.4	26.2	28.7	28.7	2.65	L†
Histidine	25.9	35.8	37.0	40.8	39.8	3.77	L**
Arginine	39.9	64.3	60.8	65.6	68.7	6.11	L**
Aspartic acid	43.8	48.3	49.1	50.9	53.7	3.77	L†
Glutamic acid	23.2	27.2	30.4	27.6	29.2	2.54	
Glycine	82.9	91.7	101.8	106.7	107.0	8.02	L*
Alanine	81.9	106.2	117.5	119.2	125.3	13.45	L*
Serine	28.7	31.2	33.5	38.6	37.2	3.01	L*
Proline	67.0	73.2	86.3	74.2	71.3	7.70	
SEAA[c]	26.1	31.8	32.8	34.6	35.7		
SNEAA[d]	40.4	46.7	50.5	50.3	51.5		

[a]Data are means of six pigs.
[b]L = linear effect of Trp; †$P < .05$; **$P < .01$.
[c]Sum of the essential amino acids with cystine and tyrosine and without tryptophan.
[d]sum of the nonessential amino acids.

level, this improvement was 10% higher for the sum of essential amino acids than for the sum of nonessential amino acids. Tryptophan efficiency in the basal diet (40.1%) was greater than protein (35.5%) and lysine (33.7%) efficiencies. Contrary to results for the other amino acids, Trp efficiency decreased linearly ($P <$ .01) to 31.5 and 26.4% at the first and second levels of crystalline Trp supplementation, respectively.

Discussion

As expected, the force-feeding technique prevented the depression of the ingestion usually associated with dietary Trp deficiency (Cortamira et al., 1991). In fact, because the feeding scale was applied each day using the estimated metabolic weight from the last weighing without anticipating any depressive effect of Trp deficiency on growth rate, pigs receiving Trp-deficient diets were favored compared with those receiving supplemented diets. The consequence was a more important positive effect of Trp on feed efficiency and on daily protein retention than on live weight gain. This could indicate that the slight overconsumption of energy from the basal diet was deposited in the form of fat.

There was no significant deviation from linearity in the response of the different variables to additional Trp. This provided evidence that Trp was still the first-limiting amino acid at the highest level of supplementation. In effect, the two supplemented diets provided only 68 and 88% of the amount of Trp necessary to adjust the intake at the ideal ratio to lysine of .18 according to Wang and Fuller (1989). Moreover, taking into account that pigs were weaned at 4 kg instead of 5 kg on a restricted feeding scale, the level of lysine itself (.94 g/MJ DE) was far from being in excess of the requirement per unit of energy (.96 g/MJ DE) as defined by INRA (1989).

Tryptophan Efficiency for Weight Gain. We can estimate from our results and from some literature data the gross efficiency of protein-bound Trp and the marginal efficiency of crystalline Trp for weight gain (Table 7). Tryptophan efficiency was comparable with that obtained by Cortamira et al. (1991) with pigs weaned at 10 d of age, under similar experimental conditions. In both experiments, the efficiency of crystalline Trp was lower than that of protein-bound Trp. This difference was less important in the data of Han et al. (1993) and Sève et al. (1991). It was nonexistent or inverted in the data of Burgoon et al. (1992) and Sato et al. (1987). In these last two experiments, pigs had ad libitum access to their diet. As observed with crystalline lysine (Batterham, 1979), crystalline Trp and feeding frequency might significantly interact on growth response. With frequent feeding, crystalline Trp could be more efficient

Table 7. Efficiency of tryptophan utilization for live weight gain according to literature

Source[a]	Daily frequency of feeding	Efficiency, kg/g: Protein-bound tryptophan[b]	Efficiency, kg/g: Crystalline tryptophan[c]
Present experiment	3 force-fed meals	.51	.11
Cortamira et al. (1991)	3 force-fed meals[d]	.47	.14
Han et al. (1992)	ad libitum	.50	.29
Sève et al. (1991)	2 meals	.40	.34
Rivera L. et al. (1976)	ad libitum	—	.54
Burgoon et al. (1992)	ad libitum	.43	.62
Sato et al. (1987)	ad libitum	.30	.62

[a]Diets were designed to contain adequate levels of all amino acids except tryptophan.
[b]Gross efficiency (basal diet) = weight gain:total tryptophan ingested.
[c]Marginal efficiency, obtained from the linear regression equation of the gain response to the supplemental tryptophan intake.
[d]At the high level of force-feeding.

than protein-bound Trp, and the reverse might happen when a limited number of meals is consumed.

Body Amino Acid Composition. The contents of valine and histidine in body protein of the experimental pigs were substantially higher than reported in the literature (Sève et al., 1995). In contrast, body protein contents of sulfur amino acids (methionine + cystine), aromatic amino acids (phenylalanine + tyrosine), and arginine were lower than previously reported. However, our data remained within the standard deviation of literature values, and it is difficult to explain the observed variations. The average content of Trp in the present pigs was 11% of that of lysine. This value is close to that of 12% measured in 45-kg Landrace × Large White crossbred pigs (Moughan and Smith, 1987). It is, however, quite low in comparison with literature means [e.g., 14% of body lysine according to ARC (1981)]. Regarding the analysis of Trp, Friedmann and Finley (1971) and Sato et al. (1984) reported a number of methodological problems related to protein hydrolysis and to the methods for separation and detection of Trp. Thus, for a measure of efficiency, the dietary Trp should be analyzed in the same way as body Trp.

Efficiency of Tryptophan for Deposition of Other Amino Acids. The improvement in efficiency associated with Trp supplementation was explained by the increase in body protein deposition, but the level of ingestion remained constant. In the present experiment, the hierarchy of gross efficiencies for amino acids other than Trp was consistent with previous data on pigs where lysine, threonine, and sulfur amino acids were considered co-limiting (Sève et al., 1995) and with the estimates made by Sève and Henry (1996) from data on the Illinois ideal protein (IIP) (Chung and Baker, 1992). Assuming the requirements for maintenance as proposed by Fuller et al. (1989), and on the basis of table digestibility data (Rhône-Poulenc, 1993; ITCF-Eurolysine, 1995), the efficiency for deposition of digestible protein-bound lysine (93% of total lysine) given with the basal diet above maintenance would be 53%. Compared with the 74% value calculated on the same bases for the efficiency of IIP lysine (Sève and Henry, 1996), this low figure would confirm that Trp was still limiting at .26% in the diet.

Efficiency of Tryptophan for Tryptophan Deposition. In the present work, protein-bound Trp efficiency was 40%, as determined with the basal diet. Estimated on the same bases as for lysine (see above) the efficiency for deposition of digestible protein-bound Trp (89% of total Trp) given above maintenance would be 54%. This estimate compared well with that of 55% previously made for Trp in the IIP (Sève and Henry, 1996). This comparison might be regarded as an indirect validation of the values of Trp content in body proteins of our pigs. That estimate must be compared with the estimate that can be made from our data for crystalline Trp (Figure 1). The linear regressions of Trp retention (Y) as a function of 100% digestible crystalline Trp intake (X) were

$$Y = .1338\ (\pm\ .0459)\ X + .0509\ (R^2 = .88)$$
for free crystalline Trp and
$$Y = .1384\ (\pm\ .0476)\ X + .0513\ (R^2 = .82)$$
for protected crystalline Trp.

Therefore, the marginal efficiency of crystalline Trp for whole-body Trp retention would be only 13.4% when introduced in a free form and 13.8% when introduced in a protected form. As anticipated from other statistical analyses, these values were not different. The large difference in the efficiency for deposition between crystalline and protein-bound Trp (13.6% on average vs 54%) explained the decrease in gross efficiency according to dietary Trp supply. From the data of Exp. 3 of Batterham et al. (1994), in which pigs were fed every 3 h either a basal or a Trp-supplemented soya diet, assuming .72% Trp in body protein gain regardless of diet, the efficiencies for deposition of Trp given above maintenance for protein-bound and above basal diet for crystalline Trp were 47 and 27%, respectively. Therefore a difference appeared although it was less important. At least three hypotheses could be formulated to explain the present results. First, an instability of the crystalline Trp in the diets could be suspected. Indeed, several months after the experiment, the added crystalline Trp was still found in the diet through free Trp extraction (Sève et al., 1991) and total Trp analysis. Second, Trp degrades progressively in an acidic solution (pH 2.2; Sato et al., 1984). These conditions can occur in the stomach during the course of digestion. However, the duration of gastric emptying is relatively short, and the protection should help avoid massive destruction

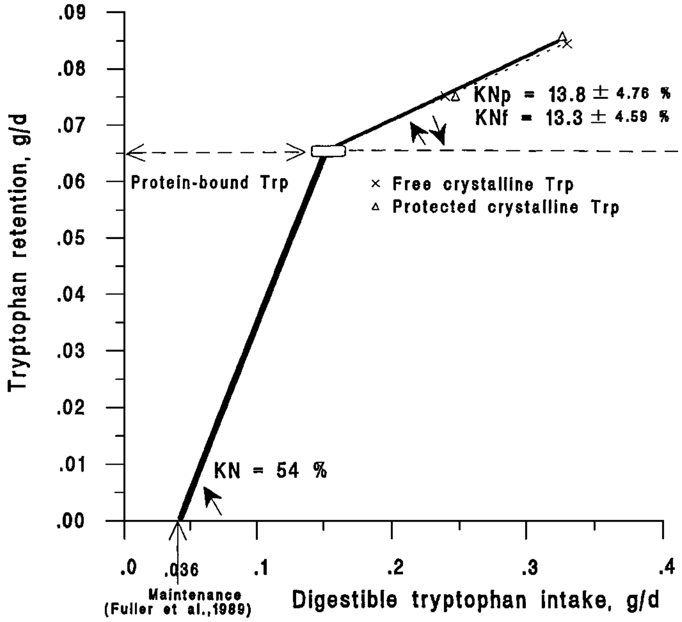

Figure 1. Linear response of tryptophan (Trp) retention to the addition of crystalline Trp, considered as 100% digestible, to a basal deficient diet. The marginal efficiencies of free (KNf) or protected (KNp) crystalline Trp were derived from the slope of the regressions. The efficiency (KN) of digestible protein-bound Trp [digestible Trp estimated from Rhône-Poulenc Animal Nutrition (1993) and ITCF-Eurolysine (1995) table] for Trp deposition was calculated as the percentage ratio of Trp retention measured with the basal diet to digestible Trp given above maintenance (Fuller et al., 1989).

of the crystalline Trp. Third, in pigs fed a limited number of meals per day, amino acids added in crystalline form to the diet would be more rapidly absorbed (Williams and Dunkin, 1980) and less efficiently utilized than protein-bound amino acids (Batterham, 1979). If too quickly absorbed, free Trp might undergo more intense catabolism in the liver than protein-bound Trp, as suggested for lysine (Batterham and Bayley, 1989).

Implications

This experiment has shown that the efficiency of crystalline tryptophan for growth or protein deposition may be much less than that of protein-bound tryptophan. Therefore, in young pigs fed tryptophan-deficient diets discontinuously at restricted levels, the crystalline tryptophan supplement required for maximal growth rate could be twice that calculated assuming the same efficiency as for digestible protein-bound tryptophan. There was no difference between free or protected supplemental tryptophan.

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