ESTIMATES OF TRUE ILEAL DIGESTIBILITIES OF CORN, SOYBEAN MEAL AND ALTERNATIVE FEED INGREDIENTS FOR SWINES[1]

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ABSTRACT - Nine crossbred barrows with an initial weight of 52.59±.57 kg were each surgically fitted with a T-cannula at the terminal ileum in order to measure the coefficients of true amino acid digestibilities (TAAD) of eight feedstuffs for subsequent use in testing the utility of amino acid digestibility values in diet formulation. The feed ingredients investigated were: corn, wheat bran (WB), two sources of soybean meal (SBM 1 and SBM 2), cottonseed meal (CSM), poultry by-product (PBP), and meat and bone meal (MBM 1 and MBM 2) from two origins. A nitrogen free diet (NFD) was used to estimate the endogenous losses of amino acids. The TAAD coefficients in corn and WB were significantly lower ($P \leq .01$) than in the other sources except for lysine in CSM and threonine in MBM 1. True lysine digestibility coefficients for corn (59.9%) was in the range of values found in the literature. The SBM 1 and SBM 2 yielded similar ($P \geq .01$) amino acid digestibility. The MBM 1 and MBM 2 despite visual differences in appearance were also similar ($P \geq .01$). The obtained estimates are in the range of literature values and can be used to calculate diets based on the amino acid digestibility.

Index terms: metabolism, digestion, digesta, amino acids.

ESTIMATIVAS DA DIGESTIBILIDADE ILEAL VERDADEIRA DO MILHO, FARELO DE SOJA E INGREDIENTES ALTERNATIVOS PARA SUÍNOS

RESUMO - Nove suínos machos castrados, com peso inicial de 52,59±0,57 kg, foram adaptados cirurgicamente com cânula-T no término do íleo, para medir os coeficientes de digestibilidade verdadeira (TAAD) de oito alimentos, e testar, posteriormente, os valores de digestibilidade de aminoácidos na formulação de dietas. Os ingredientes analisados foram: milho, farelo de trigo (WB), duas fontes de farelo de soja (SBM 1 e SBM 2), farelo de algodão (CSM), sub-produtos do abate de aves (PBP), e duas amostras de farinha de carne e ossos (MBM 1 e MBM 2). Uma dieta livre de nitrogênio (NFD) foi usada para estimar a perda endógena de aminoácidos. A TAAD no milho e WB foram significativamente menores ($P<0,01$) do que em outras fontes exceto para lisina no CSM e treonina na MBM 1. Os coeficientes de digestibilidade verdadeira da lisina no milho (59,9%) ficaram no intervalo de valores referenciados na literatura. Os farelos SBM 1 e SBM 2 apresentaram valores de digestibilidade de aminoácidos similares ($P>0,01$). As farinhas MBM 1 e MBM 2, apesar das diferenças visuais na aparência, apresentaram valores similares ($P>0,01$) entre si. As estimativas obtidas estão no intervalo da literatura podendo-se usá-las para o cálculo de dietas baseadas na digestibilidade dos aminoácidos.

Termos para indexação: metabolismo, digestão, digesta, aminoácidos.

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INTRODUCTION

A variety of methods have been used to assess amino acid digestibility in feedstuffs for swine, but ileal sampling has received the most attention. Sauer et al. (1981), using barley, found that estimation of digestibility by ileal sampling is more sensitive than fecal sampling. Previously, Zebrowska (1973a) had reported a similar finding. In addition, comparing fecal and ileal digestibility, showed that deposited protein (g/day) is best correlated with ileal digestibility values.

The more accurate estimates of amino acid digestibility found based on samples taken at the terminal ileum is presumed to be due to the fact that absorption of amino acids in the digestive tract occurs anterior to the ileo-cecal valve (Zebrowska, 1973a). Nitrogenous compounds released by microbial action in the large intestine are absorbed by the intestinal wall as ammonia, amine or amides (Low, 1982; Rerat, 1983; Tanksley Junior & Knabe, 1984); thus, estimates of amino acid disappearance based on total tract disappearance are meaningless (Zebrowska, 1973a). It is not surprising that digestibility values for amino acids based on ileal collection are consistently lower than those obtained by total fecal collection (Tanksley Junior et al., 1981; Taverner et al., 1981b; Sauer & Jorgensen, 1982; Tanksley Junior & Knabe, 1984).

Ileal sampling has been used to estimate amino acid digestibility since the early 70's when Easter & Tanksley Junior (1973) developed the methodology for re-entrant ileo-cecal cannulation. This has been modified to a simple "T" cannulation procedure for the terminal ileum. According to Moughan & Smith (1987), T-cannulas are efficient devices for ileal collection, and there is no interference with nutrient digestibility. The increasing confidence in this method can be seen in the proceedings of the 1985 meeting held in Denmark, where data based on T-cannula samples were presented by a number of research groups.

The present work was done using "classical" ileal sampling procedures to obtain digestibility estimates for subsequent use in testing the utility of amino acid digestibility values in diet formulation.

MATERIAL AND METHODS

The experiment was carried out in 1988 at the experimental facilities of the University of Illinois - USA. Nine crossbred barrows from three litters of Yorkshire x Hampshire parentage initially weighing 42.44±.46 kg were surgically fitted with individual T-cannulae as described by Horszczaruk et al. (1972) and Easter & Tanksley Junior (1973). After 14 days of post-surgical recuperation (Zebrowska, 1973b; Lin et al., 1987), procedures to measure ileal digestibility were initiated. Pigs were housed in stainless steel metabolism cages during both the adaptation and collection periods in a temperature-controlled environment. Pigs were allowed a five day period of diet adaptation (Tanksley Junior & Knabe, 1984) followed by two days of chyme collection (Taverner et al., 1981a; Sauer et al., 1982; Partridge et al., 1987). They were fed at twelve-hour intervals (7 am and 7 pm) throughout the experiment, and digesta were collected during the twelve hour period between the morning and evening meals on each of the two days (Taverner et al., 1981a; Tanksley Junior & Knabe, 1984).

Collections were made using 5x15 cm plastic bags connected to the cannula. Bags were replaced for every sampling. Timing of bag replacement was consistent across the treatments. Immediately after collection, the samples were put in a plastic bottle and maintained in a refrigerator. At the end of the day, a 400 g aliquot per animal was taken after homogenization and frozen for subsequent analyses (Partridge et al., 1987).

Chromic oxide (an external marker) was incorporated in the diets at rate of 25% and apparent ileal digestibility calculated by comparing nutrient to marker ratios in the diet and ileal digesta. All digesta samples were analyzed according to the Association of Official Analytical Chemists (1984) for dry matter, total nitrogen (by the macro--Kjeldahl method), amino acids (by ion exchange chromatography using a Beckman Amino Acid Analyzer, model 119 CL) and chromic oxide (by atomic absorption using a Perkin Elmer Spectrophotometer, model 306). Tryptophan was analyzed using alkaline hydrolysis according to the procedure of Sato et al. (1984).

The ingredients investigated (Table 1) were: corn; wheat bran (WB); two sources of soybean meal (SBM 1 and SBM 2); cottonseed meal (CSM); poultry by-product meal (PBP); and two sources of meat and bone meal (MBM 1 and MBM 2). A nitrogen free diet (NFD) was used to estimate the endogenous amino acid losses. The nine experimental diets used in this experiment are shown in Table 2. The soybean meals came from the same origin but SBM 2 was heated at 110^{0}C for two hours in a dry oven. Diets were formulated to provide similar levels of metabolizable energy, calcium and phosphorus (except for sources of animal proteins), vitamins, and minerals (National Research Council, 1979).

TABLE 1. Chemical composition of the ingredients as fed basis (%).

Variables	Ingredients tested[1]							
	Corn	WB	SBM 1	SBM 2	CSM	PBP	MBM 1	MBM 2
Dry matter	85.58	88.30	88.47	95.38	87.83	92.64	93.98	94.11
Crude protein[2]	7.33	16.15	47.43	50.22	37.63	63.97	47.40	50.23
ME[3]	3260	2208	3117	3360	2350	2911	2256	2259
ADF[4]	2.78	11.51	5.16	5.56	16.26	8.74	4.38	5.72
Cellulose[4]	2.06	7.81	3.75	4.69	9.86	4.78	1.40	2.11
Calcium[5]	.01	.09	.48	.51	.30	4.29	14.42	11.73
Total P[5]	.23	.83	.60	.71	1.14	2.31	5.77	4.33
Available P[6]	.07	.25	.18	.21	.34	2.31	5.77	4.33
Lysine[7]	.24	.63	2.91	2.78	2.03	3.46	2.78	2.96
Met+Cys[8]	.38	.52	1.43	1.55	1.26	1.97	1.32	1.32

Tryptophan[7]	.06	.26	.60	.59	.61	.50	.30	.32
Threonine[7]	.24	.51	1.87	1.77	1.47	2.60	1.81	2.12

[1] WB = wheat bran; SBM 1 and SBM 2 = soybean meals 1 (normal) and 2 (heat treated); CSM = cottonseed meal; PBP = poultry by-product; MBM 1 and MBM 2 = meat and bone meals from two origins.
[2] Determined as N x 6.25 using macro-Kjeldahl procedure (Association of Official Analytical Chemists, 1984).
[3] Metabolizable energy (kcal/kg) calculated values from Hubbel (1988) and Fonnesbeck et al. (1984).
[4] Acid detergent fiber (ADF) and cellulose were analyzed and calculated according to Goering & Van Soest (1970).
[5] Association of Official Analytical Chemists (1984) procedures for calcium (spectrophotometric) and phosphorus (colorimetric) determinations.
[6] Calculated as 30% of total phosphorus.
[7] Analyzed by ion exchange chromatography.
[8] Met = methionine; Cys = cystine; values from Hubbel (1988).

TABLE 2. Composition of diets in the ileal digestibility experiment (%).

Ingredients	Diets[1]								
	Corn	WB	SBM 1	SBM 2	CSM	PBP	MBM 1	MBM 2	N free
Corn	84.44								
WB		38.42							
SBM 1			29.52						
SBM 2				27.88					
CSM					37.21				
PBP						21.90			
MBM 1							29.54		
MBM 2								27.87	
Sucrose	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
Limestone	.73	1.44	.26	.33	1.25				.06
Dical. Phos.	1.70	.49	1.79	1.68	.42				2.78
Oil	.17	6.28	.20		5.38		5.49	4.86	2.00
Starch		42.67	54.64	56.72	44.71	64.45	50.68	53.16	80.46
Solka-Floc[2]	2.26		2.89	2.69	.33	2.95	3.59	3.41	4.00
Vit. mix.[3]	.10	.10	.10	.10	.10	.10	.10	.10	.10
Min. mix.[3]	.35	.35	.35	.35	.35	.35	.35	.35	.35
Chromic ox.	.25	.25	.25	.25	.25	.25	.25	.25	.25
Calculated composition (as fed basis)									
Crude protein[4] (%)	6.19	6.20	14.00	14.00	14.00	14.00	14.00	14.00	0
ME[4]	3100	3100	3100	3172	3100	3133	3100	3100	3168
ADF	4.00	3.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Calcium (%)	.60	.60	.60	.60	.60	.95	4.26	3.27	.60
Phosporus (%)	.50	.50	.50	.50	.50	.51	1.70	1.21	.50
Lysine (%)	.20	.24	.86	.78	.76	.76	.82	.82	0
Met+Cys. (%)	.32	.20	.42	.43	.47	.43	.39	.37	0
Threonine (%)	.20	.20	.55	.49	.55	.57	.53	.59	0
Tryptophan (%)	.05	.10	.18	.16	.23	.11	.09	.09	0

[1] WB = wheat bran; SBM 1 and SBM 2 = soybean meals 1 (normal) and 2 (heat treated); CSM = cottonseed meal; PBP = poultry by-product; MBM 1 and MBM 2 = meat and bone meals from two origins.
[2] Cellulose, James River Co. Berlin, NH.
[3] Vitamin and mineral mixtures.
[4] Metabolizable energy in kcal/kg.

Water was furnished at rate of 2 liters/kg of feed, this being the quantity used by Haydon et al. (1984). Feed was offered *ad libitum* during the first two days of the diet adaptation period. From the third day to the end of the collection period, all pigs were equally fed to the amount consumed during the first two days (Lin et al., 1987) by the pigs fed the treatment with the least consumption. All refusals were collected, dried and subtracted to establish the absolute feed intake. Adjustments of the daily ration were made in each period of the trial.

Percentage true amino acid digestibility (TAAD) was calculated according to formula reported by Sauer & Ozimek (1985): TAAD = (AAc - (AAd - AAed)/AAc) 100; where AAc = amino acid consumed, AAd = amino acid excretion in the digesta and AAed = endogenous amino acid excreted in the digesta.

Statistical analysis of amino acid digestibility data for the ingredients was done using the SAS system (SAS Institute, 1985) following the model: $Y_{ijkl} = u + T_i + P_j + L_k ++ e_{ijkl}$; where Y_{ijkl} = the ijklth observation; u = general mean; T_i = effect of the ith treatment (k=1,...8); P_j = effect of the jth period (j=1,...3); L_k = effect of the kth litter (k = 1,...3); and e_{ijkl} = residual random term. Fisher's protected LSDs were calculated in order to compare the differences between means ($P \leq .01$). Pooled standard error of the means are presented.

RESULTS AND DISCUSSION

Values presented in Table 3 are true amino acid digestibility (TAAD) estimates (expressed as a percent) for the eight feedstuffs. Values for apparent digestibility were calculated and are presented in Table 4. Calculated values for apparent digestibility were lower than those for TAAD, as expected. Apparent digestibility may underestimate digestibility of amino acids in low protein ingredients. It was pointed out by Eggum (1977) that the TAAD is independent of dietary protein level, whereas apparent digestibility increases quadratically with increasing dietary protein concentration. Corrections for endogenous amino acids are definitely necessary when intake of an amino acid is low (Parsons, 1985). Caution must be taken in interpreting values for proline and glycine, because ileal excretion of these amino acids, when pigs are fed a protein-free diet may be increased (Kies et al., 1986). Increasing the level of fiber up to 10% is responsible for increasing endogenous ileal output of amino acids (Taverner et al., 1981a). However, in the present work similar levels of cellulose were maintained in each treatment in an attempt to avoid this problem.

TABLE 3. True amino acid and crude protein digestibility coefficients for eight feedstuffs based on swine ileal digesta[1].

Item	Ingredients[2]									
	Corn	WB	SBM 1	SBM 2	CSM	PBP	MBM 1	MBM 2	SE[3]	LSD[4]
Intake (g)	1790	1351	1872	1899	1773	1902	1583	1601	105.79	457.05
Ala	79.91	63.35	81.63	81.97	69.35	80.87	80.23	81.00	1.80	7.79
Arg	94.33	94.95	96.49	96.11	92.78	89.81	88.18	89.63	1.51	6.53
Asp	73.89	67.56	85.38	85.12	78.04	62.60	69.73	69.62	2.17	9.39
Glu	84.53	85.72	88.72	88.29	85.22	77.55	73.54	75.02	1.49	6.45
Gly	67.76	55.69	77.88	78.73	69.91	78.99	80.81	82.83	3.07	13.26
His	78.53	73.90	86.47	87.13	79.26	77.44	74.46	76.58	1.66	7.17
Ile	78.96	72.48	87.49	87.14	73.62	80.60	74.65	75.36	2.22	9.60
Leu	83.33	67.31	84.22	83.71	72.11	78.59	74.44	75.92	2.20	9.49
Lys	59.92	60.00	86.07	85.43	59.72	78.15	75.86	76.52	2.02	8.74
M+C	86.17	75.93	91.83	90.91	82.99	81.70	79.23	77.87	2.33	10.06
Phe	84.51	78.14	87.95	87.72	84.06	80.07	78.28	79.02	1.80	7.77
Pro	79.71	92.21	88.59	89.50	82.16	80.65	83.33	78.93	2.54	10.97
Ser	78.40	71.74	85.77	85.57	77.51	75.74	72.16	74.34	1.66	7.18
Thr	71.69	59.56	82.90	81.54	71.50	74.15	69.11	72.65	2.52	10.90
Trp	68.39	73.25	82.79	86.37	73.93	61.51	60.82	64.31	4.39	18.99
Tyr	78.40	55.99	83.63	80.43	78.27	60.99	51.73	63.60	3.97	17.14
Val	79.26	72.69	85.98	85.41	76.93	78.87	76.40	76.70	2.02	8.72
AA Avg[5]	78.10	71.79	86.11	85.95	76.90	76.37	74.29	75.88	2.32	10.01
CP[6]	78.97	74.98	84.01	85.73	73.91	76.61	75.95	77.26	1.69	7.32

[1] Values obtained by Bellaver (1989) are means of three observations with one pig per observation.
[2] WB = wheat bran; SBM 1and SBM 2 = soybean meals 1 (normal) and 2 (heat treated); CSM = cottonseed meal; PBP = poultry by-product; MBM 1 and MBM 2 = meat and bone meals from two origins.
[3] Pooled standard error of the means.
[4] Least significant difference (P≤.01).
[5] Amino acids average.
[6] Crude protein.

During the experiment, body weights of the pigs ranged from an initial weight average of 52.59±.57 kg to an average final weight of 61.18±.57 kg. Over the weight range of 50 kg to 70 kg ileal recoveries of amino acids are not changed (Sauer et al., 1977). There were variations in feed intake. The lowest intake was by pigs fed WB and the intake was less (P<.01) than for pigs fed the SBM 1, SBM 2 and PBP. The WB intake was 2.5% of body weight when expressed on a dry matter basis. The other ingredients were consumed at a level between 2.8% and 3.6% of body weight. Haydon et al. (1984) feeding from 2.7 to 5.3% of body weight in dry matter/day and Kies et al. (1986) at levels of 5 to 10% of $kg^{.75}$ found that these variations in feed intake had no effect on apparent ileal digestibility values for amino acids. Reduction in the intakes of WB and both MBM products were due to refusals of a pre-established level of intake. Refusals have been common to other ileal digestibility studies (Moughan & Smith, 1985).

Lysine and threonine were, in general, less digestible than the other amino acids in corn and WB. This same trend has been reported by Sauer et al. (1977) and Taverner et al. (1981b). Lysine digestibility in corn and WB and threonine digestibility in WB were significantly lower ($P \leq .01$) than in the other sources of protein with the exception of lysine in CSM and threonine in MBM 1. The true lysine digestibility measured for corn (59.9%) is in the range of values found in the literature. Published values range from apparent digestibility of 48% (Black & Davies, 1987) and 56.8% (Green et al., 1987) to true digestibility of 83% (Taverner et al., 1981b). The low values found in this experiment may be related to the low protein content (7.33%) of the corn used. Apparent ileal digestibility of lysine has been shown to increase with increasing levels of protein in the diet (Taverner et al., 1981b).

Protein in WB is primarily concentrated in the aleurone layer, the outer layer of endosperm which remains attached to the pericarp during the milling process. This protein consists mainly of albumin and globulin (Eggum, 1977) that is protectively coated with cellulose, hemicellulose and minerals (Pomeranz, 1981). Therefore, the lower values of amino acid digestibility in WB can be related to the likelihood of these proteins being more difficult to digest in the small intestine.

Amino acid digestibilities were similar for SBM 1 and SBM 2. This may indicate that the heating treatment was not harsh enough to cause formation of insoluble compounds like Maillard reaction products or lysino-alanine (Hurrell & Finot, 1985). Values presented in Table 3 are in good agreement with literature values (Zebrowska, 1978; Tanksley Junior et al., 1981; Sauer et al., 1982; Imbeah et al., 1987; Heartland Lysine Incorporation, 1988).

True lysine digestibility values obtained for CSM in this work were lower than those calculated by Tanksley Junior et al. (1981). The reason for a generally low lysine digestibility in CSM is that the free gossypol and the ε-amino group of lysine can react during processing to form a less soluble compound (Tanksley Junior et al., 1981). The other amino acids in cottonseed meal were similar in digestibility to the values reported previously (Tanksley Junior et al.,1981).

The MBM 1 and MBM 2 came from different renderers and differed in color, odor and chemical composition. However, no differences in digestibility ($P \geq .01$) were found. Values reported here are greater than the apparent ileal digestibility values found by Zebrowska & Buraczewski (1977), Just et al. (1985), Mougham & Smith (1985) and Heartland Lysine Incorporation (1988) for similar products.

TABLE 4. Apparent amino acid and crude protein digestibility coefficients for eight feedstuffs based on swine ileal digesta collections[1].

Item	Ingredients[2]									
	Corn	WB	SBM 1	SBM 2	CSM	PBP	MBM 1	MBM 2	SE[3]	LSD[4]
Intake (g)	1790	1351	1872	1899	1773	1902	1583	1601	105.79	457.05
Ala	74.08	49.11	77.08	77.40	64.51	77.70	76.60	77.51	1.77	7.66
Arg	77.74	75.75	91.25	90.32	89.71	84.23	80.76	82.89	1.02	4.41
Asp	63.69	51.94	82.55	82.16	74.68	58.79	64.46	64.88	2.01	8.66
Glu	80.08	79.40	86.64	86.14	83.37	74.57	69.11	70.98	1.51	6.50
Gly	49.66	34.40	69.80	70.37	62.07	75.49	77.46	79.40	3.24	13.98
His	71.20	62.04	82.78	83.39	75.93	72.60	66.55	70.54	1.94	8.40
Ile	70.86	58.34	84.57	84.12	69.66	76.97	67.68	69.74	2.09	9.02
Leu	77.02	48.88	79.71	79.02	66.44	73.49	66.26	69.21	2.08	9.00
Lys	47.71	43.58	83.35	82.59	56.00	74.77	70.91	72.07	2.01	8.70
M+C	80.70	62.37	87.38	85.96	79.29	78.60	74.08	73.42	2.26	10.55
Phe	79.04	67.31	85.50	85.15	81.82	76.75	72.78	74.74	1.75	7.57
Pro	69.74	72.75	80.67	81.52	72.17	75.24	77.28	73.21	2.96	12.80
Ser	69.29	55.65	81.71	81.23	72.92	71.63	64.92	69.03	1.57	6.79
Thr	56.89	33.39	76.77	75.05	64.49	67.87	58.50	64.08	2.44	10.55
Trp	49.59	58.76	76.90	81.09	68.86	50.59	41.06	48.58	4.89	21.13
Tyr	62.30	27.44	76.41	70.25	71.28	50.73	33.06	50.24	4.55	19.64
Val	71.48	59.93	82.35	81.56	73.11	75.25	70.69	71.96	1.92	8.29
AA Avg[5]	67,31	55,36	81,50	81,02	72,14	71,49	66,60	69,56	2,35	10,21
CP[6]	68.93	61.05	79.00	80.93	68.87	71.98	69.68	71.64	1.69	7.30

[1] Values obtained by Bellaver (1989) are means of three observations with one pig per observation.
[2] WB = wheat bran; SBM 1 and SBM 2 = soybean meals 1 (normal) and 2 (heat treated); CSM = cottonseed meal; PBP = poultry by-product; MBM 1 and MBM 2 = meat and bone meals from two origins.
[3] Pooled standard error of the means.
[4] Least significant difference ($P \leq .01$).

[5] Amino acids average.
[6] Crude protein.

CONCLUSIONS

1. The average of true digestibility coefficients is higher for both soybean meals and lower for wheat bran.
2. Values for amino acids true digestibility coefficients reported in this work can be used in diets formulation for swines.

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