CURRENT CONCEPTS OF PROTEIN DIGESTION AND ABSORPTION IN THE PIG REVIEW

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Abstract. It is generally agreed that in the pig the amount of amino acids absorbed in the small intestine up to the terminal ileum gives a more reliable estimate of the amount available to the animal than does the conventional fecal analysis method, particularly if the diet contains protein of low quality. Due to microbial metabolism of nitrogenous material in the large intestine, only a relatively small proportion of the amino acid excretion in feces is directly related to the amino acids recovered at the distal ileum. Thus, depending on the amino acid and on the feedstuff, digestibility values obtained by the fecal analysis method overestimate (which is usually the case) or underestimate those obtained by the ileal analysis method. Therefore, it is now recognised that the ileal analysis method should be considered as an improvement over the fecal analysis method. If one accepts that the determination of amino acid digestibility values should be based on the ileal analysis method, one should consider that ileal digesta contains variable amounts of endogenous protein originating mainly from digestive secretions, sloughed-off epithelial cells and mucins. In order to get a "true" estimate of digestibility, correction should be made for the non-dietary component. True digestibility estimates should more closely describe the uptake of amino acids from the digestive tract. True digestibility has the advantage over apparent digestibility in that it is a fundamental property of the feedstuff, being independent of dietary conditions. For a given amino acid, the apparent digestibility increases exponentially with the ingested quantity, because endogenous excretion, as a percentage of total excretion, decreases proportionally. In contrast, true amino acid digestibility is not affected by the ingested quantity. Therefore, using true digestibility data allows raw materials to be accurately compared, even if they are ingested in different quantities. Endogenous protein and amino acid recoveries in ileal digesta can be divided in a non-specific and specific fraction. The non-specific recovery - also referred to as basal recovery - is related to the dry matter intake but independent of the type of feedstuff or diet. In contrast, the specific recovery - also referred to as extra recovery - is related to the composition of the feedstuff or diet (e.g. presence of inherent factors such as lectins, trypsin inhibitors and tannins). The flow of basal endogenous protein and amino acids at the ileal level can be considered as an inevitable loss for the pig. Data on the flow of basal endogenous protein and amino acids can be used to calculate true ileal digestibility values of feed ingredients for pigs. In conclusion, the use of true ileal digestible amino acids in diet formulation for pigs will contribute to (1) a more accurate evaluation of the cost/benefit value of ingredients, (2) an improved additivity of digestibility values in least cost formulation programs, (3) a more efficient use of alternative feedstuffs, (4) an improved utilization of protein (nitrogen) and amino acids for maintenance and protein deposition, (5) a better prediction of growth performance of pigs and, finally, (6) a more cost effective swine production.

Keywords: Pigs, Amino acids, Endogenous protein, True digestibility.

ŠIUOLAIKINĖS PROTEINŲ VIRŠKINIMO IR ĮSISAVINIMO KIAULIŲ ORGANIZME KONCEPCIJOS

Santrauka. Yra bendrai pripažinta, kad kiaulių organizme amino rūgščių, absorbuotų plonosiose žarnose iki klubinės žarnos, kiekis yra daug patikimesnis gyvuliui tinkančių amino rūgščių kiekio matas, negu įprastinis išmatų analizės metodas, ypač tuo atveju, jei į pašaro sudėtį įeina prastos kokybės baltymai. Dėl mikrobinės azotinių medžiagų apykaitos storosiose žarnose, tik palyginti maža amino rūgščių, išskiriamų išmatose, dalis yra tiesiogiai susijusi su amino rūgštimis, regeneruojamomis distalinėje klubinėje žarnoje. Taigi, priklausomai nuo amino rūgščių ir pašaro, virškinamumo vertė, nustatoma išmatų analizės metodu, pervertina (kas paprastai pasitaiko) arba nepakankamai įvertina duomenis, gautus klubinės žarnos tyrimo metodu. Šiuo metu jau pripažįstamas klubinės žarnos tyrimo metodo pranašumas, lyginant su išmatų tyrimo metodu. Jeigu sutinkama, kad amino rūgščių virškinamumo vertės nustatymo metodas turi remtis klubinės žarnos tyrimu, būtina pripažinti, kad klubinėje žarnoje randamas kintantis endogeninių baltymų, susidariusių virškinimo sekrecijos metu, iš nusilupusio epitelio ir mucino, kiekis. Norint gauti "tikrąją" virškinamumo vertę, būtina atlikti korekciją nemaistinės kilmės baltymui.. Tikroji virškinamumo vertė turi tiksliau parodyti amino rūgščių pasisavinimą iš virškinamojo trakto. Tikrasis virškinamumas lyginant su tariamu virškinamumu pasižymi tuo pranašumu, kad tai yra esminė maisto medžiagų savybė ir nepriklauso nuo mitybos sąlygų. Tam tikrai amino rūgščiai tariamas virškinamumas eksponentiškai didėja priklausomai nuo suėsto kiekio dėl endogeninės ekskrecijos, kai tuo tarpu bendroji ekskrecija proporcingai mažėja. Priešingai, tikrajam amino rūgšties virškinamumui, suėstas kiekis įtakos neturi. Taigi, duomenų apie tikrąjį virškinamumą naudojimas leidžia kruopščiai palyginti žaliavas, net jei jų kiekiai skirtingi. Endogeniniai proteinai ir amino rūgštys, regeneruojami klubinėje žarnoje, gali būti skirstomi į specifines ir nespecifines frakcijas. Nespecifinė regeneracija, taip pat vadinama bazine regeneracija – yra susijusi su sausos medžiagos įsisavinimu, bet nepriklauso nuo maisto medžiagų ar šėrimo tipo. Priešingai, specifinė regeneracija – taip pat vadinama papildoma regeneracija – yra susijusi su maisto medžiagų sudėtimi ir šėrimu (taip pat tokiais paveldimais faktoriais kaip lektinai, tripsino inhibitoriai ir taninai. Bazinių endogeninių baltymų srautas klubinėje žarnoje gali būti laikomas neišvengiamai nuostolingu kiaulėms. Duomenys apie bazinių endogeninių proteinų ir amino rūgščių srautą gali būti panaudoti apskaičiuoti tikrąją pašaro komponentų virškinamumo vertę kiaulių klubinėje žarnoje. Apibendrinant, galima teigti, kad tikrojo klubinėje žarnoje virškinamų amino rūgščių kiekio panaudojimas, formuojant racioną, gali būti naudingas (1) tikslesniam komponentų sąnaudų/panaudojimo efektyvumo įvertinimui, (2) tobulesniam virškinamumo rodiklių, sudarant pigiausias programas, įvertinimui, (3) efektyvesniam alternatyvių pašarų panaudojimui, (4) geresniam proteinų (azoto) ir amino rūgščių panaudojimui ir pašalinimui, (5) geresniam kiaulių augimo prognozavimui, ir galiausiai (6) pigesnei produkcijai gaminti.

Raktažodžiai: kiaulės, amino rūgštys, endogeniniai proteinai, tikrasis virškinamumas.

Introduction. It is generally agreed that in the pig the amount of amino acids absorbed in the small intestine up to the terminal ileum gives a more reliable estimate of the amount available to the animal than does the conventional fecal analysis method, particularly if the diet contains protein of low quality. Due to microbial metabolism of nitrogenous material in the large intestine, only a relatively small proportion of the amino acid excretion in feces is directly related to the amino acids recovered at the distal ileum. Thus, depending on the amino acid and on the feedstuff, digestibility values obtained by the fecal analysis method overestimate (which is usually the case) or underestimate those obtained by the ileal analysis method. Therefore, it is now recognised that the ileal analysis method should be considered as an improvement over the fecal analysis method. If one accepts that the determination of amino acid digestibility values should be based on the ileal analysis method, one should consider that ileal digesta contains variable amounts of endogenous protein. Endogenous protein and amino acids are defined as the amount or proportion of these constituents in ileal digesta or feces, which do not directly originate from the diet (Souffrant, 1991).

Considerable quantities of endogenous protein are produced from saliva, bile juice, pancreatic juice, intestinal juice, mucin and desquamated mucosal cells (Sauer et al., 2000). Endogenous protein, along with dietary protein, is subjected to digestion, and its products are reabsorbed (Fuller, 1991). The majority of endogenous protein recovered at the distal ileum is composed of sloughed cells and mucin, because these are partially resistant to enzymatic hydrolysis (Taverner et al., 1981; Moughan and Schuttert, 1991).

The secretion and the degree of re-absorption of amino acids have a significant influence on the amount of protein recovered from the distal ileum, thus on ileal protein and amino acid digestibility values. Several methods have been used to quantify the endogenous protein (amino acid) flow at the distal ileum of the pig. Earlier studies made use of conventional methods, including the feeding of protein-free diets, feeding diets containing protein sources with an assumed 100% digestibility, and mathematical regression techniques. More recently, the ^{15}N isotope dilution and the homoarginine method have been used.

The main focus of this review is directed to the development of current concepts of amino acid digestibilities and the use of true digestible amino acids in diet formulation for pigs.

Expression of true ileal amino acid digestibility

Physiological considerations. If one accepts that the determination of amino acid digestibility values should be based on the ileal analysis method, these digestibility coefficients should be consistent with two main specifications. Firstly, they must allow feed ingredients to be accurately compared, thus being independent of experimental and dietary conditions. Secondly, they must include any variation of the endogenous fraction related to the feedstuff itself, which is one of its attributes and must be considered in diet formulation. These specifications hold true for estimates of true ileal protein and amino acid digestibility.

At this point it is important to distinguish between specific and non-specific endogenous protein and amino acid losses (Souffrant, 1991). As illustrated in Figure 1, the non-specific recovery - also referred to as basal recovery or minimum gut loss - is related to the dry matter intake only but independent of dietary and experimental conditions. The level of non-specific endogenous amino acid losses, expressed as g per kg dry matter is constant at different dietary amino acid levels. The ileal flow of non-specific endogenous protein and amino acids is considered to be an inevitable source of nitrogen and amino acid losses for the pig.

In contrast to the non-specific protein and amino acid recoveries the specific recovery - also referred to as extra recovery - is variable and related to the presence of inherent factors in the feedstuff. These factors include dietary protein and fiber (Schulze, 1994; Schulze et al., 1995 a), as well as anti-nutritional factors such as protease inhibitors (Huisman et al., 1992; Jansman et al., 1994), lectins (Schulze et al., 1995b) and condensed tannins (Jansman et al., 1995).

Different methods are available to determine the endogenous protein or amino acid fraction in ileal digesta of pigs as was reviewed by Souffrant (1991), Leterme and Thewis (1995), Boisen and Moughan (1996) and Nyachoti et al. (1997a). Some of them only estimate the flow of non-specific endogenous protein, whereas others determine the total (non-specific and specific) flow of endogenous protein and/or amino acids

Determination of endogenous protein and amino acids. ***Protein-free alimentation.*** When protein-free diets are fed, all protein-containing compounds in ileal digesta are assumed to be of endogenous origin. The main criticism of this method is the non-physiological nature (Low, 1980) that may affect normal body protein metabolism (Millward et al., 1976) and, in turn may reduce the secretion of protein compounds into the gut lumen and affect the efficiency of re-absorption (Darragh et al., 1990). The fact that animals are in a negative nitrogen balance appears to affect the endogenous losses of essential amino acids at the distal ileum of the pig (de Lange et al., 1989). As indicated by Butts et al. (1993) and Donkoh et al. (1995), a protein-free diet may lack the stimulatory effect on endogenous gut protein secretions. This may lead to an underestimation of endogenous protein output at the distal ileum. In addition, dietary constituents, such as fiber and anti-nutritional factors, may increase endogenous protein losses.

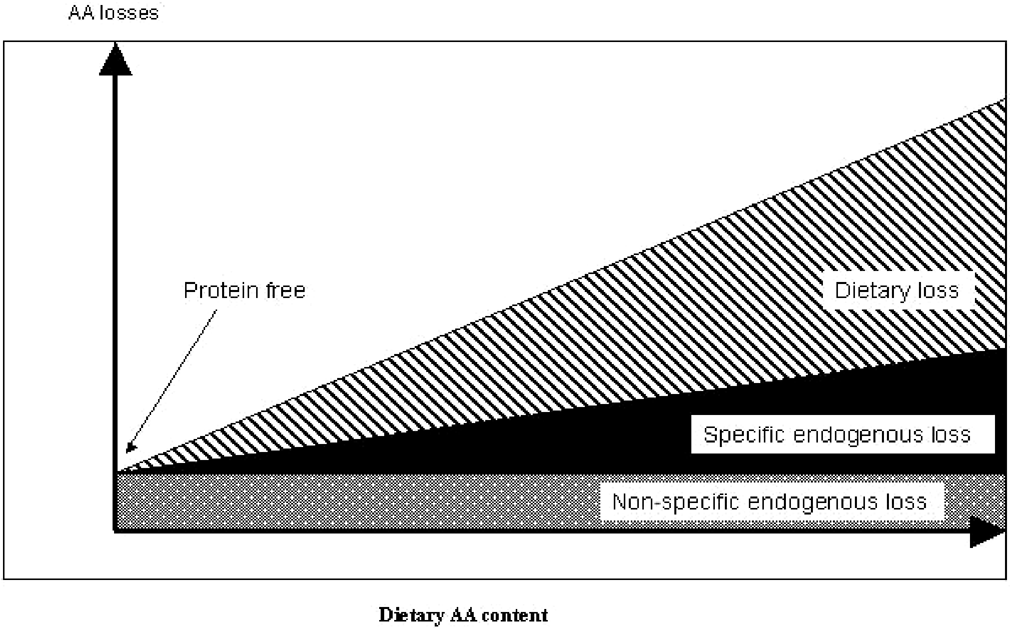

Figure 1. **Sources of amino acid losses in ileal digesta**

Low protein casein diets. Feeding a diet containing a protein source with an assumed 100% digestibility, such as casein and crystalline amino acids, may offer a desirable alternative to using a protein-free diet. However, the recovery of total protein at the distal ileum in pigs fed these diets can be lower than in pigs fed protein-free diets even if the true ileal digestibility of casein and/or crystalline amino acids is less than 100%. The validity of this method should thus be questioned until it is proven that the true digestibility values of casein and synthetic amino acids are indeed 100% (Nyachoti et al., 1997a).

Regression method. When regression methods are used, animals are fed graded levels of protein in the diet and the recovery of protein and amino acids at the distal ileum is related to protein and amino acid intake. By mathematical extrapolation, the recovery values of protein and amino acids at zero protein and amino acid intake can then be estimated. The regression method is believed to provide better estimates of endogenous protein losses compared to feeding protein-free diets (Fan et al., 1995). In addition, it allows for evaluation of the effects of various diets on endogenous protein losses (Souffrant, 1991; Fan et al., 1995). However, various studies have shown that estimates obtained with this method were not different from those obtained with feeding protein-free diets (e.g. Taverner et al., 1981; Furuya and Kaji, 1989; Donkoh et al., 1995). Furthermore, a basic assumption with the regression method, as well as with feeding protein-free diets, is that there is no relationship (interaction) between protein intake and endogenous protein losses. Based on various recent studies this basic assumption appears not to be valid; both methods result in an underestimation of endogenous protein losses (Nyachoti et al., 1997a).

Isotope dilution techniques. Isotope dilution techniques using ^{15}N have been used to label either the animal's protein pool (de Lange, 1989; Huisman et al., 1992; Schulze et al., 1995) or the dietary protein (Leterme et al., 1994; Roos et al., 1994) and allow differentiation between endogenous and undigested dietary protein. Labelling the animal's protein pool is commonly used by continuously infusing labelled amino acids and then measuring the amount of labelled amino acids present in ileal digesta. The loss of endogenous protein may be underestimated by this method because it does not account for endogenously added mucosal cells that are synthesized from labelled luminal dietary amino acids and then secreted (de Lange et al., 1992; Roos et al., 1994). Another point of critique on this technique is that not all protein-containing compounds in the precursor pools and in endogenous gut protein are uniformly labelled when labelled amino acids are infused intravenously (de Lange et al., 1992; Lien et al., 1993). ^{15}N-labelled amino acids are very expensive and this may further limit the application of this method. The ^{15}N-labeling of dietary protein poses little concerns as far as uniformity of labelling is concerned. ^{15}N supplied by dietary amino acids are quickly absorbed and incorporated into body protein, thus complicating the differentiation of undigested dietary protein and endogenous protein losses (Leterme et al., 1994; Roos et al., 1994; Tamminga et al., 1995).

Homoarginine method. The homoarginine method invo1ves the transformation of dietary lysine to homoarginine through a guanidination process (a reaction with *0*-methylisourea). This method was first suggested by Hagemeister and Erbersdobler (1985) and allows for differentiation between dietary lysine (homoarginine) and endogenous lysine in digesta. Absorbed homoarginine may be hydrolyzed by arginase in the liver to lysine and urea. Consequently, there is no endogenous homoarginine recycling into the intestinal tract.

However, long-time and high dose usage of homoarginine may cause urea poisoning. The fact that uniform guanidination of lysine in test protein sources is not always achieved, especially in high fiber feed ingredients, may impose some limitations on this method (Maga, 1981; Rutherford and Moughan, 1990; de Vrese et al., 1994). The same as with the isotope dilution method, an assumption of a constant amino acid profile of endogenous protein is needed to estimate true ileal amino acid digestibility values for the homoarginine method (e. g. Nyachoti et al., 1997b).

True versus real ileal amino acid digestibility. Corrections of apparent ileal digestibility values for both specific and non-specific protein and amino acid losses would allow for the calculation of the so called „real" ileal protein and amino acid digestibility coefficients (Low, 1982). The data presented in Table 1 clearly indicate that the specific rather than the non-specific nitrogen and amino acid losses compensate for the differences in apparent digestibility between field peas and soya protein isolate. The difference in specific endogenous losses between these feedstuffs can be attributed to variable amounts of inherent factors such as protease inhibitors. There is great interest in the evaluation of real digestibilities from a scientific point of view (e.g. de Lange et al., 1990; Mosenthin et al., 1993).

Table 1. **Comparison of apparent, true and real nitrogen and amino acid digestibilities in field peas and soya protein isolate (Adapted from Huisman et al., 1992 and Sève et al., 1994)**

Source Ingredient Item	Huisman et al. (1992) Field Peas g/100 nitrogen	Sève et al. (1994) Soya protein isolate g/100 g amino acids
Apparent digestibility	74.1	89.3
Non-specific endo-genous loss	7.8	3.5
True digestibility	81.9	92.8
Specific endogenous loss	11.0	4.5
Real digestibility	92.9	97.3

However, values of real digestibility should not be used directly in dietary formulation because these values do not include the specific feed-induced endogenous protein losses and therefore require that those unknown protein costs of digestion are included in the estimate of amino acid requirements. Consequently, the actual requirements for amino acids would depend on the ingested feedstuffs.

True ileal protein and amino acid digestibility has the advantage over both apparent and real digestibility in that it represents a fundamental property of the individual feedstuff. In other words, true digestibility values include any variation of the endogenous fraction related to the feedstuff itself. As illustrated in Figure 2, true digestibility values are not affected by the level of amino acid intake or amino acid content of the assay diet, whereas the corresponding apparent digestibility values increase exponentially with higher levels of intake because the non-specific amino acid recoveries, as percentage of total recovery, decrease proportionally.

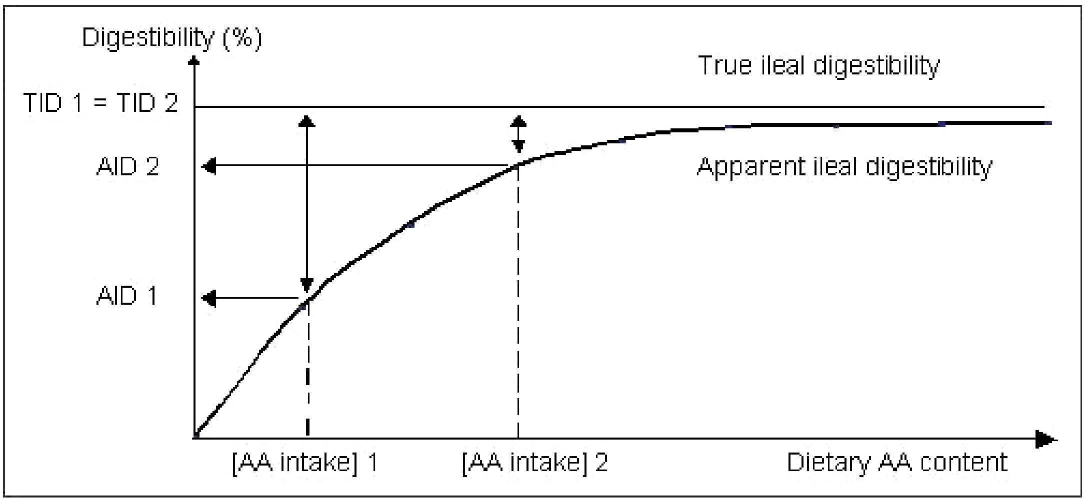

Figure 2. **Expression of apparent and true ileal amino acid digestibilities as a function of amino acid intake**

Transformation of apparent into true digestibility values. The transformation of apparent ileal amino acid digestibility values into values of true digestibility by correction for non-specific amino acid losses is described by the following equation:

$$\text{TID (\%)} = \frac{\text{AA intake - (AA excretion - Non-specific AA)}}{\text{AA intake}} \times 100$$

where TID = true ileal digestibility
AA = amino acid

Apparent digestibility values that have been transformed into true digestibility values according to the equation above were originally referred to as „standardized ileal digestibility values" (Mariscal-Landin, 1992).

Different estimates for the correction of non-specific protein and amino acid losses are momentarily used in feed tables in which true ileal protein and amino acid digestibilities are summarized (Jondreville et al., 1995; CVB, 1998; NRC, 1998; Rademacher et al., 1999, AmiPig, 2000). For example, in AmiPig (2000), promoted by AFZ, Ajinomoto Eurolysine, Aventis Animal Nutrition, INRA and ITCF, the calculations for the correction of non-specific endogenous ileal protein and amino acid recoveries are based on data that were obtained by feeding protein-free diets to growing pigs. On the other hand, Rademacher et al. (1999) transformed values of apparent ileal protein and amino acid digestibility into values of true digestibility by using existing literature data on endogenous recoveries of protein and amino acids in ileal digesta. These authors selected 33 experiments from the literature that were based on different experimental approaches. These data included conventional methods such as feeding protein-free diets without (n=16) or with parenteral infusion of amino acids (n=1) (e.g. De Lange et al., 1989a, b), the regression method (n=3) (e.g. Fan et al., 1995) and the feeding of highly digestible protein sources such as wheat gluten or casein (n=11) (e.g. Chung and Baker, 1992). In addition, the corrections for non-specific protein and amino acid recoveries in ileal digesta were based on the EHC method (n=2) (e.g. Butts et al., 1993). It was claimed that the diets in the experiments selected by Rademacher et al. (1999) contained no specific anti-nutritional factors and not more than 8% cellulose or purified neutral detergent fibre (NDF). The data of these experiments were pooled and mean values for non-specific losses of protein and amino acid recoveries were calculated.

The feeding of protein-free diets as proposed by AmiPig (2000), gives generally lower estimates of non-specific endogenous protein and amino acid recoveries as compared to estimates by Rademacher et al. (1999), which were based on different experimental approaches as previously described. The data presented in Table 2 reveal that these differences were considerably higher for threonine, which is present in relatively large concentrations in endogenous protein (Holmes et al., 1974; De Lange et al., 1989a; Mosenthin et al., 1994).

Table 2. **Comparison of non-specific endogenous protein and amino acid recoveries in ileal digesta of growing pigs (g/kg dry matter intake)**

Source Item	AmiPig (2000)			Rademacher et al. (1999)
	Lab A[1]	Lab B[1]	Lab C[1]	
Nx6.25	8.66	7.22	9.67	11.82
LYS	0.29	0.24	0.41	0.40
MET	0.08	0.05	0.13	0.11
MET+ CYS	0.22	0.22	0.30	0.32
THR	0.33	0.27	0.39	0.61
TRY	0.09	0.09	0.17	0.14

[1] Laboratory

As can be expected, the method used for correction of apparent digestibility values has little effect on true digestibility estimates in high-protein feedstuffs with a relatively high apparent digestibility of amino acids and protein such as soyabean meal (Table 3). Differences in true digestibility values in relation to the method used for estimating non-specific protein and amino acid recoveries are more pronounced in feed ingredients with lower apparent protein and amino acid digestibilities, in particular with respect to threonine and tryptophan.

True digestible amino acids in diet formulation. It is claimed that the transformation of apparent ileal amino acid digestibilities into true values will improve the additivity of digestibility values in mixtures of different feed ingredients. There is growing evidence that non-specific endogenous amino acid losses are likely to interfere with additivity of apparent amino acid digestibilities in mixtures of feed ingredients (Imbeah et al., 1988; Fan et al., 1995; Nyachoti et al., 1997a, b). For example, Nyachoti et al. (1997b) concluded from the results of their study that there may be a lack of additivity in apparent ileal amino acid digestibilities when low-protein feedstuffs such as barley are combined with high-protein feed ingredients such as canola meal (Table 4). The correction of apparent ileal amino acid digestibilities for non-specific amino acid losses that are assumed not to be affected by differences in diet composition, will eliminate these effects. The resulting true amino acid digestibilities are more likely to be additive than the corresponding apparent digestibility values (Mariscal-Landin, 1992; Jondreville et al., 1995; Boisen and Moughan, 1996; NRC, 1998; Rademacher et al., 1999).

Table 3. **Comparison of true ileal protein and amino acid digestibility values (%) in selected feedstuffs**

Ingredients	Barley	Wheat	Peas	Rapeseed meal	Soyabean meal	Sugarbeet pulp
Crude Protein						
NRC (1998)	-	-	-	-	-	-
Rademacher et al. (1999)	80	89	79	73	87	46
AmiPig (2000)	80	88	80	76	87	53
LYS						
NRC (1998)	79	81	88	78	89	51
Rademacher et al. (1999)	76	84	81	74	89	55
AmiPig (2000)	75	81	83	75	89	50
MET						
NRC (1998)	86	90	84	86	91	64
Rademacher et al. (1999)	82	90	74	81	90	59
AmiPig (2000)	84	89	80	87	88	61
MET + CYS						
NRC (1998)	86	90	83	84	87	44
Rademacher et al. (1999)	81	89	70	75	86	53
AmiPig (2000)	84	90	75	84	87	43
THR						
NRC (1998)	81	84	83	76	85	30
Rademacher et al. (1999)	80	86	76	71	86	28
AmiPig (2000)	75	83	76	75	86	31
TRY						
NRC (1998)	80	90	81	75	87	41
Rademacher et al. (1999)	77	88	70	71	87	50
AmiPig (2000)	79	88	73	80	86	41

Table 4. **Observed and calculated apparent and true ileal digestibilities for selected amino acids in barley, canola meal and a mixture of barley and canola meal (Adapted from Nyachoti et al., 1997b)**

	Barley	Canola meal	Mixture of barley and canola meal		
Item			Observed	Calculated[1]	Difference[2]
AID[3], (%)					
LYS	53.5	62.6	63.6	59.0	4.6
THR	63.7	62.4	67.7	62.9	4.8
ISO	65.3	73.2	78.6	70.6	8.0
VAL	67.6	69.5	72.1	65.7	6.4
TID[4,5], (%)					
LYS	87.1	84.6	85.8	85.8	0.0
THR	97.0	97.8	96.6	97.5	-0.9
ISO	95.1	99.7	100.2	97.4	2.8
VAL	89.1	97.4	96.4	93.1	3.3

[1] Calculated from observed digestibilities in the pure ingredients and their contents in the mixture of barley and canola meal
[2] Calculated as observed minus calculated values
[3] Apparent ileal digestibility
[4] True ileal digestibility
[5] Determined with the homoarginine method

Additivity of amino acid digestibility values in the diet formulation for pigs by least cost formulation programs is essential since these programs use individual digestibility coefficients for each feedstuff to fulfil the amino acid specifications. True digestibility values allow feed ingredients to be accurately compared and contribute to the precision of diet formulation.

It is claimed that the application of true protein and amino acid digestibility values in diet formulation for growing pigs will promote the use of alternative low-protein feedstuffs and various by-products of the food processing industry. In the following two examples, two commercially available diets, referred to as reference diets, are formulated to contain as main ingredients corn and soyabean meal (Table 5) or barley, wheat and soyabean meal (Table 6). These diets contained equal levels of ME (13.5 MJ per kg), N x 6.25 (18.5%) and total lysine (1.05%).

Table 5. **The use of true ileal digestible lysine in the formulation of a corn-soyabean meal based diet and two types of mixed diets**

Ingredient (%)	Corn-Soyabean meal	Mixed diet A[1]	Mixed diet B[2]
Corn	54.3	38.0	35.6
Wheat middlings	20.0	17.0	21.0
Soyabean meal, 44 % CP	22.3	14.9	17.7
Rice bran	-	20.0	19.0
Cottonseed meal	-	6.3	3.0
Tallow	-	0.74	0.68
DL-Methionine	0.08	0.07	0.10
L-Lysine•HCl	0.24	0.30	0.30
L-Threonine	0.06	0.08	0.08
Vitamins and minerals	3.02	2.61	2.54
Energy and nutrients			
ME (MJ/kg)	13.5	13.5	13.5
N x 6.25 (%)	18.3	18.3	18.3
Lysine (%)	1.05	1.05	1.08
Lysine, true ileal digestible (%)	0.92	0.88	0.92
Feed cost (US $ per 100 kg)[3]	12.56	11.46	11.45

[1] Formulated to contain equal levels of crude protein and total lysine as corn-soyabean meal diet
[2] Formulated to contain equal levels of crude protein and true ileal digestible lysine as the corn-soyabean meal diet
[3] Based on US ingredient prices, February 2002

Table 6. **The use of true ileal digestible lysine in the formulation of a wheat-barley-soyabean meal based diet and two types of mixed diets**

Ingredient (%)	Wheat-Barley-Soyabean meal	Mixed diet A[1]	Mixed diet B[2]
Barley	28.8	-	-
Wheat	45.0	15.3	30.0
Soyabean meal, 44 % CP	19.4	9.3	19.5
Rye	-	30.0	25.0
Canola meal	-	18.9	
Triticale		20.0	11.7
Wheat bran	-	-	8.0
Tallow	3.16	3.50	2.35
DL-Methionine	0.10	0.05	0.10
L-Lysine•HCl	0.30	0.21	0.28
L-Threonine	0.10	0.03	0.11
Vitamins and minerals	3.14	2.71	2.96
Energy and nutrients			
ME, MJ/kg	13.5	13.5	13.5
N x 6.25, (%)	18.3	18.3	18.3
Lysine (%)	1.05	1.05	1.06
Lysine, true ileal digestible (%)	0.94	0.87	0.94
Feed cost (EURO per 100 kg)[3]	16.24	14.99	15.84

[1] Formulated to contain equal levels of crude protein and total lysine level as wheat-barley-soyabean meal diet
[2] Formulated to contain equal levels of crude protein and true ileal digestible lysine as the wheat-barley-soyabean meal diet
[3] Based on European ingredient prices, February 2002

By complete or partial replacement of corn, barley, wheat and soyabean meal in the reference diets by alternative protein sources such as cottonseed meal, canola meal and peas and by-products such as wheat bran and rice bran, two types of diets were formulated, referred to as mixed diets type A and B (Tables 5 and 6).

The mixed diets type A were formulated to contain the same level of ME (13.5 MJ per kg), N x 6.25 (18.5%) and total lysine (1.05%) as the corresponding reference diets in Tables 5 and 6. However, due to the substitution of dietary components with a relatively high true ileal digestibility of lysine by those with lower digestibility coefficients, lower contents of true ileal digestible lysine in the mixed diets type A in comparison to the corresponding reference diets were obtained. The level of true ileal digestible lysine in the mixed diets type A declined from 0.92 to 0.88% (Table 5) and from 0.93 to 0.88% (Table 6) as compared to the reference diets based on corn and soyabean meal, and barley, wheat and soyabean meal, respectively. This decline in the content of true ileal digestible lysine would certainly have a negative effect on the growth performance of pigs, provided that these figures are below the actual lysine requirement of the animals.

As a further example, two mixed diets type B were formulated that contained the same level of ME (13.5 MJ per kg) and N x 6.25 (18.5%) as compared to the reference diets and the mixed diets type A (Tables 5 and 6). However, to compensate for the lower content of true ileal digestible lysine in the mixed diets type A, the total dietary lysine level was elevated by 1 to 3%. As a result, there was no difference in the level of true ileal digestible lysine between the reference diets and the corresponding mixed diets type B. Consequently, no negative impact on growth performance of pigs could be expected.

Formulating more complex mixed diets according to type A, while maintaining the same level of total lysine as in the reference diets based on corn and soyabean meal or barley, wheat and soyabean meal, significantly reduced feed costs by approximately 8 to 9% (Tables 5 and 6). However, replacements of grain cereals and soyabean meal by increasing proportions of alternative protein sources and by-products resulted in a pronounced decline in the level of true ileal digestible lysine, which in turn, most likely will result in a loss of growth performance.

On the other hand, formulating more complex diets according to type B by maintaining the same levels of true ileal digestible lysine as in the reference diets decreased feed costs by approximately 9 and 3% as compared to the reference diets based on corn and soyabean meal (Table 5), and barley, wheat and soyabean meal, respectively (Table 6). In other words, savings in feed costs varied between 3 and 9% compared to standard diets based on cereal grains and soyabean meal while maintaining the same content of true ileal digestible lysine in the diets. Therefore the use of true ileal amino acid digestibility values in diet formulation for growing pigs offers the potential not only to improve the precision of diet formulation, but also to improve the productivity in pig production for lower feed costs.

Conclusion. The transformation of apparent into true ileal amino acid digestibility values is based on estimates for the correction of non-specific amino acid losses. True ileal amino acid digestibility coefficients are independent of the amino acid level in the assay diet and reflect a fundamental property of the feedstuff itself, not being influenced by differences in dietary conditions. Consequently, true amino acid digestibility values can be used in diet formulation for growing pigs to quantify the amino acids available for maintenance and tissue accretion at least for a wide range of commonly used feed ingredients, which have not been subjected to high temperature treatment during feed processing.

The use of true ileal digestible amino acids in diet formulation will contribute to (1) a more accurate evaluation of the cost/benefit value of ingredients, (2) an improved additivity of digestibility values in least cost formulation programs, (3) a more efficient use of alternative feedstuffs, (4) an improved utilization of protein (nitrogen) and amino acids for maintenance and protein deposition, (5) a better prediction of growth performance of pigs and finally, (6) a more cost effective pig production.

However, there exists considerable variation between estimates of non-specific amino acid losses at the ileal level. Consequently, different estimates are used in various tables in which true ileal amino acid digestibility values are summarized. Since the results from different feed tables are not compatible when being used in diet formulation for growing pigs, there is a need to standardize the estimates used for correction of apparent digestibility values. Finally, the expression of true ileal amino acid digestibility and its use in diet formulation requires the assessment of the animal's requirement for digestible amino acids. In other words, the non-specific endogenous amino acid losses have to be taken into account when expressing amino acid requirements according to the concept of ideal protein.

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