Available online at www.sciencedirect.com
ScienceDirect
Livestock Science 109 (2007) 282–285
LIVESTOCK SCIENCE
www.elsevier.com/locate/livsci

Short communication

Definition of apparent, true, and standardized ileal digestibility of amino acids in pigs ☆

H.H. Stein [a], M.F. Fuller [b], P.J. Moughan [c], B. Sève [d], R. Mosenthin [e], A.J.M. Jansman [f], J.A. Fernández [g], C.F.M. de Lange [h,*]

[a] *University of Illinois, Urbana, IL, USA*
[b] *State University of New York, Stony Brook, NY, USA*
[c] *Riddet Centre, Massey University, Palmerston North, New Zealand*
[d] *I.N.R.A. — Centre de Recherches de Rennes, Saint Gilles, France*
[e] *University of Hohenheim, Institute of Animal Nutrition, Stuttgart, Germany*
[f] *Animal Sciences Group, Lelystad, The Netherlands*
[g] *Danish Institute of Agricultural Science, Tjele, Denmark*
[h] *University of Guelph, Guelph ON, Canada*

Abstract

Measures of ileal digestibility (ID) are used routinely as estimates of amino acid (AA) bio-availability in pig feed ingredients. Values for ID may be expressed as apparent (AID), standardized (SID), or true (TID). Values for AID are calculated by deducting the total ileal outflow of AA (the sum of endogenous losses (IAA_{end}) and non-digested dietary AA) from dietary AA intake. The IAA_{end} may be separated into basal losses, which are not influenced by feed ingredient composition, and specific losses induced by feed ingredient characteristics such as anti-nutritional factors and dietary fiber. If the AID values are corrected for total IAA_{end}, then values for TID are calculated. Lack of additivity of AID values in feed formulation may be overcome by correcting AID values for basal IAA_{end} only, which yields SID values. Until reliable procedures for the routine measurement of specific IAA_{end} become available, it is suggested that SID values are used for feed formulation. It is advisable that basal IAA_{end} are measured in digestibility experiments and that these losses are reported with SID values.

Keywords: Amino acids; Digestibility; Pigs

1. Introduction

The assessment of the bio-availability of each of the dietary amino acids (AA) is critical for evaluating the nutritional value of pig feed ingredients and for estimating AA requirements of pigs. Measures of ileal digestibility (ID) of AA are used routinely as estimates of AA bio-availability. However, in some instances ID can over-estimate bio-availability of AA in pig feed

☆ This paper is part of the special issue entitled "Digestive Physiology in Pigs" guest edited by José Adalberto Fernández, Mette Skou Hedemann, Bent Borg, Jensen, Henry Jørgensen, Knud Erik Bach Knudsen and Helle Nygaard Lærke.

* Corresponding author. Tel.: +1 519 824 4120x56477; fax: +1 519 836 9873.
E-mail address: cdelange@uoguelph.ca (C.F.M. de Lange).

1871-1413/$ - see front matter © 2007 Elsevier B.V. All rights reserved.
doi:10.1016/j.livsci.2007.01.019

ingredients. This applies in particular to heat treated feed ingredients or when fermentation in the proximal part of the GI tract (mouth to ileum) of pigs results in a net loss of AA (Fuller, 2003). Ileal digestibility of AA can be expressed as apparent (AID), true (TID), or standardized (SID) ileal digestibility depending on which proportion of the ileal AA outflow is included in the calculation. There are advantages and disadvantages associated with using each of these approaches, and it is important that clear distinctions among the three approaches are made. It is the objective of the current contribution to describe differences among values for AID, TID, and SID in order to bring clarity to terminology to characterize AA availability in pig fed ingredients. More extensive discussions of the various measures of AA availability and digestibility in pig feed ingredients are presented by Jansman et al. (2002), GFE (2005), and Stein et al. (2006).

2. Sources of amino acids in ileal digesta

Values for ileal AA digestibility are calculated by subtracting the quantity of an AA in ileal digesta outflow from the quantity that is ingested by the animal (Sauer and Ozimek, 1986). The ileal digesta contain unabsorbed exogenous AA of dietary origin as well as AA of endogenous origin that are usually referred to as ileal endogenous AA losses (IAA_{end}). These losses represent endogenously synthesized proteins and other AA containing compounds that are secreted into the intestinal lumen of the pig and not digested and reabsorbed prior to the distal ileum. The IAA_{end} consist of basal IAA_{end} and specific IAA_{end}. Therefore, the three sources that are present in ileal digesta collected from pigs are undigested dietary AA, basal IAA_{end}, and specific IAA_{end}.

2.1. Undigested feed protein

It is recognized that differences in digestibility among and within feed ingredients exist due to variations in the quantities of unabsorbed dietary AA that are collected in ileal digesta (Sauer and Ozimek, 1986). The total quantities of undigested dietary AA that are collected in the ileal digesta are, therefore, determined by the dietary protein source, and the dietary inclusion level of this protein source.

No techniques are available to measure directly all undigested dietary AA in ileal digesta. However, the homoarginine technique may give a measure of the quantities of undigested dietary Lys in ileal digesta (Moughan and Rutherfurd, 1990). The isotope dilution technique as applied by de Lange et al. (1992) may also estimate the quantity of dietary Leu and a few other AA that are present in the ileal digesta. In vitro digestibility assays can, in principle, also provide estimates of the amount of undigested dietary amino acids in ileal digesta (Boisen and Fernández, 1995).

2.2. Basal endogenous losses

The basal IAA_{end} represent the quantities of AA that will be lost from the animal regardless of the diet that is being fed. These animal induced losses are not influenced by the feed ingredient composition *per se*, but they are strongly influenced by the total dry matter intake (DMI) of the animal (Boisen and Fernández, 1995; Hess and Sève, 1999; Moter and Stein, 2004) and, for this reason, they are expressed in relation to DMI. They may also be affected by the animal's physiological state or by experimental conditions.

The basal IAA_{end} may be measured using a N-free diet, the regression method or the peptide alimentation technique. All of these procedures have their advantages and limitations and yield variable estimates of IAA_{end}. However, across a large number of experiments, mean values for IAA_{end} obtained with feeding N-free diets and the regression method are relatively similar (10.5 and 12.0 g CP per kg DMI, respectively), but lower than the value of 17.2 g CP per kg DMI obtained with the peptide alimentation technique (Jansman et al., 2002). Based on an in vitro technique, Boisen and Fernández (1995) estimated basal endogenous losses to be 13.2 g protein per kg DMI.

2.3. Specific endogenous losses

The specific IAA_{end} represent the losses above the basal IAA_{end} that are induced by specific feed ingredient characteristics, such as the concentration and type of fiber or anti-nutritional factors. Primarily because of metabolic costs associated with IAA_{end}, attempts should continue to characterize diet effects on these losses. When feeding highly digestible purified proteins (i.e., casein or egg protein), the specific IAA_{end} are minimal, but if feed ingredients containing fibers or anti-nutritional factors are fed, specific IAA_{end} may contribute more than 50% to the total IAA_{end}.

No procedures are available for directly measuring specific IAA_{end}. However, total (specific plus basal) IAA_{end} for certain AA may be estimated using the homo-arginine technique and the isotope dilution technique. Specific IAA_{end} can then be calculated by subtracting the basal IAA_{end} from the total IAA_{end}. In addition, in vitro techniques may provide estimates of IAA_{end} for specific ingredients or complete diets, for example as a function of in vitro determined ileal DM digestibility (Boisen and Fernández, 1995).

3. Apparent ileal digestibility

The AID for a given AA is calculated by subtracting the total ileal outflow of that AA from the quantity ingested by the pig according to Eq. (1):

$$\mathrm{AID}(\%) = [(\mathrm{AA\ intake} - \mathrm{ileal\ AA\ outflow})/\mathrm{AA\ intake}] \times 100 \quad (1)$$

The word 'apparent' is used to reflect that both non-digested dietary AA and IAA_{end} contribute to the total ileal outflow. Values for AID, therefore, represent the net disappearance of AA from the digestive tract prior to the distal ileum.

The major concern with the use of AID is that values for AID obtained in individual feed ingredients are not always additive in mixed diets (Stein et al., 2005). This represents a major problem in practical diet formulation, because additivity of values for individual feed ingredients is essential for accurate predictions of growth performance in pig production systems. The main reason for this lack of additivity is the non-linear relationship between dietary AA level and observed AID, for example when varying the inclusion level of a test feed ingredient in an N-free basal diet (Fan et al., 1994). This lack of additivity can be overcome partly by correcting ileal AA outflow for basal IAA_{end} that are induced by the N-free component of the experimental diet that is used in digestibility studies (CVB, 2004; INRA-AFZ-INAPG, 2004).

4. True ileal amino acid digestibility

Values for TID represent the proportion of dietary AA that disappear from the digestive tract prior to the distal ileum, and they do not include IAA_{end}. TID are calculated according to Eq. (2):

$$\mathrm{TID}(\%) = [(\mathrm{AA\ intake} - (\mathrm{ileal\ AA\ outflow} - \mathrm{total\ IAA_{end}}))/\mathrm{AA\ intake}] \times 100 \quad (2)$$

Primarily because of the difficulty of accurately measuring total IAA_{end}, TID values for feed ingredients are rarely available. In addition, because total IAA_{end} are subtracted from the ileal outflow, values for TID do not distinguish between feed ingredients that induce different levels of specific IAA_{end}. Therefore, values for TID do not predict the quantities of AA that are available for protein synthesis in an animal and values for TID should not be used in practical diet formulation, unless diet effects on specific IAA_{end} are considered as part of the animal AA requirements.

5. Standardized ileal digestibility

Values for SID are calculated as values for AID except that the basal IAA_{end} is subtracted from the ileal outflow according to Eq. (3):

$$\mathrm{SID}(\%) = [(\mathrm{AA\ intake} - (\mathrm{ileal\ AA\ outflow} - \mathrm{basal\ IAA_{end}}))/\mathrm{AA\ intake}] \times 100 \quad (3)$$

Because only the basal IAA_{end} are subtracted from the outflow, any components that are specific to the feed ingredient are included in the calculation, thus, values for SID distinguish between feed ingredients inducing different levels of specific IAA_{end}. Since values for SID are additive in mixed diets (Stein et al., 2005), the major disadvantages of AID and TID (i.e., lack of additivity and a need to explicitly represent specific IAA_{end}, respectively) are overcome if values for SID are used in diet formulation. It should be noted, however, that values for SID are influenced by the estimate of basal IAA_{end}, and therefore, also by the level of feed intake. As a consequence, values for basal IAA_{end} and values for SID should be measured in the same environment and in animals fed close to their voluntary feed intake. In addition, when using SID values in feed formulation, the basal endogenous loss must be considered as part of the animals' AA requirement.

6. Conclusions

Values for AID should not be used in practical diet formulation because the first values are not always additive in a mixed diet. Likewise, values for TID should not be used in diet formulations unless specific IAA_{end} are measured and considered in the animal's AA requirement. However, values for SID reflect both TID and specific IAA_{end} and are usually additive in mixed diets. It is, therefore, recommended that values for SID are used in diet formulations, but care should be taken that basal IAA_{end} are estimated properly and reflected in dietary AA requirements. To further improve the estimation of AA availability from digestibility measurements, future research should aim at estimating the metabolic costs associated with both ileal and colonic specific IAA_{end}, enteric fermentation in the upper gut, the chemical form in which AA are absorbed, and further refinements of in vitro methods.

References

Boisen, S., Fernández, J.A., 1995. Prediction of the apparent ileal digestibility of protein and amino acids in feedstuffs and feed mixtures for pigs by in vitro analyses. Anim. Feed Sci. Technol. 51, 29–43.

CVB, 2004. Veevoedertabel (Table of Nutritional Value of Feed Ingredients). Centraal Veevoederbureau, P. O. Box 2176, 8203 AD Lelystad, The Netherlands.

de Lange, C.F.M., Sauer, W.C., Souffrant, W.B., Lien, K., 1992. ^{15}N-leucine and ^{15}N-isoleucine isotope dilution techniques versus the ^{15}N-isotope dilution technique for determining the recovery of endogenous protein and amino acids in digesta collected from the distal ileum in pigs. J. Anim. Sci. 70, 1848–1856.

Fan, M.Z., Sauer, W.C., Hardin, R.T., Lien, K.A., 1994. Determination of apparent ileal amino acid digestibility in pigs: effect of dietary amino acid level. J. Anim. Sci. 72, 2851–2859.

Fuller, M., 2003. Amino acid bioavailability — a brief history. In: Ball, R.O. (Ed.), Digestive Physiology in Pigs. Proc. 9th Intl. Symp., vol. 1. Univ. Alberta, AL, Canada, pp. 183–198.

GFE, 2005. Standardised precaecal digestibility of amino acids in feedstuffs for pigs — methods and concepts. In: Martens, H. (Ed.), Mitteilungen des Ausschusses für Bedarfsnormen der Gesellschaft für Ernährungsphysiologie (Communications of the Committee for Requirement and Standards of the Society of Nutrition Physiology. Proc. Soc. Nutr. Physiol., vol. 14, pp. 185–205.

Hess, V., Sève, B., 1999. Effects of body weight and feeding level on basal ileal endogenous losses in growing pigs. J. Anim. Sci. 77, 3281–3288.

INRA-AFZ-INAPG, 2004. In: Sauvant, D., Perez, J.-M., Tran, G. (Eds.), Tables of Composition and Nutritional Value of Feed Materials. Wageningen Academic Publishers, Wageningen, The Netherlands.

Jansman, A.J.M., Smink, W., van Leeuwen, P., Rademacher, R., 2002. Evaluation through literature data of the amount and amino acid composition of basal endogenous crude protein at the terminal ileum of pigs. Anim. Feed Sci. Technol. 98, 49–60.

Moter, V., Stein, H.H., 2004. Effect of feed intake on endogenous losses and amino acid and energy digestibility by growing pigs. J. Anim. Sci. 82, 3518–3525.

Moughan, P.J., Rutherfurd, S.M., 1990. Endogenous flow of total lysine and other amino acids at the distal ileum of the protein-free or peptide-free rat: the chemical labeling of gelatin protein by transformation of lysine to homoarginine. J. Sci. Food Agric. 52, 179–192.

Sauer, W.C., Ozimek, L., 1986. Digestibility of amino acids in swine. Results and their applications. Livest. Prod. Sci. 15, 367–388.

Stein, H.H., Pedersen, C., Wirt, A.R., Bohlke, R.A., 2005. Additivity of values for apparent and standardized ileal digestibility of amino acids in mixed diets fed to growing pigs. J. Anim. Sci. 83, 2387–2395.

Stein, H., Fuller, M., Moughan, P.J., Seve, B., de Lange, C.F.M., 2006. Amino acid availability and digestibility in pig feed ingredients: terminology and application. J. Anim. Sci. 85, 172–180.