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# Prediction of basal endogenous losses of amino acids based on body weight and feed intake in pigs fed nitrogen-free diets¤

***Predicción de las pérdidas endógenas basales de aminoácidos a partir del peso corporal y consumo de alimento en cerdos sometidos a dietas libres de nitrógeno***

***Predição das perdas basais endógenas de aminoácidos a partir do peso corporal e do consumo de alimento em porcos submetidos a dietas livres de nitrogênio***

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**Summary**

**Background:** accurate estimations of basal endogenous losses (BEL) of amino acids (AA) are important for the calculation of standardized ileal digestibility values. **Objectives:** to address the influence of body weight (BW) and feed intake on BEL of crude protein (CP) and AA and to develop prediction equations for BEL of CP and AA in pigs fed nitrogen-free diets. **Methods:** based on data derived from 34 research papers, prediction equations for BEL of CP and AA were generated using BW and feed intake per maintenance feed intake (FI:MFI) based on energy concentration as independent variables. **Results:** initial BW (IBW) and FI:MFI ranged from 13.8 to 109.8 kg and from 1 to 5, respectively. Mean values for BEL of CP, Lys, Met, Thr, and Trp were 17.2 (CV = 50.9%), 0.42 (CV = 56.0%), 0.14 (CV = 80.8%), 0.55 (CV = 41.3%), and 0.14 (CV = 57.5%) g/kg dry matter intake (DMI), respectively. The FI:MFI was negatively correlated with BEL of CP and AA except Met ($r < -0.39$; $p<0.05$). Prediction equations for estimating the BEL of CP and AA (g/kg DMI) developed were: BEL of CP = 47.5 – ($8.09 \times 10^{-2} \times$ IBW) – ($8.83 \times$ FI:MFI) with $R^2 = 0.32$ and $p = 0.011$; BEL of Lys = 0.979 – ($1.00 \times 10^{-3} \times$ IBW) – ($0.174 \times$ FI:MFI) with $R^2 = 0.24$ and $p = 0.014$; BEL of Thr = 1.09 – ($1.82 \times 10^{-3} \times$ IBW) – ($0.153 \times$ FI:MFI) with $R^2 = 0.28$ and $p = 0.007$; and BEL of Trp = 0.552 – ($1.11 \times 10^{-3} \times$ IBW) – ($0.120 \times$ FI:MFI) with $R^2 = 0.47$ and $p = 0.002$. **Conclusion:** based on the equations above, IBW and FI:MFI clearly decrease BEL of CP and AA. The equations provided in this paper may be used for estimating BEL of CP and AA.

**Key words**: *modeling, standardized ileal digestibility, swine.*

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**Resumen**

**Antecedentes:** la estimación precisa de las pérdidas endógenas basales (BEL) de aminoácidos (AA) es importante para calcular los valores de la digestibilidad ileal estandarizada. **Objetivos:** establecer la influencia del peso corporal y el consumo de alimento sobre las BEL de proteína cruda (CP) y AA, y desarrollar ecuaciones de predicción para las BEL de CP y AA en cerdos alimentados con dietas libres de nitrógeno. **Métodos:** basados en información proveniente de 34 artículos científicos, fueron generadas ecuaciones de predicción para las BEL de CP y AA usando el peso corporal (BW) y el consumo de alimento por consumo de mantenimiento (FI:MFI) con base en la concentración de energía como variables independientes. **Resultados:** BW y FI:MFI variaron de 13,8 a 109,8 kg y de 1 a 5, respectivamente. Los valores de la media para BEL de CP, Lys, Met, Thr, y Trp fueron 17,2 (CV = 50,9%), 0,42 (CV = 56,0%), 0,14 (CV = 80,8%), 0,55 (CV = 41,3%), y 0,14 (CV = 57,5%) g/kg de consumo de materia seca (DMI), respectivamente. El FI:MFI se correlacionó negativamente con las BEL de CP y AA excepto con la Met ($r < –0,39$; $p<0,05$). Las ecuaciones de predicción para estimar las BEL de la CP y AA (g/kg DMI) desarrolladas fueron: BEL de CP = 47,5 – ($8,09 \times 10^{-2} \times$ IBW) – (8,83 × FI:MFI) con un $R^2 = 0,32$ y un p = 0,011; BEL de Lys = 0,979 – ($1,00 \times 10^{-3} \times$ IBW) – (0,174 × FI:MFI) con un $R^2 = 0,24$ y un p = 0,014; BEL de Thr = 1,09 – ($1,82 \times 10^{-3} \times$ IBW) – (0,153 × FI:MFI) con un $R^2 = 0,28$ y un p = 0,007; y las BEL de Trp = 0,552 – ($1,11 \times 10^{-3} \times$ IBW) – (0,120 × FI:MFI) con un $R^2 = 0,47$ y un p = 0,002. **Conclusión:** con base en las anteriores ecuaciones, el IBW y el FI:MFI claramente redujeron las BEL de CP y AA. Las ecuaciones suministradas en este artículo pueden ser utilizadas para estimar las BEL de CP y AA.

**Palabras clave**: *digestibilidad ileal estandarizada*, *modelación, porcinos.*

**Resumo**

**Antecedentes:** a estimação precisa das perdas endógenas basais (BEL) de aminoácidos (AA) é importante para calcular os valores da digestibilidade ileal padronizada. **Objetivos:** estabelecer a influencia do peso corporal e do consumo de alimento sobre as BEL da proteína bruta (CP) e AA, e desenvolver equações de predição para as BEL da CP e AA em porcos alimentados com dietas livres de nitrogênio. **Métodos:** baseados em informação proveniente de 34 artigos científicos, foram geradas equações de predição para as BEL da CP e AA usando o peso corporal (BW) e o consumo de alimento por consumo de manutenção (FI:MFI) com base na concentração de energia como variáveis independentes. **Resultados:** BW e FI:MFI variaram de 13,8 a 109,8 kg e de 1 a 5, respectivamente. Os valores da média para BEL da CP, Lys, Met, Thr, e Trp foram 17,2 (CV = 50,9%), 0,42 (CV = 56,0%), 0,14 (CV = 80,8%), 0,55 (CV = 41,3%), e 0,14 (CV = 57,5%) g/kg de consumo de matéria seca (DMI), respectivamente. O FI:MFI teve correlação negativa com as BEL da CP e AA exceto com a Met ($r < –0,39$; $p<0,05$). As equações de predição para estimar as BEL da CP e AA (g/kg DMI) desenvolvidas foram: BEL da CP = 47,5 – ($8,09 \times 10^{-2} \times$ IBW) – (8,83 × FI:MFI) com um $R^2 = 0,32$ e um p = 0,011; BEL de Lys = 0,979 – ($1,00 \times 10^{-3} \times$ IBW) – (0,174 × FI:MFI) com um $R^2 = 0,24$ e um p = 0,014; BEL de Thr = 1,09 – ($1,82 \times 10^{-3} \times$ IBW) – (0,153 × FI:MFI) com um $R^2 = 0,28$ e um p = 0,007; e as BEL de Trp = 0,552 – ($1,11 \times 10^{-3} \times$ IBW) – (0,120 × FI:MFI) com um $R^2 = 0,47$ e um p = 0,002. **Conclusão:** Com base nas anteriores equações, o IBW e o FI:MFI claramente diminuíram as BEL da CP e AA. As equações fornecidas neste artigo podem ser utilizadas para estimar as BEL do CP e AA.

**Palavras chave:** *digestibilidade ileal padronizada, modelação, porcinos*.

## Introduction

An accurate determination of the concentration of digestible crude protein (CP) and amino acids (AA) is the major factor to take into consideration in determining standardized ileal digestibility (SID) values of feed ingredients. The SID is widely used in expressing AA requirements and AA contents in feedstuffs for swine diet formulation (Sauvant *et al*., 2004; Stein *et al*., 2007; NRC, 2012). For calculating SID of CP and AA, basal endogenous losses (BEL) of CP and AA generally expressed as g per kg of dry matter intake (DMI) should be accurately estimated.

The mean values for the BEL of CP and AA in the literature have been reported (Jansman *et al*., 2002; NRC, 2012). However, the BEL values of CP and

AA largely vary among animal experiments (Viljoen *et al*., 1998; Pahm *et al*., 2008; Kim *et al*., 2009) potentially due to the differences in a) body weight (BW; Høøk Presto *et al.,* 2010), b) structure of dietary fiber (Leterme and Théwis, 2004), and c) feed intake level (Hess and Sève, 1999; Stein *et al*., 1999).

Although the factors affecting the BEL of CP and AA have been studied and the mean BEL values have been reported (Jansman *et al*., 2002; NRC, 2012), prediction models for estimating BEL of CP and AA are currently not available. Prediction equations for BEL of CP and AA may be used for the calculation of SID of CP and AA values in feedstuffs without a nitrogen (N)-free diet group, and can also help accurate estimations of maintenance AA for the determination of AA requirements in an approach used in NRC (2012). Therefore, the objective of the present work was to develop prediction equations for BEL of CP and AA in pigs fed N-free diets using data from the literature.

## Materials and methods

### *The database*

Data were derived from 34 research papers in refereed journals that used pigs cannulated at the distal ileum and fed N-free diets to measure BEL of CP and AA. The database consisted of BEL of CP and AA (g/kg DMI, Table 1), BW (kg), feed intake level, experimental period (d), and fiber content (%) in the N-free diet.

Final BW was calculated based on NRC (2012) and experimental periods. Mean BW was calculated using the initial BW (IBW) and final BW. Feed intake per maintenance feed intake (FI:MFI) based on energy concentration was calculated to remove the contribution of BW on feed intake. Experimental periods were calculated using the experimental design and duration of adaptation and collection periods.

### *Statistical analysis*

Association among variables expressed as correlation coefficients among IBW, FI:MFI, BEL of CP, and BEL of AA were determined by CORR procedure of SAS (SAS Inst. Inc., Cary, NC). Prediction equations for BEL of CP and AA were generated by PROC REG of SAS using BEL of CP and AA as dependent variables and IBW, the square of IBW, final BW, the square of final BW, mean BW, the square of mean BW, FI:MFI, experimental period, and dietary fiber content as independent variables. Based on root mean square error (RMSE), Mallows statistic [C(p)], regression coefficient ($R^2$), and p-value, redundant independent variables were excluded. Observations that had a Cook's distance value greater than 0.30 were excluded.

## Results

The IBW in the studied dataset ranged from 13.8 to 109.8 kg and mean values for BEL of CP and

**Table 1.** Variability of basal endogenous losses of crude protein and indispensable amino acids (g/kg dry matter intake)[1].

| Item | *n*[2] | Mean | Standard deviation | Maximum | Minimum | Coefficient of variation, % |
|---|---|---|---|---|---|---|
| Crude protein | 33 | 17.2 | 8.76 | 48.6 | 7.94 | 50.9 |
| Arg | 42 | 0.55 | 0.36 | 1.79 | 0.17 | 65.1 |
| His | 42 | 0.18 | 0.08 | 0.53 | 0.08 | 46.4 |
| Ile | 42 | 0.34 | 0.20 | 1.20 | 0.13 | 58.4 |
| Leu | 42 | 0.57 | 0.28 | 1.72 | 0.22 | 49.0 |
| Lys | 42 | 0.42 | 0.24 | 1.39 | 0.14 | 56.0 |
| Met | 41 | 0.14 | 0.12 | 0.64 | 0.03 | 80.8 |
| Phe | 42 | 0.36 | 0.17 | 1.05 | 0.13 | 46.7 |
| Thr | 42 | 0.55 | 0.23 | 1.53 | 0.12 | 41.3 |
| Trp | 30 | 0.14 | 0.08 | 0.43 | 0.06 | 57.5 |
| Val | 42 | 0.48 | 0.25 | 1.48 | 0.07 | 51.8 |

[1]The values were based on 34 research papers (Moughan *et al*., 1991; Chung and Baker, 1992; Viljoen *et al.,* 1998; Stein *et al.,* 1999; Zhang *et al.,* 2002; Otto *et al.,* 2003; Warnants *et al.,* 2003; Leterme and Théwis, 2004; Moter and Stein, 2004; Stein *et al.,* 2004; Bohlke *et al.,* 2005; Petersen *et al.,* 2005; Stein *et al.,* 2005; Gottlob *et al.,* 2006; Stein *et al.,* 2006; Pedersen *et al.,* 2007; Widmer *et al.,* 2007; Cervantes-Pahm and Stein, 2008; Pahm *et al.,* 2008; Yin *et al.,* 2008; Baker and Stein, 2009; Kim *et al.,* 2009; Urriola *et al.,* 2009; Cozannet *et al.,* 2010; Jacela *et al.,* 2010; Almeida *et al.,* 2011; González-Vega *et al.,* 2011; Jacela *et al.,* 2011; Ren *et al.,* 2011; Reyna *et al.,* 2011; Zhai and Adeola, 2011; González-Vega and Stein, 2012; Ji *et al.,* 2012; Li *et al.,* 2013).

[2]The number of observation for crude protein, Met, and Trp was less than 42 due to the data unavailability.

AA (g/kg DMI) are presented in table 1. The BEL of Met had the greatest variability among experiments (0.03 to 0.64 g/kg DMI, CV = 80.8%) and the BEL of Thr had the lowest variability (0.12 to 1.53 g/kg DMI, CV = 41.3%). The range for BEL of CP was 7.94 to 48.6 g/kg DMI with CV of 50.9%.

The BEL of CP was positively correlated with all indispensable AA ($r > 0.35$; $p<0.05$; Table 2). The FI:MFI was negatively correlated with BEL of CP and AA except Met ($r < -0.39$; $p<0.05$). Mean BW, final BW, and concentration of dietary fiber were not correlated with BEL of CP and AA (data not shown).

Prediction equations for estimating the BEL of CP and AA (g/kg DMI) developed are provided in table 3: BEL of CP = 47.5 – ($8.09 \times 10^{-2}$ × IBW) – (8.83 × FI:MFI) with $R^2 = 0.32$ and p = 0.011; BEL of Lys = 0.979 – ($1.00 \times 10^{-3}$ × IBW) – (0.174 × FI:MFI) with $R^2 = 0.24$ and p = 0.014; BEL of Thr = 1.09 – ($1.82 \times 10^{-3}$ × IBW) – (0.153 × FI:MFI) with $R^2 = 0.28$ and p = 0.007; and BEL of Trp = 0.552 – ($1.11 \times 10^{-3}$ × IBW) – (0.120 × FI:MFI) with $R^2 = 0.47$ and p = 0.002.

**Table 2.** Correlation coefficients among initial body weight (IBW, kg), feed intake per maintenance feed intake based on energy concentration (FI:MFI), and basal endogenous losses of crude protein (CP) and amino acids (g/kg dry matter intake).

| Item | IBW | FI:MFI | Basal endogenous loss | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | CP | Arg | His | Ile | Leu | Lys | Met | Phe | Thr | Trp | Val |
| IBW | - | –0.10 | –0.08 | –0.12 | –0.12 | 0.01 | –0.07 | 0.03 | –0.16 | 0.00 | –0.12 | –0.15 | –0.11 |
| FI:MFI | | - | –0.52** | –0.39* | –0.54** | –0.60** | –0.50** | –0.57** | –0.29 | –0.53** | –0.56** | –0.64** | –0.54** |
| CP | | | - | 0.95** | 0.88** | 0.85** | 0.76** | 0.81** | 0.36* | 0.79** | 0.85** | 0.83** | 0.82** |
| Arg | | | | - | 0.74** | 0.54** | 0.50** | 0.58** | 0.30 | 0.48** | 0.66** | 0.51** | 0.53** |
| His | | | | | - | 0.85** | 0.84** | 0.85** | 0.52** | 0.79** | 0.84** | 0.61** | 0.82** |
| Ile | | | | | | - | 0.91** | 0.92** | 0.57** | 0.87** | 0.90** | 0.78** | 0.96** |
| Leu | | | | | | | - | 0.95** | 0.78** | 0.94** | 0.92** | 0.78** | 0.93** |
| Lys | | | | | | | | - | 0.68** | 0.89** | 0.90** | 0.72** | 0.92** |
| Met | | | | | | | | | - | 0.71** | 0.62** | 0.76** | 0.68** |
| Phe | | | | | | | | | | - | 0.89** | 0.80** | 0.88** |
| Thr | | | | | | | | | | | - | 0.83** | 0.93** |
| Trp | | | | | | | | | | | | - | 0.81** |

*p<0.05, **p<0.01.

**Table 3.** Prediction equations for basal endogenous losses of crude protein (CP) and amino acids (g/kg dry matter intake).

| Item | Intercept | Independent variable[1] | | Statistical parameter | | |
|---|---|---|---|---|---|---|
| | | IBW | FI:MFI | RMSE[2] | $R^2$ | p-value |
| CP | 47.5 | $-8.09 \times 10^{-2}$ | –8.83 | 5.27 | 0.32 | 0.011 |
| SE[3] | 9.79 | $3.89 \times 10^{-2}$ | 2.96 | | | |
| p-value | < 0.001 | 0.048 | 0.007 | | | |
| Arg | 0.956 | $-1.56 \times 10^{-3}$ | –0.129 | 0.215 | 0.11 | 0.161 |
| SE | 0.250 | $1.45 \times 10^{-3}$ | 0.074 | | | |
| p-value | < 0.001 | 0.290 | 0.093 | | | |
| His | 0.368 | $-6.82 \times 10^{-4}$ | –0.053 | 0.055 | 0.25 | 0.012 |
| SE | 0.064 | $3.72 \times 10^{-4}$ | 0.019 | | | |
| p-value | < 0.001 | 0.076 | 0.010 | | | |
| Ile | 0.796 | $-7.95 \times 10^{-4}$ | –0.143 | 0.135 | 0.24 | 0.014 |
| SE | 0.157 | $9.09 \times 10^{-4}$ | 0.047 | | | |
| p-value | < 0.001 | 0.388 | 0.004 | | | |
| Leu | 1.14 | $-1.82 \times 10^{-3}$ | –0.161 | 0.213 | 0.16 | 0.066 |
| SE | 0.248 | $1.44 \times 10^{-3}$ | 0.074 | | | |
| p-value | < 0.001 | 0.217 | 0.037 | | | |
| Lys | 0.979 | $-1.00 \times 10^{-3}$ | –0.174 | 0.164 | 0.24 | 0.014 |
| SE | 0.190 | $1.10 \times 10^{-3}$ | 0.057 | | | |

Continues

**Table 3.** Continued

| Item | Intercept | Independent variable[1] | | Statistical parameter | | |
|---|---|---|---|---|---|---|
| | | IBW | FI:MFI | RMSE[2] | $R^2$ | p-value |
| p-value | < 0.001 | 0.370 | 0.005 | | | |
| Met | 0.330 | $-9.38 \times 10^{-4}$ | –0.045 | 0.115 | 0.08 | 0.299 |
| SE | 0.134 | $7.77 \times 10^{-4}$ | 0.040 | | | |
| p-value | 0.020 | 0.237 | 0.269 | | | |
| Phe | 0.725 | $-7.18 \times 10^{-4}$ | –0.109 | 0.124 | 0.18 | 0.044 |
| SE | 0.144 | $8.37 \times 10^{-4}$ | 0.043 | | | |
| p-value | < 0.001 | 0.398 | 0.016 | | | |
| Thr | 1.09 | $-1.82 \times 10^{-3}$ | –0.153 | 0.145 | 0.28 | 0.007 |
| SE | 0.169 | $9.82 \times 10^{-4}$ | 0.050 | | | |
| p-value | < 0.001 | 0.073 | 0.005 | | | |
| Trp | 0.552 | $-1.11 \times 10^{-3}$ | –0.120 | 0.059 | 0.47 | 0.002 |
| SE | 0.101 | $5.05 \times 10^{-4}$ | 0.030 | | | |
| p-value | < 0.001 | 0.041 | 0.001 | | | |
| Val | 1.15 | $-2.24 \times 10^{-3}$ | –0.182 | 0.179 | 0.27 | 0.008 |
| SE | 0.209 | $1.21 \times 10^{-3}$ | 0.062 | | | |
| p-value | < 0.001 | 0.074 | 0.006 | | | |

[1]IBW = initial body weight (kg); FI:MFI = feed intake per maintenance feed intake based on energy concentration. [2]RMSE = root mean square error. [3]SE = standard error.

## Discussion

To measure ileal endogenous flow of CP and AA, researchers used the N-free diet method, highly digestible N sources, or regression techniques (Jansman *et al*., 2002; Stein *et al*., 2007). However, the values for BEL of CP and AA were different among experimental methods (Jansman *et al*., 2002). In the present work, we used data from experiments employing N-free diets.

All mean values for BEL of CP and AA were fairly comparable to the data in NRC (2012) and had relatively high variability (Table 1). The ratios of BEL of AA to BEL of Lys in this work are fairly in agreement with previously reported data (Jansman *et al*., 2002; NRC, 2012). Høøk Presto *et al*. (2010) also suggested that AA composition (expressed in ratio of CP) of endogenous flow was quite consistent.

Hess and Sève (1999) suggested that BEL of CP and some AA (g/kg DMI) increased when feeding level was decreased in 45 kg pigs but not in 77 kg pigs. In a study by Moter and Stein (2004), the negative association between feeding level and BEL of CP and AA (g/kg DMI) was very clearly demonstrated. The clarity of response in the later study appears to be due to the larger range of feed intake, the higher number of observations, or both compared with the study by Hess and Sève (1999). Thus, feeding levels in a wide range apparently affect BEL of CP and AA (g/kg DMI). However, feeding level is very positively correlated with BW. “Feed intake per maintenance feed intake based on energy concentration” employed in the present work represents the amount of feed intake independent from IBW. In many AA digestibility experiments, feed allowance was 3 times the maintenance energy requirements (i.e., 3 FI:MFI). Because a heavier pig needs greater energy quantity for maintenance than a lighter pig, feed allowance for a heavier pig is more than for a lighter pig. In the present work, we tried to remove the effect of BW from the effects of feed intake on BEL of CP and AA by using the concept of FI:MFI. The lack of association between BW and BEL of CP and AA may be due to the large variation in experimental periods among observations or by the potential carryover effect of experimental diets consumed before the N-free diet.

Prediction equations for estimating BEL of CP and AA (g/kg DMI) were determined by IBW and FI:MFI (Table 3). The square of IBW, final BW, the square of final BW, mean BW, the square of mean BW, experimental period and dietary fiber concentration were also used to generate prediction equations, but these variables were not included in the final model due to the lack of significance. Thus, IBW and FI:MFI were used in the prediction equations. Except prediction equations for BEL of Arg, Leu, and Met, p-values of all equations were less than 0.05. Prediction equations for BEL of Trp had the greatest $R^2$ and lowest p-value ($R^2 = 0.47$; $p = 0.002$, respectively). The $R^2$-values of other prediction equations were relatively low, which may be due to the large variation in the estimated values among experiments and the error associated with AA and index (e.g., Cr) analysis or ileal digesta sampling procedure. Initial BW and FI:MFI were negatively correlated with BEL of CP and most indispensable AA in agreement with previous studies (Hess and Sève, 1999; Moter and Stein, 2004; Høøk Presto *et al*., 2010).

Basal endogenous losses of CP and AA may be estimated using prediction equations proposed in this study. More research is needed to confirm and improve the accuracy of the prediction equations.

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