Animal Feed Science and Technology 181 (2013) 80–86

Contents lists available at SciVerse ScienceDirect

Animal Feed Science and Technology

journal homepage: www.elsevier.com/locate/anifeedsci

Comparative amino acid digestibility in US blood products fed to weanling pigs

F.N. Almeida[a], J.K. Htoo[b], J. Thomson[c], H.H. Stein[a,*]

[a] Department of Animal Sciences, University of Illinois, Urbana, IL 61801, USA
[b] Evonik Industries AG, Hanau 63457, Germany
[c] Evonik Degussa Corporation, Kennesaw, GA 30144, USA

ARTICLE INFO

Article history:
Received 29 October 2012
Received in revised form 25 February 2013
Accepted 8 March 2013

Keywords:
Amino acids
Blood cells
Blood meal
Blood plasma
Digestibility
Pigs

ABSTRACT

Blood products are commonly used in diets for weanling pigs, but the different processing techniques that are used in the production of different blood products may result in differences in amino acid (AA) digestibility among products. There are, however, no comparative data on the standardized ileal digestibility (SID) of AA among different blood products when fed to weanling pigs. Thus, the objective of this experiment was to compare values for the SID of crude protein (CP) and AA in spray-dried animal blood (SDAB), spray-dried blood cells (SDBC), spray-dried plasma protein (SDPP), avian blood meal (ABM), and in porcine blood meal (PBM), when fed to weanling pigs. Seven weanling barrows (initial body weight: 11.5 ± 1.1 kg) were equipped with a T-cannula in the distal ileum and allotted to a 7×7 Latin Square design with 7 diets and 7 periods in each square. One of the diets was based on casein, and 5 diets were based on a mixture of casein and each blood product. A nitrogen-free diet was used to measure basal endogenous losses of AA and CP. The SID of CP in SDAB, SDBC, and SDPP were greater ($P<0.01$) than the SID of CP in ABM and PBM (1.040, 0.945, 0.995, 0.704, and 0.689, respectively). The SID of lysine was also greater ($P<0.01$) in SDAB (0.998), SDBC (0.976), and SDPP (0.981) than in ABM (0.740) and in PBM (0.786), but the SID of lysine in ABM was not different ($P>0.05$) from the SID of lysine in PBM. The mean SID of indispensable AA was greater ($P<0.01$) in SDAB, SDBC, and SDPP than in ABM and in PBM. The mean SID of total AA was also greater ($P<0.01$) in SDAB, SDBC, and SDPP than in ABM and in PBM. In conclusion, the SID of AA in SDAB, SDBC, and SDPP is greater than the SID of AA in ABM and PBM, which indicates that inclusion of spray dried blood products in diets to weanling pigs may be preferred over inclusion of blood meal. No differences exist in the SID of AA between blood meal from avian or porcine species when fed to weanling pigs.

1. Introduction

The US slaughter industry produces blood products that may be used in diets for weanling pigs because of the high nutritional qualities of blood protein (DeRouchey et al., 2002). Variations in performance of pigs fed blood products, however, have been observed (Steidinger et al., 2000). Although rich in crude protein (CP) and amino acids (AA), the quality of blood

Abbreviations: AA, amino acids; ABM, avian blood meal; AID, coefficient of ileal apparent digestibility; CP, crude protein; PBM, porcine blood meal; SDAB, spray dried animal blood; SDBC, spray dried blood cells; SDPP, spray dried plasma protein; SID, coefficient of ileal standardized digestibility.

* Corresponding author. Tel.: +1 217 333 0013; fax: +1 217 333 7088.
E-mail address: hstein@illinois.edu (H.H. Stein).

0377-8401/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.anifeedsci.2013.03.002

products may be affected by processing techniques (Meeker, 2009), which include the application of heat. If products are over-heated, Maillard reactions occur, thus, potentially decreasing the digestibility of AA, especially lysine (Nursten, 2005).

Spray-dried animal blood (SDAB) is obtained from whole blood collected from slaughtered animals and an anticoagulant is added to the blood at the time of collection (Ockerman and Hansen, 2000). The spray drying process is characterized by an average inlet temperature of 225°C and a relatively low outlet temperature of less than 70°C (Ockerman and Hansen, 2000). Spray-dried blood cells (SDBC) and spray-dried plasma protein (SDPP) are also manufactured from blood that is collected from animals at slaughter plants, and sodium citrate is added as an anticoagulant before the blood is centrifuged and blood cells are separated from plasma. Each fraction is then spray dried, yielding SDBC and SDPP, respectively (Ockerman and Hansen, 2000; vanDijk et al., 2001). Blood meal is produced by drying whole blood using flash driers, roller driers or drum driers. The process involves several steps including decantation, cooking, pressing, drying, and grinding. Moisture is removed in the cooking process and dryers are used to bring the product to the desired dry matter. The drying process may affect the nutritional quality of blood meal because it may lead to the condensation of lysine with reducing sugars through the Maillard reactions, and thus decrease the availability (*i.e.*, use of lysine for protein synthesis) of lysine to pigs (Bellaver, 2005).

Because of the different processing techniques that are used in production of the blood products, the AA digestibility among blood products may be different. For example, it has been demonstrated that the digestibility of N in 20 sources of blood meal fed to rats is greatly affected by a combination of type of dryer, temperature in the drier, and time in the drier (Moughan et al., 1999). In that experiment the N digestibility coefficient in blood meal that was batch-dried for 210 min at 150°C was 170 compared with 950 in blood meal that was spray-dried for 30 s at 95°C. There are, however, no comparative data on the AA digestibility in different blood products produced in the US when fed to weanling pigs. Thus, the objectives of the present experiment were to determine the apparent ileal digestibility (AID) and the standardized ileal digestibility (SID) of CP and AA in SDAB, SDBC, SDPP, and 2 sources of blood meal when fed to weanling pigs.

2. Materials and methods

The protocol for the experiment was reviewed and approved by the Institutional Animal Care and Use Committee at the University of Illinois. The experiment was conducted at the Swine Research Center at the University of Illinois. Pigs were the offspring of G-performer boars mated to F-25 females (Genetiporc, Alexandria, MN, USA). Blood products used in this experiment included SDAB, SDBC, and SDPP, which were sourced from APC Inc., Ankeny, IA, USA, flash dried avian blood meal (ABM) that was sourced from Griffin Industries LLC, Cold Spring, KY, USA, and porcine blood meal (PBM) that was sourced from Consumers Supply Distributing Co., North Sioux City, SD, USA; casein was procured from International Ingredients Inc., St. Louis, MO, USA (Table 1).

2.1. Animals, diets, and experimental design

Seven weanling barrows (average initial body weight: 11.5 ± 1.1 kg) were equipped with a T-cannula in the distal ileum and allotted to a 7 × 7 Latin square design with 7 diets and 7 periods in each square. Pigs were housed in individual pens (1.2 m × 1.5 m) in an environmentally controlled room (27°C, 76% humidity). A feeder and a nipple drinker were installed in each pen. The average final body weight at the end of the experiment was 17.5 kg ± 1.5 kg.

Seven diets were formulated (Tables 2 and 3). The first diet, which contained casein as the only source of CP and AA, was used to determine the AID and SID of CP and AA in casein and to allow the calculation of AID and SID of CP and AA in blood products by the difference procedure (Fan and Sauer, 1995). Five diets were based on a mixture of casein and each blood product. The final diet was a nitrogen-free diet that was used to measure basal endogenous losses of AA and CP at the ileal level. Vitamins and minerals were included in all diets to meet or exceed current requirement estimates (NRC, 1998). All diets also contained 4 g/kg of chromic oxide as an indigestible marker.

2.2. Feeding and sample collection

Pigs were fed once daily at a level of 3 times the daily maintenance energy requirement, and water was available at all times throughout the experiment. Pig weights were recorded at the beginning of each period and the amount of feed supplied each day (d) was also recorded. The initial 5 d of each period were considered an adaptation period to the diet. Ileal digesta (approximately 30% of the daily flow) were collected for 8 h on d 6 and 7 using standard operating procedures (Almeida et al., 2011).

2.3. Sample analyses and data processing

Digesta samples were lyophilized and ground to pass a 2 mm screen prior to chemical analysis. Diets, ingredients, and ileal samples were analyzed for AA by ion-exchange chromatography with postcolumn derivatization with ninhydrin. Amino acids were oxidized with performic acid, which was neutralized with Na metabisulfite (Llames and Fontaine, 1994; Commission Directive, 1998). Amino acids were liberated from the protein by hydrolysis with 6 *N* HCL for 24 h at 110°C and quantified with the internal standard (Norleucine)by measuring the absorption of reaction products with ninhydrin at

Table 1
Analyzed nutrient composition of ingredients (g/kg, as-fed basis unless otherwise indicated).

Item	Ingredient[a]					
	Casein	SDAB	SDBC	SDPP	ABM	PBM
Dry matter	924	929	933	913	903	906
Gross energy(MJ/kg)	19.2	21.6	22.2	19.9	22.1	22.1
Fat[b]	–	9	12	69	37	28
Crude protein	809	894	926	770	884	946
Lysine:CP ratio[c]	0.082	0.092	0.096	0.090	0.085	0.087
Ash	44	42	25	81	18	14
Indispensable amino acid						
Arginine	17.8	35.7	34.2	43.4	44.7	38.0
Histidine	22.1	52.9	61.7	26.5	49.7	71.3
Isoleucine	45.9	6.9	2.8	24.4	36.5	5.5
Leucine	78.5	113.7	126.2	76.4	96.0	127.9
Lysine	66.5	82.6	88.8	69.5	74.7	82.4
Methionine	22.6	11.4	12.9	7.6	10.9	7.0
Phenylalanine	35.6	65.2	72.5	43.7	54.2	64.1
Threonine	35.8	44.6	42.9	45.8	42.0	29.3
Tryptophan	8.1	15.2	15.8	13.6	17.8	15.3
Valine	58.1	75.4	83.5	51.6	58.0	84.6
Dispensable amino acid						
Alanine	29.7	72.5	82.6	42.3	66.0	77.0
Aspartic acid	64.1	91.9	96.2	77.0	80.5	110.4
Cysteine	4.8	8.8	4.4	24.9	12.5	6.0
Glutamic acid	175.2	78.9	72.8	105.2	84.9	76.1
Glycine	21.1	37.4	40.6	27.6	32.5	44.8
Proline	84.8	34.4	33.5	42.9	34.5	33.3
Serine	45.6	46.5	45.8	45.3	36.2	40.6

[a] Spray dried animal blood (SDAB), spray dried blood cells (SDBC), and spray dried plasma protein (SDPP) were sourced from APC Inc., Ankeny, IA, USA; avian blood meal (ABM) was sourced from Griffin Industries LLC, Cold Spring, KY, USA; porcine blood meal (PBM) was sourced from Consumers Supply Distributing Co., North Sioux City, SD, USA; casein was sourced from International Ingredients Inc., St. Louis, MO, USA.
[b] Fat = acid hydrolyzed ether extract.
[c] Calculated by expressing the concentration of lysine in each ingredient as ratio of the concentration of CP and given as a fraction of 1 (Stein et al., 2009).

Table 2
Ingredient composition of experimental diets (g/kg, as-fed basis).

Ingredient	Diet[a]						
	SDAB	SDBC	SDPP	ABM	PBM	Casein	Nitrogen-free
Casein	90.0	90.0	90.0	90.0	90.0	180.0	–
Blood product	90.0	90.0	90.0	90.0	90.0	–	–
Maize starch	340.0	340.0	343.0	340.0	340.0	342.0	686.0
Lactose	200.0	200.0	200.0	200.0	200.0	200.0	–
Sucrose	150.0	150.0	150.0	150.0	150.0	150.0	200.0
Soybean oil	50.0	50.0	50.0	50.0	50.0	50.0	40.0
Solkafloc[b]	40.0	40.0	40.0	40.0	40.0	40.0	30.0
Monocalcium phosphate	12.0	12.0	6.0	12.0	12.0	10.0	–
Dicalcium phosphate	–	–	–	–	–	–	20.0
Limestone	12.0	12.0	15.0	12.0	12.0	12.0	8.0
Chromic oxide	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Magnesium oxide	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Potassium carbonate	4.0	4.0	4.0	4.0	4.0	4.0	4.0
NaCl	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Vitamin-mineral premix[c]	3.0	3.0	3.0	3.0	3.0	3.0	3.0

[a] Spray dried animal blood (SDAB), spray dried blood cells (SDBC), and spray dried plasma protein (SDPP) were sourced from APC Inc., Ankeny, IA, USA; avian blood meal (ABM) was sourced from Griffin Industries LLC, Cold Spring, KY, USA; porcine blood meal (PBM) was sourced from Consumers Supply Distributing Co., North Sioux City, SD, USA; casein was sourced from International Ingredients Inc., St. Louis, MO, USA.
[b] Fiber Sales and Development Corp., Urbana, OH, USA.
[c] Provided the following quantities of vitamins and micro minerals per kilogram of complete diet: Vitamin A as retinyl acetate, 11,128 IU; vitamin D_3 as cholecalciferol, 2204 IU; vitamin E as DL-alpha tocopheryl acetate, 66 IU; vitamin K as menadionenicotinamide bisulfite, 1.42 mg; thiamin as thiamine mononitrate, 0.24 mg; riboflavin, 6.58 mg; pyridoxine as pyridoxine hydrochloride, 0.24 mg; vitamin B_{12}, 0.03 mg; D-pantothenic acid as D-calcium pantothenate, 23.5 mg; niacin as nicotinamide and nicotinic acid, 44 mg; folic acid, 1.58 mg; biotin, 0.44 mg; Cu, 10 mg as copper sulfate; Fe, 125 mg as iron sulfate; I, 1.26 mg as potassium iodate; Mn, 60 mg as manganese sulfate; Se, 0.3 mg as sodium selenite; and Zn, 100 mg as zinc oxide.

Table 3
Analyzed nutrient composition of experimental diets (g/kg, as-fed basis).

Item	Diet[a]						
	SDAB	SDBC	SDPP	ABM	PBM	Casein	Nitrogen-free
Dry matter	949.0	952.0	951.0	946.0	944.0	952.0	926.0
Crude protein	150.0	151.0	142.0	154.0	158.0	135.0	2.0
Indispensable amino acid							
Arginine	4.8	4.5	5.5	5.6	4.9	3.1	–
Histidine	6.8	7.4	4.4	6.4	8.4	3.9	–
Isoleucine	4.8	4.3	6.5	7.6	4.7	8.3	–
Leucine	17.6	18.2	14.2	15.9	18.6	14.1	–
Lysine	13.5	13.7	12.4	12.8	13.4	11.9	–
Methionine	3.1	3.1	2.8	3.0	2.5	3.9	–
Phenylalanine	9.1	9.5	7.3	8.2	9.0	6.4	–
Threonine	7.2	7.0	7.6	7.0	5.9	6.5	–
Tryptophan	1.8	1.9	1.9	2.3	2.1	1.4	–
Valine	12.3	12.6	10.1	10.6	13.0	10.4	–
Dispensable amino acid							
Alanine	9.4	10.0	6.6	8.8	9.4	5.4	–
Aspartic acid	14.2	14.3	13.1	13.2	15.8	11.6	–
Cysteine	1.2	0.8	2.7	1.6	1.0	0.9	–
Glutamic acid	23.1	22.0	26.0	23.9	23.0	31.5	–
Glycine	5.3	5.5	4.5	4.9	6.0	3.8	–
Proline	10.7	10.4	11.7	10.8	10.6	15.1	–
Serine	8.3	8.1	8.4	7.5	7.7	8.1	–

[a] Spray dried animal blood (SDAB), spray dried blood cells (SDBC), and spray dried plasma protein (SDPP) were sourced from APC Inc., Ankeny, IA, USA; avian blood meal (ABM) was sourced from Griffin Industries LLC, Cold Spring, KY, USA; porcine blood meal (PBM) was sourced from Consumers Supply Distributing Co., North Sioux City, SD, USA; casein was sourced from International Ingredients Inc., St. Louis, MO, USA.

570 nm. Tryptophan was determined by HPLC with fluorescence detection (extinction 280 nm, emission 356 nm), after alkaline hydrolysis with barium hydroxide octahydrate for 20 h at 110°C (Commission Directive, 2000). Diets, ingredients, and ileal samples were also analyzed for dry matter by drying in an oven at 103°C for 4 h (method 935.29; AOAC International, 2007), and for CP following the Dumas procedure (method 968.06; AOAC International, 2007). Diets and ileal samples were analyzed for chromium (method 990.08; AOAC International, 2007). Ingredients were also analyzed for ash (method 942.05; AOAC International, 2007), acid hydrolyzed ether extract (method 954.02; AOAC International, 2007), and for gross energy using a bomb calorimeter (Model 6300, Parr Instruments, Moline, IL, USA).

Coefficients of apparent ileal digestibility of CP and AA in each diet were calculated as described by Baker et al. (2010). The basal endogenous flow to the distal ileum of each AA was determined based on the flow obtained after feeding the N-free diet. By correcting the AID values for the ileal endogenous losses of CP and each AA, SID values for CP and AA in each diet were calculated (Baker et al., 2010) By subtracting the contribution of casein to the concentration of digestible CP and AA in the diets containing casein and each blood product, the digestibility of CP and AA in each blood product was calculated using the difference procedure (Fan and Sauer, 1995).

2.4. Statistical analysis

Data were analyzed using the Proc MIXED procedure of SAS (SAS Institute Inc., Cary, NC). The Univariate procedure was used to detect outliers. Observations that were more than 3 standard deviations from the treatment mean were considered outliers. Two outliers for SDBC and 1 outlier for PBM were observed and subsequently removed from the data set. The model included diet as the fixed effect, whereas pig and period were random effects. For all calculations, pig was the experimental unit and an α level of 0.05 was used to assess differences among means.

3. Results

All pigs remained healthy and easily consumed their diets throughout the experiment. Concentrations of dry matter and crude protein in SDBC, SDPP, ABM, and PBM (Table 1) are in close agreement with previously reported values (DeRouchey et al., 2002, 2003; Meeker, 2009; NSNG, 2010). Likewise, the concentrations of all dispensable AA in SDBC and in the 2 sources of blood meal used in this experiment were in agreement with values that were reported by NRC (1998) and by DeRouchey et al. (2002).

The AID (Table 4) of CP in SDAB was greater ($P<0.01$) than the AID of CP in ABM and PBM, but not different ($P>0.05$) from the AID of CP in SDBC, SDPP, and casein. The AID of all AA, except isoleucine, cysteine, and glycine, were greater ($P<0.05$) in SDAB, SDBC, SDPP, and casein than in ABM and PBM. The AID of lysine in SDAB, SDBC, SDPP, and casein was greater ($P<0.01$) than the AID of lysine in ABM and in PBM (0.952, 0.940, 0.941, 0.926, 0.702, and 0.751, respectively), but the AID of lysine in ABM was not different ($P>0.05$) from the AID of lysine in PBM. The mean AID of indispensable AA and the mean AID of total AA were also greater ($P<0.01$) in SDAB, SDBC, SDPP, and casein than in ABM and PBM.

Table 4
Coefficient of apparent ileal digestibility of crude protein and amino acids in US blood products fed to weanling pigs[a].

Item	Blood products[b]						SEM[c]	P-value
	SDAB	SDBC	SDPP	ABM	PBM	Casein		
Crude protein	0.881w	0.813w	0.853w	0.585x	0.575x	0.808w	0.0367	<0.01
Indispensable amino acid								
Arginine	0.918w	0.859wx	0.924w	0.675y	0.603y	0.775x	0.0331	<0.01
Histidine	0.973w	0.957w	0.928wx	0.656z	0.754y	0.870x	0.0311	<0.01
Isoleucine	0.642x	0.015y	0.882w	0.604x	0.110y	0.916w	0.0770	<0.01
Leucine	0.953w	0.939w	0.925w	0.625y	0.727x	0.930w	0.0271	<0.01
Lysine	0.952w	0.940w	0.941w	0.702x	0.751x	0.926w	0.0245	<0.01
Methionine	0.945w	0.914w	0.886w	0.672x	0.582x	0.946w	0.0331	<0.01
Phenylalanine	0.948w	0.935w	0.918w	0.623y	0.721x	0.915w	0.0267	<0.01
Threonine	0.886w	0.819w	0.858w	0.581x	0.494x	0.785w	0.0440	<0.01
Tryptophan	0.868w	0.842w	0.878w	0.629x	0.700x	0.808w	0.0297	<0.01
Valine	0.947w	0.927w	0.908w	0.603y	0.717x	0.907w	0.0260	<0.01
Mean	0.935w	0.911w	0.908w	0.639x	0.699x	0.902w	0.0258	<0.01
Dispensable amino acid								
Alanine	0.940w	0.928w	0.891wx	0.626y	0.701y	0.827x	0.0273	<0.01
Aspartic acid	0.940w	0.899wx	0.886wx	0.613y	0.686y	0.817x	0.0312	<0.01
Cysteine	0.776wx	0.328yz	0.896w	0.509xyz	0.258z	0.587xy	0.0949	<0.01
Glutamic acid	0.947w	0.862w	0.916w	0.613x	0.624x	0.866w	0.0450	<0.01
Glycine	0.733w	0.623wx	0.558wx	0.449x	0.411x	0.583wx	0.0104	<0.01
Serine	0.923w	0.855wx	0.877wx	0.592y	0.588y	0.823x	0.0302	<0.01
Mean	0.876w	0.749x	0.837wx	0.567y	0.545y	0.750x	0.0411	<0.01
Total amino acids	0.906w	0.830w	0.873w	0.603x	0.622b	0.826w	0.0314	<0.01

w–z means within a row with different superscript letters are different (P<0.05).

[a] Data are means of 7 observations per treatment.

[b] Spray dried animal blood (SDAB), spray dried blood cells (SDBC), and spray dried plasma protein (SDPP) were sourced from APC Inc., Ankeny, IA, USA; avian blood meal (ABM) was sourced from Griffin Industries LLC, Cold Spring, KY, USA; porcine blood meal (PBM) was sourced from Consumers Supply Distributing Co., North Sioux City, SD, USA; casein was sourced from International Ingredients Inc., St. Louis, MO, USA.

[c] SEM = standard error of the means.

The SID (Table 5) of CP in SDAB, SDBC, SDPP and casein were greater (P<0.01) than the SID of CP in ABM and PBM (1.040, 0.945, 0.995, 0.965, 0.704, and 0.689, respectively). The SID of lysine was also greater (P<0.01) in SDAB (0.998), SDBC (0.976), SDPP (0.981), and casein (0.970) than in ABM (0.740) and in PBM (0.786), but the SID of lysine in ABM was not different (P>0.05) from the SID of lysine in PBM. Similarly, the mean SID of indispensable AA was greater (P<0.01) in SDAB, SDBC, SDPP, and casein than in ABM and in PBM. The mean SID of total AA was also greater (P<0.01) in SDAB, SDBC, SDPP, and casein than in ABM and in PBM. The SID for most AA in SDAB was close to 1.0, with the exceptions of arginine, isoleucine, and threonine, which had SID values slightly above 1.0. The SID of histidine, leucine, phenylalanine, and valine were less (P<0.01) in ABM than in PBM. However, for most AA, no differences in the SID between ABM and PBM were observed.

4. Discussion

The AID of CP for casein and SDPP are in agreement with values reported by Mateo and Stein (2007) and Cervantes-Pahm and Stein (2010). The reason for the differences observed between the AID of the 2 blood meals and the spray dried blood products may be that the degree of heat damage during processing of ABM and PBM is greater than that during processing of SDAB, SDBC or SDPP. We are not aware of the specific temperatures and drying times of the blood products used in this experiment, but it has been reported that commercial blood meal sources are exposed to drying times that range from 0.5 to 240 min under temperatures varying from 92 to 500°C (Moughan et al., 1999). Spray dried blood products, however, are exposed to temperatures ranging from 200 to 250°C (Ockerman and Hansen, 2000) but for short periods of time, which may be advantageous compared with other drying methods (Torrallardona, 2010). Processing of feed proteins involving heat may cause Maillard reactions, which in its initial stage, involves the reaction between the amino group of lysine and the carbonyl group of a reducing sugar (Nursten, 2005). Therefore, lysine that reacts with reducing sugars is unavailable to pigs, and thus, the digestibility of lysine is reduced (González-Vega et al., 2011). The lysine:CP ratio may be used as an indicator of heat damaged proteins because the lysine concentration in heat damaged feed ingredients is reduced whereas the CP concentration remains constant (Kim et al., 2012). Thus, the relatively lower values for the lysine:CP ratio in ABM and PBM (0.085 and 0.087, respectively) compared with the lysine:CP ratio in SDAB (0.092), SDBC (0.096), and SDPP (0.090) may also indicate that the degree of heat damage in ABM and PBM was indeed greater than that of SDAB, SDBC, or SDPP. The lysine:CP ratio in spray-dried bovine blood meal (0.129) is also greater than the lysine:CP ratio in flash-dried bovine blood meal (0.085) indicating that spray drying causes less heat damage than flash-drying, in which blood is dried for a relatively short time (3.5 min) under temperatures that vary from 260 to 427°C (Kramer et al., 1978; Kats et al., 1994). Among 20 sources of blood meal, it was observed that the N digestibility coefficient was much lower in 7 samples (511) with an average lysine:CP ratio of 0.081than the N digestibility coefficient in 7 samples (896) with an average lysine:CP ratio of 0.084 (Moughan et al., 1999).

Table 5
Coefficient of standardized ileal digestibility of crude protein and amino acids in US blood products fed to weanling pigs[a,b].

Item	Blood products[c]						SEM[d]	P-value
	SDAB	SDBC	SDPP	ABM	PBM	Casein		
Crude protein	1.040w	0.945w	0.995w	0.704x	0.689x	0.965w	0.0332	<0.01
Indispensable amino acid								
Arginine	1.040w	0.978w	1.010w	0.756x	0.702x	0.993w	0.0301	<0.01
Histidine	1.010w	0.983w	0.983w	0.686y	0.775x	0.940w	0.0308	<0.01
Isoleucine	1.100w	0.904x	0.985wx	0.672y	0.485z	0.974wxy	0.0408	<0.01
Leucine	0.999w	0.977w	0.981w	0.670y	0.761x	0.987w	0.0267	<0.01
Lysine	0.998w	0.976w	0.981w	0.740x	0.786x	0.970w	0.0238	<0.01
Methionine	1.021w	0.978w	0.978w	0.740x	0.701x	0.982w	0.0326	<0.01
Phenylalanine	0.999w	0.977w	0.979w	0.673y	0.764x	0.994w	0.0262	<0.01
Threonine	1.038w	0.962w	0.975w	0.717x	0.686x	0.944w	0.0421	<0.01
Tryptophan	0.990w	0.938w	0.967w	0.693x	0.770x	0.961w	0.0275	<0.01
Valine	1.005w	0.975w	0.977w	0.665y	0.760x	0.973w	0.0254	<0.01
Mean	1.005w	0.970w	0.977w	0.697x	0.753x	0.978w	0.0250	<0.01
Dispensable amino acid								
Alanine	1.010w	0.983w	0.989w	0.688x	0.755x	0.969w	0.0265	<0.01
Aspartic acid	1.024w	0.970wx	0.965wx	0.691y	0.743y	0.917x	0.0303	<0.01
Cysteine	1.042w	0.803wx	0.970w	0.650xy	0.551y	0.950w	0.0838	<0.01
Glutamic acid	1.074w	0.972x	0.981wx	0.694y	0.715y	0.908x	0.0392	<0.01
Glycine	1.093w	0.920wx	0.958wx	0.792xy	0.661y	1.134w	0.1000	<0.05
Serine	1.048w	0.971wx	0.980wx	0.722y	0.709y	0.934x	0.0284	<0.01
Mean	1.048w	0.936x	0.974wx	0.706y	0.689y	0.969wx	0.0362	<0.01
Total amino acids	1.027w	0.953w	0.976w	0.702x	0.721x	0.973w	0.0286	<0.01

w–z means within a row with different superscript letters are different (P<0.05).

[a] Data are means of 7 observations per treatment.

[b] Coefficients of ileal standardized digestibility were calculated by correcting coefficient of ileal digestibility values for the basal endogenous losses (g/kg of dry matter intake), which were determined by feeding pigs a N-free diet: crude protein, 22.40; arginine, 0.71; histidine, 0.28; isoleucine, 0.50; leucine, 0.85; lysine, 0.55; methionine, 0.15; phenylalanine, 0.53; threonine, 1.08; tryptophan, 0.22; valine, 0.71; alanine, 0.81; aspartic acid, 1.22; cysteine, 0.34; glutamic acid, 1.38; glycine, 2.20; proline, 4.61; and serine, 0.95.

[c] Spray dried animal blood (SDAB), spray dried blood cells (SDBC), and spray dried plasma protein (SDPP) were sourced from APC Inc., Ankeny, IA, USA; avian blood meal (ABM) was sourced from Griffin Industries LLC, Cold Spring, KY, USA; porcine blood meal (PBM) was sourced from Consumers Supply Distributing Co., North Sioux City, SD, USA; casein was sourced from International Ingredients Inc., St. Louis, MO, USA.

[d] SEM = standard error of the means.

Thus, it appears that lysine:CP is a valuable indicator of the nutritional quality of protein in feed ingredients. The current results support this hypothesis. Values for the AID of most AA in ABM and PBM used in this experiment were relatively lower compared with values for the AID of AA determined in 3 different sources of blood meal (Ravindran et al., 2005). This observation may also reflect the effects of heat damage during processing of blood meal, because the average lysine:CP ratio (0.086) in this experiment is less than that observed (0.103) by Ravindran et al. (2005).

Values for the SID of AA in SDPP are in agreement with previously reported values (Gottlob et al., 2006). To our knowledge, values for the SID of AA in SDAB fed to pigs have not been reported, but values for the SID of lysine determined in the present experiment for SDBC, SDPP, casein, ABM, and PBM are in close agreement with previously published values (Rayadurg, 2005; Cervantes-Pahm and Stein, 2010; NSNG, 2010).

Values for the SID of AA that are greater than 1.0 have been reported (Kadim et al., 2002; Adedokun et al., 2008), and it was suggested that the reason for such observations may be that the test ingredient has a low concentration of AA compared with the concentration of AA in the endogenous AA. However, that was not the case in the present experiment. Diets used in this experiment contained 90 g/kg casein and in poultry it has been observed that increasing levels of casein in diets from 0 to 150 g/kg linearly increases the endogenous AA flow in ileal digesta (Adedokun et al., 2007). An increase in endogenous AA will result in increased SID values. Thus, it is possible that the reason we observed values for SID above 1.0 may be a result of relatively high values for endogenous AA induced by the use of casein in diets. Nevertheless, data from this experiment clearly indicate that spray-dried blood products have SID values for AA that are close to 1.0.

Results from this experiment also indicated that the nutritional quality of blood meal manufactured from avian or porcine species is not different. This observation is in agreement with Kats et al. (1994) who observed no differences in performance of weanling pigs fed blood meals from different species.

5. Conclusions

In conclusion, the SID of AA in SDAB, SDBC, and SDPP is greater than the SID of AA in ABM and PBM, which indicates that inclusion of spray dried blood products in diets to weanling pigs may be preferred over inclusion of blood meal. No differences exist in the SID of AA between blood meal from avian or porcine species when fed to weanling pigs.

Acknowledgement

Financial support for this research from Evonik Industries AG, Hanau, Germany, is greatly appreciated.

References

Adedokun, S.A., Adeola, O., Parsons, C.M., Lilburn, M.S., Applegate, T.J., 2008. Standardized ileal amino acid digestibility of plant feedstuffs in broiler chickens and turkey poults using a nitrogen-free or casein diet. Poult. Sci. 87, 2535–2548.

Adedokun, S.A., Lilburn, M.S., Parsons, C.M., Adeola, O., Applegate, T.J., 2007. Effect of age and method on ileal endogenous amino acid flow in turkey poults. Poult. Sci. 86, 1948–1954.

Almeida, F.N., Petersen, G.I., Stein, H.H., 2011. Digestibility of amino acids in corn, corn coproducts, and bakery meal fed to growing pigs. J. Anim. Sci. 89, 4109–4115.

AOAC International, 2007. In: Hortwitz, W., Latimer Jr., G.W. (Eds.), Official Methods of Analysis of AOAC International. , 18th ed. AOAC International, Gaithersburg, MD, USA, Rev. 2.

Baker, K.M., Kim, B.G., Stein, H.H., 2010. Amino acid digestibility in conventional, high-protein, or low-oligosaccharide varieties of full-fat soybeans and in soybean meal by weanling pigs. Anim. Feed Sci. Technol. 162, 66–73.

Bellaver, C., 2005. Limitações e vantagens do uso de farinhas de origem animal naalimentação de suínos e de aves, www.cnpsa.embrapa.br/sgc/sgc_publicacoes/publicacao_u5u82m5u.pdf

Cervantes-Pahm, S.K., Stein, H.H., 2010. Ileal digestibility of amino acids in conventional, fermented, and enzyme-treated soybean meal and in soy protein isolate, fish meal, and casein fed to weanling pigs. J. Anim. Sci. 88, 2674–2683.

Commission Directive, 1998. Establishing community methods for 434 the determination of amino acids, crude oils and fats, andolaquindoxin feeding stuff and amending Directive 71/393/EEC, annex part A. Determination of Amino Acids. Offic. J. L257:14–23.

Commission Directive, 2000. Establishing community methods for the determination of vitamin A, vitamin E and tryptophan, annex part C. Determination of Tryptophan. Offic. J. L174:45–50.

DeRouchey, J.M., Tokach, M.D., Nelssen, J.L., Goodband, R.D., Dritz, S.S., Woodworth, J.C., James, B.W., 2002. Comparison of spray-dried blood meal and blood cells in diets for nursery pigs. J. Anim. Sci. 80, 2879–2886.

DeRouchey, J.M., Tokach, M.D., Nelssen, J.L., Goodband, R.D., Dritz, S.S., Woodworth, J.C., Webster, M.J., James, B.W., 2003. Effects of blood meal pH and irradiation on nursery pig performance. J. Anim. Sci. 81, 1013–1022.

Fan, M.Z., Sauer, W.C., 1995. Determination of apparent ileal amino acid digestibility in barley and canola meal for pigs with the direct, difference, and regression methods. J. Anim. Sci. 73, 2363–2374.

González-Vega, J.C., Kim, B.G., Htoo, J.K., Lemme, A., Stein, H.H., 2011. Amino acid digestibility in heated soybean meal fed to growing pigs. J. Anim. Sci. 89, 3617–3625.

Gottlob, R.O., DeRouchey, J.M., Tokach, M.D., Goodband, R.D., Dritz, S.S., Nelssen, J.L., Hastad, C.W., Knabe, D.A., 2006. Amino acid and energy digestibility of protein sources for growing pigs. J. Anim. Sci. 84, 1396–1402.

Kadim, I.T., Moughan, P.J., Ravindran, V., 2002. Ileal amino acid digestibility assay for the growing meat chicken – comparison of ileal and excreta amino acid digestibility in the chicken. Br. Poult. Sci. 43, 588–597.

Kats, L.J., Nelssen, J.L., Tokach, M.D., Goodband, R.D., Weeden, T.L., Dritz, S.S., Hansen, J.A., Friesen, K.G., 1994. The effects of spray-dried blood meal on growth performance of the early-weaned pig. J. Anim. Sci. 72, 2860–2869.

Kim, B.G., Kil, D.Y., Zhang, Y., Stein, H.H., 2012. Concentrations of analyzed or reactive lysine, but not crude protein, may predict the concentration of digestible lysine in distillers dried grains with solubles (DDGS) fed to pigs. J. Anim. Sci. 90, 3798–3808.

Kramer, S.L., Waibel, P.E., Behrends, B.R., El Kandelgy, S.M., 1978. Amino acids in commercially produced blood meals. J. Agric. Food Chem. 26, 979–981.

Llames, C.R., Fontaine, J., 1994. Determination of amino acids in feeds: Collaborative study. J. Assoc. Off. Anal. Chem. 77, 1362–1402.

Meeker, D.L., 2009. North American Rendering – processing high quality protein and fats for feed. R. Bras. Zootec. 38, 432–440.

NRC, 1998. Nutrient Requirements of Swine, 10th ed. NationalAcademy Press, Washington DC, USA.

NSNG, 2010. National Swine Nutrition Guide, 1st ed. US Pork Center of Excellence, Ames, IA, USA.

Nursten, H., 2005. The Maillard reaction. Chemistry, Biochemistry, and Implications. Royal Society of Chemistry, Cambridge, UK.

Mateo, C.D., Stein, H.H., 2007. Apparent and standardized ileal digestibility of amino acids in yeast extract and spray dried plasma protein by weanling pigs. Can. J. Anim. Sci. 87, 381–383.

Moughan, P.J., Dong, G.Z., Pearson, G., Wilkinson, B.H.P., 1999. Protein quality in blood meal: II. The effect of processing on in vivo nitrogen digestibility in rats, protein solubility and FDBN-available lysine. Anim. Feed Sci. Technol. 79, 309–320.

Ockerman, H.W., Hansen, C.L., 2000. Animal By-Product Processing and Utilization. CRC Press, Boca Raton, FL, USA.

Ravindran, V., Hew, L.I.L., Ravindran, G., Bryden, W.L., 2005. Apparent ileal digestibility of amino acids in dietary ingredients for broiler chickens. J. Anim. Sci. 81, 85–97.

Rayadurg, V., 2005.Factors affecting the nutrient digestibility in weanling and grower pigs. Ph.D. Dissertation, South Dakota State University, Brookings, USA.

Steidinger, M.U., Goodband, R.D., Tokach, M.D., Dritz, S.S., Nelssen, J.L., McKinney, L.J., Borg, B.S., Campbell, J.M., 2000. Effects of pellet conditioning temperatures on weanling pig performance. J. Anim. Sci. 78, 3014–3018.

Stein, H.H., Connot, S.P., Pedersen, C., 2009. Energy and nutrient digestibility in four sources of distillers dried grains with solubles produced from corn grown within a narrow geographical area and fed to growing pigs. Asian-Aust. J. Anim. Sci. 22, 1016–1025.

Torrallardona, D., 2010. Spray dried animal plasma as an alternative to antibiotics in weanling pigs: a review. Asian-Aust. J. Anim. Sci. 23, 131–148.

vanDijk, A.J., Everts, H., Nabuurs, M.J.A., Margry, R.J.C.F., Beynen, A.C., 2001. Growth performance of weanling pigs fed spray-dried animal plasma: a review. Livest. Prod. Sci. 68, 263–274.