Nutritional Value of Animal Proteins Fed to Pigs

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Summary

The most commonly used animal proteins in the swine feed industry are meat and bone meal and fish meal, which have a relatively high concentration of amino acids (AA) and also are excellent sources of digestible Ca and P. The concentration of bones in these products is reflected in the concentration of ash and the digestibility of P in fish meal and meat and bone meal is negatively correlated with the concentration of ash in the products. By-products of the poultry industry include chicken meal, poultry by product meal, and AV-E digest, which are often included in diets fed to weanling pigs, because these ingredients contribute to an increase in performance of newly weaned pigs. Hydrolyzed feather meal is also a by-product of the poultry industry that may be used in diets fed to growing finishing pigs. Hydrolyzed intestinal proteins have become available during recent years and are now often included as AA sources in dies fed to weanling pigs. Blood products, either ring dried, drum dried, or spray dried, are also valuable sources of AA, and the spray dried blood products have excellent digestibility values for AA and P. Co-products of the dairy industry includes dried whey powder and whey permeate. Unlike other feed ingredients of animal origin, whey powder and whey permeate are not rich in AA and they are primarily used in diets fed to weanling pigs as sources of lactose. However, whey powder and whey permeate also provide P with an excellent digestibility.

Introduction

Feed ingredients of animal origin have been used in diets fed to pigs as a source of AA, minerals, and vitamins from the earliest days of commercial pig production. However, after production of synthetic forms of all vitamins became possible and it was discovered that inorganic minerals and plant sources of proteins can cover the requirements of pigs for AA, Ca, and P, use of animal proteins no longer was a prerequisite for successful pig production. Animal proteins are, therefore, mainly used in diets fed to newly weaned pigs, who do not tolerate large quantities of soybean meal in the diets. However, many animal proteins may also be used in diets fed to older pigs, where they may supply easily digestible sources of AA, Ca, and P.

Historically, meat and bone meal and fish meal have been the most used animal proteins, but many other animal proteins are produced as by-products or co-products of the human food industry. Recently, several new products have become available as a result of difficulties for other industries in eliminating by-products in a cost-effective way. However, the increases in the costs of feed ingredients that have taken place during recent years makes processing of by-products from other industries more economical, which has resulted in several new products entering the marketplace. It is the objective of this contribution to provide an update on energy and nutrient digestibility of the feed ingredients of animal origin that are available to the feed industry.

Fish Meal

Fish meal is an animal protein that is used in diets fed to weanling pigs because of its high digestibility and favorable AA composition (Kim and Easter, 2001). However, quality of fish meal may vary according to the processing methods and the type of fish used to produce the meal (Stoner et al., 1990; Kim and Easter, 2001). Fish meal may be produced from whole fish or from a mixture of whole fish and fish by-products from the human food industry. The production of fillets from whole fish for human consumption leaves some soft tissue and the bones, which is not used in the human food industry, but can be used for fish meal production. In the production of fish oil, the oil is extracted using a mechanical extraction process and the partly de-oiled meal is subsequently used for fish meal production (AAFCO, 2011; Cho and Kim, 2011).

Different species of fish such as anchovy, herring, menhaden, and white fish may be used to produce fish meal (NRC, 1998) and the nutritional value of the fish meal depends on the species used to produce the meal as well as the drying temperature (Kim and Easter, 2001). Regardless of the species used, the quantity of bones included in fish meal is indicated by the concentration of ash in the meal. In meals with low concentrations of bones, the ash concentration is around 12%, but if there is a large concentration of bones in the meal, the concentration of ash can exceed 20%. The average concentration of ash in 6 sources of Select Menhaden fish meal that were procured by the University of Illinois from 2008 to 2012 is 19.3 ± 0.89% (Table 1) indicating that this source of fish meal contains relatively large quantities of fish bones. The concentration of CP in fish meal can also be used as a predictor of the amount of bones in the meal because the concentration of CP usually is reduced as the amount of bones in the meal is increased.

The best qualities of fish meal have CP concentrations close to 70%, but other qualities have concentrations of CP between 62 and 65% (Sauvant et al., 2004). The average CP concentration in 9 sources of Select Menhaden fish meal that were procured by the University of Illinois from 2008 to 2012 is 63.4 ± 1.27% (Table 1). Fish meal usually contains 9 – 10% fat, but because fish oil is mostly long-chained unsaturated fatty acids, an antioxidant is usually included in the meal to prevent oxidation of the oil.

Due to the high concentration of fat in fish meal, the apparent total tract digestibility (**ATTD**) of GE is relatively high and concentrations of DE and ME in Select Menhaden fish meal is 3,797 and 3,472 kcal/kg (as fed basis; average of 5 sources; Table 2). Thus concentrations of DE and ME in fish meal are slightly greater than in corn and soybean meal.

Fish meal is a rich source of AA that are relatively well digested by pigs. The average standardized ileal digestibility (**SID**) of indispensable AA is 86.9% and the SID of Lys, Met, Thr, and Trp is 86.1, 87.2, 84.7, and 89.9%, respectively. The concentration of P and Ca in fish meal is relatively high due to the inclusion of bones in the meal (Malde et al., 2009), and the P in fish meal has an average value for the standardized total tract digestibility (**STTD**) of 67.1%. For meat and bone meal, it has been reported that the ATTD of P is reduced as the concentration of ash increases because the digestibility of P from bone is less than the digestibility of P from soft tissue (Hua et al., 2005). It is possible, that increased concentrations of bone in fish meal also results in reduced digestibility of P, but this hypothesis has not been investigated. The calcium in fish bones is, however, well digested and the digestibility by pigs of Ca in fish bones is similar to that in calcium carbonate (Malde et al., 2009).

Fish meal is usually used in diets for weanling pigs because young pigs do not tolerate soybean protein in great quantities. In contrast, animal proteins are well tolerated and 5 to 10% fish meal is often used in diets fed to weanling pigs (Chiba, 2001; Cho and Kim, 2011). The G:F ratio increases linearly if fish meal is included in the diet (Bergstrom et al., 1997), which is likely a result of the relatively high DE and ME in fish meal.

Products of the Dairy Industry

As milk is processed for human consumption, several feed ingredients are produced from the part of the milk that is not used in the human food industry. Casein is a high protein product that is produced from defatted milk via enzyme or acid coagulation (AAFCO, 2011). Casein contains the majority of the proteins in milk and has a favorable AA composition (Table 1) and the AA are easily digested (Table 2) by pigs. However, due to the relatively high cost, casein is usually not used in commercial diets fed to pigs, but casein is often used in synthetic or semisynthetic diets used in research diets fed to pigs.

Whey is a co-product of the cheese manufacturing industry and if dried can be used in diets fed to weanling pigs as a source of lactose. Whey powder contains 65-70% lactose, 13-15% CP, and up to 15% ash. However, the proteins in whey powder may be extracted to produce whey protein concentration, which is used in the human food industry. The resulting de-proteinized whey is called whey permeate and contains 80 to 85% lactose and 5 to 15% ash (Nessmith et al., 1997b). If the ash is removed from whey permeate, a low-ash whey permeate, which contains 85-90% lactose, is produced (Kim et al., 2012).

The digestibility of energy in whey powder and whey permeate is greater than in a corn-soybean meal diet (Kim et al., 2012). The concentration of DE and ME in whey powder is greater than in whey permeate, but low-ash whey permeate has a concentration of DE and ME that is similar to that of whey powder (Table 2; Kim et al., 2012). The standardized total tract digestibility (STTD) of P in whey powder is not different from the STTD of P in whey permeate and the STTD of P in both of these ingredients is greater than 90% (Table 2).

Whey powder is an effective source of lactose in diets for weanling pigs (Cera et al., 1988), and whey powder supports weight gain of weanling pigs to the same extend as lactose (Mahan, 1993). However, whey permeate is as effective as a source of lactose as whey powder and may also be used in diets fed to weanling pigs (Nessmith et al., 1997a; Naranjo et al., 2010). Inclusion of 25% whey powder in a corn-soybean meal diet fed to weanling pigs increases weight gain during the initial 21 d post-weaning (Lepine et al., 1991) and it is common to include between 15 and 20% lactose in diets fed to pigs during the initial 2 weeks post weaning. The response to lactose is reduced in the later stages of the post-weaning period, and the optimum inclusion of lactose in week 3 and 4 post-weaning is 7.5% (Cromwell et al., 2008).

By-Products of the Poultry Industry

Chicken Meal and Poultry Byproduct Meal

Chicken meal (**CM**) and poultry by product meal (**PBM**) are protein ingredients that have a concentration of AA that is similar to that of fish meal (Table 3; Keegan et al., 2004). Poultry by-product meal is produced from the offal of carcasses of slaughtered poultry and includes feet, necks, undeveloped eggs, and intestines (AAFCO, 2011). Chicken meal is prepared from clean flesh and skin of chickens without or with bone derived from the whole carcass of poultry (AAFCO, 2011). However, the quality of CM and PBM depends on the quality of the rendered parts that are used in the production (Dong et al., 1993).

Chicken meal and PBM are often used in diets for pets and pigs as replacements for fish meal (Yamka et al., 2003; Keegan et al., 2004; Zier et al., 2004). Pigs fed diets containing PBM from d 0 to 28 post-weaning have growth performance that is not different from that of pigs fed fish meal, blood meal, and spray dried protein plasma (Keegan et al., 2004; Zier et al., 2004). However, the high concentration of ash in PBM may impact growth performance of pigs (Keegan et al., 2004).

The concentration of most nutrients is similar in CM and PBM (Table 3), but PBM contains more fat and more GE than CM. Chicken meal also contains more ash than PBM, which indicates that more bones are added to CM than to PBM. The ATTD of GE is similar for CM and PBM (Table 4), but the DE and ME are greater in PBM than in CM. In contrast, the SID of most indispensable AA in CM and PBM are not different.

AV-E Digest

AV-E digest is a protein ingredient that is produced from extruded egg albumins, enzymatically hydrolyzed whole spent hens, and soybean meal (**SBM**), which is used as a carrier. AV-E digest is used mainly to replace fish meal in weanling pig diets. There is limited information related to the palatability of this ingredient and no data on growth performance of pigs fed diets containing AV-E-Digest have been published.

The GE and CP concentration in AV-E digest is slightly less than in CM and PBM, but there is more ash and AEE in AV-E digest than in CM and PBM (Table 3). This is probably due to a greater addition of bones to AV-E digest. The use of SBM as a carrier increases the absorption of fat in the final product (Myer et al., 2004) and aids in improving the flowability of the product. The DE and ME in AV-E digest are slightly less than in CM and PBM (Table 4). The SID of most indispensable AA are greater in AV-E digest compared with CM and PBM, which may be a result of the SBM that is included in the product because the SID of AA in SBM is greater than in PBM and CM.

Feather Meal

Fresh poultry feathers are collected from the poultry processing industry. Cleaned feathers may be processed by steam to hydrolyze the keratins in the feathers, which increases the digestibility of AA in the feathers (van Heugten and van Kempen, 2002; Apple et al., 2003). Poultry blood may or may not be added to the hydrolyzed feather before they are dried. Hydrolyzed feather meal with added blood contain more AA and less fat than if no blood is added to the feathers, but the concentration of gross energy and most nutrients other than AA and fat in feather meal without blood is similar to that in feather meal with blood (Table 3). The concentration of P and Ca is less in hydrolyzed feather meal than in most other animal proteins because feather meal does not contain bones.

The DE and ME in feather meal without blood are greater than in feather meal with blood (Table 4), which is likely due to the greater concentration of AEE in feather meal without blood. The ATTD and STTD of P are also greater in feather meal without blood than in feather meal with blood, which is difficult to explain because P digestibility in blood products is relatively high (Almeida and Stein, 2011). There is, however, very little P in avian blood meal so the addition of blood to hydrolyzed feather meal may not contribute to any measurable differences in the meal. The SID of indispensable AA is also slightly greater in feather meal without blood than in feather meal with blood, which indicates that the addition of blood did not improve the digestibility of AA in feather meal. It is possible that the reason for this observation is that if blood is added to the feather meals, more heating is needed in the drying process, which may result in reduced AA digestibility in the feather meal with blood. However, the variation in energy and nutrient digestibility among sources of hydrolyzed feather meal is relatively high (Wang and Parsons, 1997), and the variation among sources is greater than the effects of adding blood to the meals. It is possible that these differences are a result of differences in processing procedures because each facility uses a unique setting for steam pressure and time of hydrolysis when feather meal is hydrolyzed (Moritz and Latshaw, 2001). There is, however, no information about the exact impact of specific processing procedures on nutrient and energy digestibility in hydrolyzed feather meal, but the variability among sources is the biggest concern in terms of utilizing feather meal in diets fed to swine.

Pigs fed a corn-SBM diet with an inclusion of 8% feather meal have growth performance that is not different from that of pigs fed a corn-SBM diet without feather meal (van Heugten and van Kempen, 2002). However, inclusion of 10 or 20% feather meal in diets fed to growing-finishing pigs may result in reduced feed intake and average gain (Ssu et al., 2004). Inclusion of up to 9% hydrolyzed feather meal in diets fed to finishing pigs from 67 kg to market does not result in any change of carcass composition or feed conversion, but may reduce average daily gain (Chiba et al., 1996).

Intestinal Co-Products and Meat Meals

PEP 2+ and PEP50

PEP2+ and PEP50 are produced from hydrolyzed porcine intestinal mucosa that is left after heparin has been extracted from the intestines. During production of PEP2+, dried fermentation biomass, which is a by-product of the production of synthetic Lys, is mixed with hydrolyzed intestinal mucosa, and enzymatically treated, low-antigen SBM is used as a carrier. In contrast, in the production of PEP50, conventional SBM is mixed with intestinal mucosa to enhance fat absorption and faster drying of the product.

Both PEP2+ and PEP50 are high protein products that may be used as replacements for fish meal in diets fed to weanling pigs. Inclusion rates of up to 6% of each product in phase 2 diets do not negatively influence pig growth performance (Myers et al., 2011).

The concentrations of CP and most AA are slightly less in PEP2+ and PEP50 than in fish meal, but the concentration of Lys is greater in PEP2+ than in PEP50, which is likely a result of the dried fermentation biomass that is included in PEP2+. The concentration of ash is also less, but the concentration of GE is greater, in PEP2+ and PEP50 than in fish meal (Table 5). The DE and ME in PEP2+ and PEP50 are comparable with that of most other animal protein sources (Table 6), but the STTD of P in PEP2+ and PEP50 is relatively high compared with the STTD of P in most other feed ingredients, which partly offsets the lower concentration of P in these ingredients compared with fish meal. The SID of AA in PEP2+ and PEP50 is similar to the SID of AA in fish meal.

DPS 50 RD

A product called DPS 50RD is produced from enzymatically hydrolyzed porcine mucosa and small intestines that have been roller-dried after heparin has been extracted. The concentration of AA in DPS 50RD is relatively high (Table 5) and the SID of most indispensable AA is greater in DPS 50RD than in most other animal proteins with the exception of PEP2+ and PEP50 (Table 6). It has been indicated that DPS50 may replace soybean meal, fish meal, whey powder, or blood cells in diets fed to weanling pigs without negatively impacting pig growth performance (Zimmerman and Sparks, 1996; Lindeman et al., 2000). A carry over effect of DPS50 on performance of pigs during 2 to 3 weeks after feeding of DPS 50RD was discontinued has been suggested (Zimmerman and Sparks, 1996), but this effect has not been verified in subsequent experiments.

Meat and Bone Meal

In the animal slaughter industry, processing of animals to obtain products for human consumption leaves parts of animals that can be used to produce meat and bone meal (**MBM**). This product consists of rendered products from mammal tissues that is finely ground and dried to obtain a meal. Meat and bone meal contains bones from the animals, but hair, hoofs, blood, horns, rumen contents, and manure are not included in MBM (AAFCO, 2011). Meat and bone meal may replace inorganic P in diets fed to pigs without negatively affecting growth performance or bone structure (Traylor et al. (2005), and MBM can contribute up to 30% of the CP needed in diets fed to pigs (Hendriks et al., 2002).

Some variability among sources of MBM has been reported due to differences in the origin and quality of the raw materials used to produce MBM. However, most producers of MBM blend products to market MBM that contains either 50% CP or 56% CP. The concentration of CP, acid hydrolyzed ether extract, and GE is similar to that in many other animal proteins, but the concentrations of ash, P, and Ca are greater than in most other ingredients due to the inclusion of animal bones in the product. The concentration of DE and ME in MBM is less than in corn and soybean meal (Olukosi and Adeola, 2009) and there is a negative correlation between the concentration of ash in MBM and the ME of the product (Olukosi and Adeola, 2009). The concentration of ash in MBM is largely a consequence of the concentration of bone in the product. As the concentration of bone is increased, the concentration of not only ash, but also Ca and P is increased in MBM.

There is, however, a negative correlation between the concentration of ash in MBM and the STTD of (Sulabo and Stein, 2013) because the digestibility of P in soft tissue is greater than in bone tissue (Jongbloed and Kemme, 1990). Nevertheless, the average STTD of P in MBM (68.8%; Table 6) is close to that in fish meal and MBM is, therefore, a rich source of digestible P. The ATTD of Ca in MBM varies from 53 to 81% and the average ATTD in MBM (65%) is close to the average ATTD of Ca in fish meal and in calcium carbonate (Sulabo and Stein, 2013).

Blood Products

Ring Dried or Drum Dried Blood Meals

Avian, porcine, and bovine blood meal are produced from clean and fresh avian, porcine, or bovine blood exclusive of all extraneous materials such as hair, stomach contents, and intestinal contents (AAFCO, 2011). To produce dried blood meal, the fresh blood is decanted, cooked, dried, and ground (Bellaver, 2005). The nutritional value of blood meal varies according to the processing procedures used and specifically, the drying procedure influences the digestibility of AA in blood meal (Moughan et al., 1999; Pearson et al., 1999). Historically, blood meals have been ring dried or drum dried and these procedures are still widely used in the industry.

The energy and nutrient composition of avian, porcine, and bovine blood meal are similar with the exception that bovine blood has a reduced concentration of Ile compared with avian blood meal (Table 7). The ATTD of P is less in avian blood meal than in porcine blood meal, but this is mainly due to the reduced concentration of P in avian blood meal compared with porcine blood meal. Therefore, when values for STTD of P are calculated, no difference between the 2 ingredients is observed (Table 8; Almeida and Stein, 2011). The average SID of most indispensable AA in avian blood meal is also similar to the SID of indispensable AA in porcine blood meal, but the SID of most indispensable AA in bovine blood meal is greater than in the avian and porcine meals (Table 8).

Spray Dried Blood Products

Spray drying of blood meal is accomplished by spraying blood into a draft of warm and dry air (AAFCO, 2011). The procedure usually leads to blood products with a high nutrient digestibility and the particle size of the blood is reduced, which contributes to an increase in the nutritional value of blood products (FEDNA, 2010). Spray dried blood products are used in weanling pig diets due to the high digestibility of nutrients in these ingredients (Grinstead et al., 2000).

Whole fresh blood may be spray dried to produce spray dried blood meal (**SDBM**). Because of the low temperature used in the drying procedure compared with ring drying or drum drying, SDBM has a greater SID of AA than blood meal that has not been spray dried (Table 8; Moughan et al., 1999). Spray dried blood meal may be included at 6% in diets fed to pigs from d 7 to 28 post-weaning to maximize growth performance, but after d 21, the use of SDBM is not critical for increasing growth performance of pigs (Kats et al., 1994).

Blood may be centrifuged before drying to separate plasma and blood cells. Each of the 2 streams are subsequently spray dried and spray dried plasma protein (**SDPP**) and spray dried blood cells (**SDBC**) are produced (AAFCO, 2011). The dried products are sometimes granulated to improve handling characteristics.

The concentrations of CP and AA are greater in SDBC than in SDPP, whereas the concentration of ash, Ca, and P are greater in SDPP than in SDBC. The P in SDPP is 100% digestible (Bunzen et al., 2008; Almeida and Stein, 2011), which is likely a result of the fact that no cell membranes are present in SDPP. The SID of AA is similar in SDPP and SDBC, but the concentration of Met and Ile is low in both ingredients. However, the SID of Ile is less in SDBC than in SDPP, which indicates that addition of synthetic Ile, may be needed when SDBC is included in the diets.

Spray dried blood protein plasma is commonly used in phase 1 and phase 2 diets (0 to 7 and 7 to 14 d, post-weaning, respectively) fed to weanling pigs because this ingredient stimulates feed intake (Ermer et al., 1994). Inclusion of up to 6% SDPP in diets fed to weanling pigs increases ADG and ADFI and the positive effect is more noticeable in week 1 and 2 post-weaning than in subsequent weeks (Van Dijk et al., 2001). Inclusion of 6% SDBC in diets feed to growing pigs may decrease G:F, but inclusion of 5% SDBC supports growth performance that is similar to that of the control diet (Kerr et al., 2004).

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Table 1. Analyzed nutrient composition of fish meal and milk products, as-fed basis

Item	Fish meal	Casein	Whey powder	Whey permeate	Whey permeate, low ash
GE, kcal/kg	4,423	4,586	3,6,20	3,426	3,657
DM, %	91.5	91.8	90.0	97.6	98.4
CP, %	63.4	86.8	13.4	4.3	3.0
Ash, %	19.3	4.4	11.6	9.0	1.7
AEE[1], %	9.0	0.1	-	0.8	-
P, %	3.1	0.7	0.6	0.6	0.1
Ca, %	5.2	0	0.5	0.4	0.1
Lactose, %	-	-	66.0	76.1	88.8
Indispensable, AA %					
Arg	3.66	2.84	0.26	-	-
His	1.40	3.65	0.21	-	-
Ile	2.56	3.22	0.65	-	-
Leu	4.32	9.58	1.11	-	-
Lys	4.76	7.47	0.93	-	-
Met	1.68	1.96	0.15	-	-
Phe	2.39	5.01	0.35	-	-
Thr	2.40	3.65	0.68	-	-
Trp	0.61	1.19	0.23	-	-
Val	3.01	6.73	0.62	-	-
Dispensable, AA %					
Ala	3.82	4.36	0.52	-	-
Asp	5.40	7.27	1.09	-	-
Cys	0.50	0.46	0.22	-	-
Glu	7.73	14.51	1.81	-	-
Gly	4.44	2.54	0.21	-	-
Pro	2.82	6.95	0.59	-	-
Ser	2.04	4.17	0.43	-	-
Tyr	1.89	3.76	0.26	-	-
Total AA	55.41	89.30	10.32	-	-

[1]AEE = acid hydrolyzed ether extract.

Table 2. Concentration of DE and ME and the apparent total tract digestibility (ATTD) of energy and P, the standardized total tract digestibility (STTD) of P, and the standardized ileal digestibility (SID) of CP and AA in fish meal and milk products.

Item	Fish meal	Casein	Whey powder	Whey permeate	Whey permeate, low ash
Energy					
ATTD of GE, %	86.3	-	-	-	-
DE, kcal/kg	3,797	-	3,494	3,177	3,626
ME, kcal/kg	3,472	-	3,317	3,009	3,537
Phosphorus					
ATTD of P, %	63.4	-	84.3	86.1	55.9
STTD of P[1], %	67.1	-	91.2	93.1	91.8
SID of CP and AA[2], %					
CP	84.1	98.4	-	-	-
Indispensable AA					
Arg	92.1	99.7	-	-	-
His	86.2	97.0	-	-	-
Ile	86.9	96.6	-	-	-
Leu	87.3	98.2	-	-	-
Lys	86.1	98.1	-	-	-
Met	87.2	98.5	-	-	-
Phe	85.7	98.7	-	-	-
Thr	84.7	94.1	-	-	-
Trp	89.9	96.2	-	-	-
Val	85.4	97.2	-	-	-
Mean	86.9	97.5	-	-	-
Dispensable AA					
Ala	85.8	96.1	-	-	-
Asp	78.7	95.4	-	-	-
Cys	77.7	92.7	-	-	-
Glu	86.2	95.4	-	-	-
Gly	90.7	103.0	-	-	-
Pro	106.1	112.9	-	-	-
Ser	84.2	94.4	-	-	-
Tyr	85.4	98.0	-	-	-
Mean	86.9	98.5	-	-	-
All AA	86.9	97.9	-	-	-

[1] Values for STTD were calculated by correcting values for ATTD for basal EPL.

[2] Values for SID were calculated by correcting the values for AID for basal ileal endogenous losses.

Table 3. Analyzed nutrient composition of chicken meal (CM), poultry by-product meal (PBM), AV-E digest, and feather meal without and with blood, as-fed basis

Item	CM	PBM	AV-E digest	Feather meal without blood	Feather meal with blood
GE, kcal/kg	4,907	5,226	4,783	5,529	5,422
DM, %	96.8	94.8	93.8	92.0	93.5
CP, %	66.0	62.3	49.5	81.2	82.2
Ash, %	14.2	11.3	14.6	1.8	1.9
AEE[1], %	11.0	14.3	15.8	9.4	7.0
P, %	2.4	1.9	1.8	0.2	0.3
Ca, %	4.4	2.7	3.3	0.5	0.5
Indispensable, AA %					
Arg	4.05	4.05	3.19	5.63	5.53
His	1.25	1.32	1.05	0.70	1.27
Ile	2.43	2.35	2.03	3.79	3.85
Leu	4.27	4.25	3.49	6.63	7.07
Lys	3.49	3.96	2.90	1.83	2.68
Met	1.09	1.26	0.76	0.55	0.66
Phe	2.42	2.41	2.17	3.96	4.14
Thr	2.27	2.37	1.76	3.69	3.76
Trp	0.58	0.60	0.43	0.45	0.56
Val	3.15	2.92	2.45	6.13	6.25
Dispensable, AA %					
Ala	3.78	3.92	2.77	3.75	4.07
Asp	4.67	4.84	4.24	5.21	5.61
Cys	0.96	0.59	0.75	4.09	3.74
Glu	7.56	7.68	6.59	8.48	8.51
Gly	5.56	5.63	3.93	6.34	5.88
Pro	4.06	3.52	2.98	7.87	7.16
Ser	2.65	2.38	1.74	8.48	7.53
Tyr	1.92	2.08	1.69	2.23	2.47
Total AA	56.16	56.13	44.92	79.79	80.71

[1]AEE = acid hydrolyzed ether extract.

Table 4. Concentration of digestible and metabolizable energy, apparent total tract digestibility (ATTD) of energy and P, standardized total tract digestibility (STTD) of P, and standardized ileal digestibility (SID) of CP and AA in chicken meal (CM), poultry by-product meal (PBM), AV-E digest, and feather meal without and with blood, as-fed basis

Item	CM	PBM	AV-E digest	Feather meal without blood	Feather meal with blood
Energy					
ATTD of GE, %	89.2	87.9	92.6	-	-
DE, kcal/kg	4,161	4,805	4,145	5,194	4,752
ME, kcal/kg	3,694	4,348	3,235	4,947	4,446
Phosphorus					
ATTD of P, %	-	-	-	82.5	73.3
STTD of P[1], %	-	-	-	96.9	80.0
SID of CP and AA[2], %					
CP	67.4	72.1	75.8	69.6	66.3
Indispensable AA					
Arg	79.1	81.8	86.0	82.1	79.6
His	62.8	67.4	75.0	64.9	58.2
Ile	65.8	67.9	79.6	80.9	79.1
Leu	65.2	68.6	79.7	75.8	71.1
Lys	60.5	68.9	77.1	56.4	65.3
Met	74.9	75.2	84.2	67.4	67.5
Phe	64.7	68.0	75.6	78.5	73.8
Thr	63.3	67.1	76.1	68.4	65.6
Trp	69.7	72.7	91.2	80.4	80.1
Val	63.5	70.0	74.5	77.6	73.0
Mean	67.0	70.9	79.5	72.9	70.9
Dispensable AA					
Ala	69.7	73.5	80.2	71.8	68.3
Asp	48.2	53.1	66.6	47.6	46.2
Cys	55.4	55.6	48.9	58.6	54.4
Glu	64.9	72.3	68.8	65.5	62.6
Gly	67.1	70.5	71.1	71.5	69.3
Pro	76.3	89.2	79.6	64.9	60.7
Ser	71.1	73.2	75.9	76.5	72.9
Tyr	66.3	72.1	78.3	71.8	70.0
Mean	64.9	69.9	71.2	66.0	63.0
All AA	66.1	70.5	76.0	70.0	67.6

[1] Values for STTD were calculated by correcting values for ATTD for basal EPL.

[2] Values for SID were calculated by correcting the values for AID for basal ileal endogenous losses.

Table 5. Analyzed nutrient composition of PEP2+, PEP50, DPS 50RD, and meat and bone meal (MBM), as-fed basis

Item	Peptone P2+	Peptone P50	DPS 50 RD	MBM
GE, kcal/kg	4,934	4,630	-	4,143
DM, %	95.2	94.7	-	95.5
CP, %	59.5	53.6	49.7	52.8
Ash, %	12.0	10.1	-	26.5
AEE[1], %	13.1	7.4	-	13.1
P, %	0.8	0.7	-	4.2
Ca, %	-	-	-	8.6
NDF, %	2.5	5.8	-	-
ADF, %	1.4	3.6	-	-
Indispensable, AA %				
Arg	3.47	3.13	2.36	3.61
His	1.35	1.19	0.98	1.04
Ile	2.62	2.21	1.98	1.57
Leu	4.52	3.82	3.56	3.32
Lys	4.86	3.59	3.21	2.99
Met	1.09	0.80	0.86	0.75
Phe	2.48	2.23	1.90	1.85
Thr	2.27	1.81	1.85	1.72
Trp	0.49	0.47	0.30	0.35
Val	3.22	2.63	2.52	2.33
Dispensable, AA %				
Ala	3.24	2.47	2.72	3.91
Asp	5.41	4.77	4.03	3.95
Cys	0.71	0.61	1.00	0.45
Glu	7.53	7.09	6.34	6.14
Gly	3.01	2.41	3.34	6.74
Pro	2.67	2.33	2.41	4.07
Ser	1.89	1.67	1.46	1.91
Tyr	2.01	1.62	1.57	1.31
Total AA	52.84	44.85	43.37	48.02

[1]AEE = acid hydrolyzed ether extract.

Table 6. Concentration of digestible and metabolizable energy, apparent total tract digestibility (ATTD) of P, standardized total tract digestibility (STTD) of P, and standardized ileal digestibility (SID) of CP and AA in PEP2+, PEP50, DPS 50RD, and meat and bone meal (MBM), as-fed basis

Item	PEP2+	PEP50	DPS 50 RD	MBM
Energy				
DE, kcal/kg	4,587	4,348	-	-
ME, kcal/kg	4,291	4,122	-	-
Phosphorus				
ATTD of P, %	90.6	68.0	-	65.9
STTD of P[1], %	97.6	76.2	-	68.8
SID of CP and AA[2], %				
CP	78.2	84.1	76.2	84.1
Indispensable AA				
Arg	91.5	95.5	89.4	95.5
His	81.0	87.2	81.5	87.2
Ile	83.3	87.9	84.3	87.9
Leu	84.2	88.6	86.8	88.6
Lys	84.1	87.5	84.2	87.5
Met	83.9	89.1	89.4	89.1
Phe	81.8	87.1	85.5	87.1
Thr	78.1	83.5	81.1	83.5
Trp	95.3	94.1	97.1	94.1
Val	82.8	87.2	83.3	87.2
Mean	84.0	88.3	86.3	88.3
Dispensable AA				
Ala	83.4	88.5	83.6	88.5
Asp	72.4	80.6	81.3	80.6
Cys	43.6	57.5	72.9	57.5
Glu	76.4	78.7	68.4	78.7
Gly	79.7	85.2	74.1	85.2
Pro	144.4	148.4	84.1	148.4
Ser	80.1	87.2	81.3	87.2
Tyr	84.2	88.6	89.1	88.6
Mean	83.0	89.3	79.3	89.3
All AA	83.6	88.8	81.9	88.8

[1] Values for STTD were calculated by correcting values for ATTD for basal EPL.

[2] Values for SID were calculated by correcting the values for AID for basal ileal endogenous losses.

Table 7. Analyzed energy, DM, and nutrient composition of avian blood meal, porcine blood meal, bovine blood meal, spray dried plasma protein (SDPP), spray dried blood cells (SDBC), and spray dried blood meal (SDBM), as-fed basis

Item	Avian blood meal	Porcine blood meal	Bovine blood meal	SDPP	SDBC	SDBM
GE, kcal/kg	5,278	5,278	-	4,687	5,302	5,159
DM, %	89.6	90.3	92.7	90.6	93.3	93.5
CP, %	87.7	89.0	95.0	77.3	94.2	93.8
Ash, %	1.80	1.4	-	8.1	2.5	4.2
AEE[1], %	0.4	0.3	-	0.5	0.1	0.1
P, %	0.3	0.7	-	1.3	0.8	-
Ca, %	0.1	0.3	-	0.1	0.3	-
Indispensable, AA %						
Arg	4.52	4.10	3.27	4.42	3.61	3.54
His	5.03	5.88	5.91	2.52	6.73	5.96
Ile	3.75	2.15	0.42	2.44	0.35	0.62
Leu	9.75	11.06	12.45	7.56	12.79	11.77
Lys	7.61	7.81	8.59	6.99	8.62	7.995
Met	1.02	0.86	1.28	0.87	0.98	0.89
Phe	5.46	5.73	6.81	4.24	6.80	6.215
Thr	4.13	3.39	3.77	4.71	3.51	3.48
Trp	1.38	1.53	1.24	1.45	1.50	1.61
Val	5.92	7.12	8.46	5.22	8.49	7.93
Dispensable, AA %						
Ala	6.58	6.77	7.58	4.04	7.81	7.155
Asp	8.06	9.40	8.75	7.73	10.17	9.53
Cys	1.92	0.71	0.53	1.90	0.52	0.75
Glu	8.29	7.72	6.46	10.55	7.48	7.31
Gly	3.26	3.80	3.69	2.74	4.22	3.945
Pro	3.36	3.30	3.1	4.19	3.25	3.235
Ser	3.30	3.58	3.47	4.53	4.12	3.855
Tyr	2.99	3.03	2.25	3.88	1.93	1.78
Total AA	86.29	87.91	88.03	79.96	92.84	87.57

[1]AEE = acid hydrolyzed ether extract.

Table 8. Apparent total tract digestibility (ATTD) of P, standardized total tract digestibility (STTD) of P, and standardized ileal digestibility (SID) of CP and AA in avian blood meal, porcine blood meal, bovine blood meal, spray dried plasma protein (SDPP), spray dried blood cells (SDBC), and spray dried blood meal (SDBC), as-fed basis

Item	Avian blood meal	Porcine blood meal	Bovine blood meal	SDPP	SDBC	SDBM
Phosphorus						
ATTD of P, %	57.5	76.5	-	91.3	-	-
STTD of P[1], %	86.1	89.7	-	102.8	-	-
SID of CP and AA[2], %						
CP	70.4	68.9	81.7	96.0	92.3	93.8
Arg	75.6	70.2	88.1	97.4	98.5	96.9
His	68.6	77.5	92.2	94.3	98.3	98.5
Ile	67.2	33.6	71.9	93.5	58.3	86.6
Leu	67.0	76.1	91.6	94.5	97.7	97.9
Lys	74.0	78.6	90.5	94.2	97.6	98.0
Met	74.0	70.1	84.3	94.0	96.0	96.7
Phe	67.3	76.4	91.4	94.5	97.8	98.0
Thr	71.7	68.6	88.2	92.7	95.9	96.9
Trp	69.3	77.0	89.6	94.1	95.2	97.2
Val	66.5	76.0	91.2	93.3	97.7	97.8
Mean	70.1	70.3	87.3	94.4	93.2	96.2
Ala	68.8	75.5	90.9	93.4	99.8	98.1
Asp	69.1	74.3	90.0	91.4	97.7	98.2
Cys	65.0	55.1	87.2	91.2	84.5	95.3
Glu	69.4	71.5	87.4	91.5	93.6	98.3
Gly	79.2	66.1	81.3	90.2	100.6	97.4
Pro	103.7	28.7	-	105.5	97.0	152.4
Ser	72.2	70.9	86.4	93.4	96.8	97.0
Tyr	-	-	88.5	89.2	88.0	90.2
Mean	65.9	55.3	87.4	93.2	94.7	103.3
All AA	68.4	64.0	87.4	93.9	93.9	99.2

[1] Values for STTD were calculated by correcting values for ATTD for basal EPL.

[2] Values for SID were calculated by correcting values for AID for basal ileal endogenous losses.