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ASSESSMENT OF AMINO ACID, CALCIUM, AND PHOSPHORUS DIGESTIBILITY IN MEAT AND BONE MEAL FOR GROWING PIGS AND BROILER CHICKS

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Background

Rendering by-products are commonly used in swine and poultry diets at relatively low levels. Although the inclusion level is relatively low, meat and bone meal and other rendering by-products are considered to be excellent sources of calcium (Ca), phosphorus (P), B-complex vitamins, and amino acids. Although the Ca and P levels are variable, most products contain between 7 to 10% Ca and 3.5 to 5.0% P. Because of the relative high concentrations of these minerals in meat and bone meal, diets containing 3 to 5% meat and bone meal may contain ample Ca and P to meet the pig's requirements for total Ca and P. However, this is true only if the Ca and P are highly available.

Early reported research using meat and bone meal in diets for pigs indicated a linear reduction in growth performance when increasing levels of meat and bone meal were fed to weanling and growing-finishing pigs (Poe and Hudman, 1962; Puchal et al., 1962; Evans and Liebholz, 1979). It was suggested that the reduction in performance might have been because of reduced palatability, excessive mineral content, or a poorer balance of amino acids in the meat and bone meal supplemented diets.

Studies at the University of Kentucky indicate that when swine diets containing meat and bone meal are supplemented with synthetic tryptophan, growth performance is not adversely affected (Cromwell et al., 1991). In three studies, we found that optimal growth performance could be achieved if the diets were supplemented with .03% synthetic tryptophan for every 10% meat and bone meal used in the diet. Knabe (1989) reported similar effects on growth performance when growing-finishing pigs were fed diets either with or without meat and bone meal when they were equalized for digestible lysine and tryptophan.

The scientific literature on the bioavailability of P in meat and bone meal is confusing. Recent studies conducted with chicks and turkey poults have shown that the bioavailability of P in meat and bone meal is essentially equivalent to the bioavailability of P in mono- or dicalcium phosphate (Waldroup and Adams, 1994; Sell and Jeffrey, 1996). On the other hand, Coffey and Cromwell (1995) reported that the P in meat and bone meal was only 78% bioavailable for chicks. Data on the bioavailability of P in meat and bone meal for pigs is relative sparse. The NRC (1988) listed a bioavailability of 89% for meat and bone meal, but that value was based on a single estimate from one study with pigs (Huang and Allee, 1981). Subsequent studies with pigs conducted at our station indicated that the P in meat and bone meal is much lower, between 63 to 69% (Burnell et al. 1989; Coffey and Cromwell, 1993). Recently, in studies supported by the Fats and Proteins Research Foundation and summarized in our 1999 report, we found that the P in meat and bone meal was 87 to 90% as bioavailable to pigs as the P in monosodium phosphate.

The reason for the discrepancy in the estimates of P bioavailability is not clear. Burnell et al. (1989) indicated that the low availability estimate may have been due to the fact that approximately 30% of the P in their meat and bone meal was in large particles (4 mm or greater) which may have been poorly degraded in the tract. Yet, this particular product was typical of the meat and bone meal commonly fed by swine producers in our area. Particle size of meat and bone meals did not affect its utilization by poults in a study by Sell and Jeffrey (1996).

Knabe et al. (1989) investigated ileal amino acid digestibilities of meat and bone meal processed by batch cooking systems compared to newer continuous cooking systems. They reported that the bioavailability of tryptophan was low and quite variable, ranging from 35 to 65%. Their data indicate that the bioavailability of tryptophan and other amino acids is lower in meat and meat by-products compared to other high protein feedstuffs. The NRC (1998) lists the ileal digestibility of tryptophan in meat and bone meal as 60% compared to 80% for solvent extracted soybean meal. Very little information is available about what factors other than processing equipment might influence the availability of amino acids. This information is of paramount importance when formulating diets for both poultry and swine, especially if diets are formulated on an ileal digestible basis.

The traditional method of obtaining digesta for ileal amino acid digestibility determination is by cannulation of the terminal ileum. This method is expensive and can only be accomplished on a small number of pigs at one time. Recently a different method of collection ileal digesta was investigated by researchers in New Zealand (Donkoh et al., 1994). This group of researchers compared collection of digesta from the terminal ileum using the traditional T-cannulation and a slaughter method. In the slaughter method, pigs are anaesthetized prior to sampling of digesta from the terminal ileum and euthanized with a barbiturate after sampling. This method does have the advantage of causing minimal interference with the animal's digestive tract and allows for digesta to be taken from several sites along the digestive tract. Another advantage to the slaughter method is that cannulation requires surgery that might alter normal digestive function.

Donkon et al. (1994) reported that the method of collection did not influence the measurement of apparent ileal digestibility of nitrogen or amino acids. As expected, ileal amino acid digestibility was lower than that for total tract amino acid digestibility. Furthermore, when the researchers compared the between-animal variation for ileal amino acid digestibility in intact and cannulated pigs, the variation about the mean was low and of similar magnitude. A similar method for ileal digesta collection using the slaughter method has been reported for intact broiler chickens (Kadim and Moughan, 1997). These reports suggest that the slaughter method of intact animals is suitable for ileal digesta and determination of apparent amino acid digestibility.

A greater usage of meat and bone meal in swine and poultry diets would mean less dependence on inorganic phosphates to meet the pig's available P requirement. However, if the estimated bioavailability of P that is given to meat and bone meal is too high, this could result is P deficiency which will reduce growth rate and efficiency of feed utilization, reduce carcass leanness, and reduced bone mineralization. On the other hand, if the estimated bioavailability of P given to meat and bone is too low, this would result in excessive excretion of P in the manure. Excessive P excretion is undesirable from an environmental standpoint in that it contributes to environmental pollution (Cromwell, 1998).

Therefore, a better understanding of the biological availability of nutrients in meat and bone meal is needed in order for this byproduct to be effectively utilized in swine and poultry feeds.

Objectives

1. To determine the ileal digestibility of calcium, phosphorus, and amino acids in meat and bone meal from two sources that vary in ash content for pigs.

2. To determine the ileal digestibility of calcium, phosphorus, and amino acids in meat and bone meal processed at different processing conditions for pigs.

3. To determine phosphorus bioavailability and ileal digestibility of calcium, phosphorus, and amino acids in meat and bone meal for broiler chicks.

General Procedures

Sources of Meat and Bone Meal. The sources of meat and bone meal used in these experiments were obtained following consultation with Dr. Gary Pearl, Director of Technical Services of the Fats and Proteins Research Foundation. Samples of the products were analyzed for dry matter, crude protein, fat, ash, Ca, and P in our laboratory using standard procedures. In addition, Ca and amino acids of the samples were analyzed by the University of Missouri Experiment Station Chemical Laboratories, Columbia, Missouri. Table 1 shows the composition of the meat and bone meals used in all of the studies.

For the particle size studies, we obtained a common source of meat and bone meal with assistance of Mr. Steve Thomas, Griffin Industries. The meat and bone meal analyzed 44.8% protein, 10.9% Ca and 5.5% P. Cracks were ground in a hammermill to various degrees of fineness in the Grain Science Department at Kansas State University in cooperation with Dr. Keith Behnke. Two particle sizes, representing coarse and fine, were selected based on the amount that passed through 6- or 12-mesh screens, respectively.

For the source studies, meat and bone meal originating from swine and cattle were used. Meat and bone meal from swine is considerably higher in protein content and considerably lower in ash content that meat and bone meal from cattle. We obtained two sources of meat and bone meal for this study; one originated from packing plants that killed only hogs and one was from a plant that killed only cattle. The high-ash (cattle) source was higher in ash (42.7 vs 23.1%), Ca (14.3 vs 7.4%), and P (7.1 vs 3.7%), and lower in crude protein (40.0 vs 59.7%) than the low-ash (swine) source. Particle size was similar for the two sources.

For the processing studies, a blended meat and bone meal from a common source was subjected to additional processing pressure and temperature to determine if excessively high processing temperature has a negative effect of the bioavailability of Ca and P as is does with amino acids. A common source of meat and bone meal was split into three batches. One batch was not further processed and served as the control. A second batch was placed in a laboratory scale model cooker and subjected to 30 psi pressure for 20 minutes. A third batch was processed similarly except that it was subjected to 60 psi of pressure for 20 minutes. The further processing was performed by Darling Industries, Irving, Texas, in cooperation with Dr. Ross Hamilton.

Pig Experiments. Four experiments were conducted. The growth performance, bone data, and bioavailability data were given in our 1999 final report to the Fats and Proteins Research Foundation. Fecal and ileal digesta were collected from these same pigs at the end of the experiments for determination of apparent digestibility of amino acids, Ca, and P.

The first two pig experiments involved meat and bone meal of varying ash content. In these studies, low-ash pork, high-ash beef, and a 50:50 blend of the two products were used. The second two pig experiments assessed meat and bone meal subjected to three processing pressures.

During the final week of the pig studies, chromic oxide was included in the diets at .20%. Fecal samples were collected during the last 2 days of the experiment. After the pigs were killed, ileal digesta was collected using the procedures described by Donkoh et al. (1994). In this procedure, digesta from the terminal ileum anterior to the ileocecal valve is collected using the "slaughter method" instead of the traditional "cannulation method." In our study, the pigs were anaesthetized using Telazol (4.4 mg/kg BW, Fort Dodge Animal Health, Fort Dodge, IA) and xylazine-100 (4.4 mg/kg BW, Butler Co., Columbus, OH). After locating the ileocecal valve, the ileum was tied off in two locations. The first location was at the ileocecal valve, followed by another at approximately 10-15 cm cranial of the ileocecal valve. The ileal chyme of the sampled section was approximately 200 ml and was placed into two separate collection vials. The first vial contained the digesta from the lower section and the second vial was for the digesta in the upper section. After collection of the digesta samples, the pigs were euthanased with 6 ml of Socumb (sodium pentobarbital, Butler Co., Columbus, OH). The digesta samples were collected and placed on ice for about 4 hours until frozen. The samples later were lyophilized, ground, and analyzed for concentrations of Ca, P, Cr, crude protein (N x 6.25), and amino acids. Diets were also analyzed for these nutrients. The ratio of indigestible Cr in diets and feces (or digesta) and the ratio of nutrients in diets and feces (or digesta) was used to calculate the apparent digestibility of the nutrients.

Chick Experiment. An experiment was conducted with young broiler chicks to determine the bioavailability of P in the various meat and bone meal products and to assess the effects of these products on the ileal digestibility of amino acids, P and Ca. The meat and bone meals used in this chick study were the same products that were used in previous pig experiments that were summarized in our 1999 report to the Fats and Proteins Research Foundation. In those experiments, we evaluated the effects of particle size, ash content, and processing conditions on the bioavailability of P in meat and bone meal for growing pigs.

Male, broiler-type chicks were obtained from a hatchery, placed in tiered batteries, and fed a common diet for 3 days. On day 3, the chicks were weighed and 420 were allotted to treatments in five replications of seven chicks per pen and fed the experimental diets for 15 days. Body weight gain and feed intake was determined for calculation of daily gain, daily feed intake, and feed:gain ratio. At the end of the experiment, all chicks were killed and the legs removed and frozen. Later, the tibias were removed, cleaned, and used for determination of bone strength and ash measurements. Breaking strength was determined using an Instron machine. Breaking strength was the amount of force applied at the center of the fresh bone when placed horizontally on two supports 3.2 cm apart. The tibias were then dried, extracted with ether, and ashed in a muffle furnace. The total and percentage of ash on a dry, fat-free bone basis was determined.

Using the slope-ratio procedures, bone strength and ash data were statistically analyzed to determine the slope of the responses when regressed on dietary P intake of the chicks. The basal diet was used in calculating the regressions of each P source. A comparison of the two slopes was used to estimate the bioavailability of the P in meat and bone meal, relative to the bioavailability of P in monosodium phosphate (given a value of 100). The bioavailabilities, based on tibia breaking strength and tibia ash content in grams, were averaged to give an overall estimate of the relative bioavailability of the P in the meat and bone meals.

Samples of ileal digesta were collected from two chicks per pen using procedures described by Kadim and Moughan (1997). The samples were obtained following halothane anesthesia and cervical dislocation. Ileal digesta was gently removed from the lower half of the ileal section posterior to the Meckel's diverticulum and the ileo-cecal valve. The digesta samples were pooled within pen, frozen, lyophilized, and ground before analysis of Ca, P, Cr, and amino acids. Because of the small sample size, Replicates 1 and 2 were pooled together and Replicates 4 and 5 were also pooled together for chemical analysis.

Statistical Analysis and Reporting of Data. All of the data in each experiment were subjected to statistical analysis using standard analysis of variance procedures (Snedecor and Cochran, 1989) and utilizing the Statistical Analysis System (SAS, 1986). Summaries of each experiment which include a title page with pertinent information on the study, the composition of the diets, and the results in table form are included with this report.

Experimental Results Obtained for Each Objective

Objective 1 - Determine the ileal digestibility of amino acids, phosphorus, and calcium in meat and bone meal from two souces that vary in ash content for pigs.

Two experiments were conducted under this objective to assess the effects of source of meat and bone meal (pork with low ash vs beef with high ash) on nutrient availability.

Experiment 9813A. The first experiment utilized twelve crossbred barrows initially averaging 80 kg. The pigs were housed in stainless steel metabolism crates. They were allotted to four dietary treatments with three replications per treatment. Dietary treatments were:

1. Low P basal diet (.32% P)
2. Basal + .125% added P from monosodium phosphate
3. Basal + .125% added P from meat and bone meal of pork origin (low ash)
4. Basal + .125% added P from meat and bone meal of beef origin (high ash)

The basal diet was a corn-soybean meal diet formulated to 14.75% crude protein, .80% lysine, .32% Ca, and .32% P. The substitution of monosodium phosphate and meat and bone meal was at the expense of corn starch such that the levels of corn and soybean meal were held constant across dietary treatments. Calcium carbonate was added to Diet 2 to provide .25% Ca, the same level of Ca provided by the meat and bone meal in Diets 3 and 4; hence, the Ca level was the same (.57%) in Diets 2-4. Chromic oxide (.20%) was added to all dietary treatments to allow for the calculation of apparent digestibility of nutrients using the indirect ratio method. Feces and ileal digesta were collected after a 5-d adaptation period, processed as previously described, and analyzed for Cr, Ca, P, N, and amino acids. Similar analyses were performed on the diets. Apparent ileal digestibility of Ca, P, crude protein, and amino acids were then calculated based on the concentrations of indigestible Cr and of the other nutrients in feed and ileal digesta.

Supplementing the basal diet with P and Ca from either monosodium phosphate and calcium carbonate or meat and bone meal resulted in an increase in the apparent ileal digestibility of crude protein and the amino acids. Source of added P and Ca (i.e., monosodium phosphate vs meat and bone meal) did not influence amino acid digestibility. Source of meat and bone meal products (i.e., high-ash beef vs low-ash pork) did not affect amino acid digestibility values except for tryptophan. Pigs fed the high-ash meat and bone meal tended to have a lower tryptophan digestibility (88.6 vs 91.9%; $P<.10$) than pigs fed the low-ash meat and bone meal.

As expected, supplementing the diet with Ca and P increased the apparent Ca and P digestibility, both ileal and total tract. Ileal digestibility of P tended to be higher for diets containing high-ash vs low-ash meat and bone meal. Fecal and ileal digestibilities of Ca and P of diets containing meat and bone meal were similar to diets containing monosodium phosphate.

Experiment 9816A. The second experiment was a 35-day feeding trial involving 36 crossbred pigs. The pigs were individually penned in an environmentally controlled room and allowed to consume their diets on an ad libitum basis. There were six diets with six replications per treatment. The low- and high-ash meat and bone meal was the same as used in the previous experiment. Diets were as follows:

1. Low P basal diet (.32% P)
2. Basal + .10% added P from monosodium phosphate
3. Basal + .20% added P from monosodium phosphate
4. Basal + .20% added P from meat and bone meal of pork origin (low ash)
5. Basal + .20% added P from meat and bone meal (50:50 blend of pork:beef)
6. Basal + .20% added P from meat and bone meal of beef origin (high ash)

The basal diet was formulated to provide 16.3% crude protein, .95% lysine, .70% Ca and .34% P. Calcium level was maintained at .70% in all diets. Fecal and ileal digesta samples were collected from all pigs receiving Diets 1, 3, 4, 5, and 6 as described in the first experiment.
All procedures were the same as those described previously.

The apparent ileal digestibility of crude protein and most of the amino acids was not improved when supplemental P was added to the basal diet. Source of P, whether from monosodium phosphate or meat and bone meal, did not affect nutrient ileal digestibility. With respect to ash content of the meat and bone meal, there were very little changes in amino acid digestibilities when either the low-ash or the blended meat and bone meal was fed, but an increase occurred when the high-ash meat and bone meal was fed. This pattern resulted in a quadratic response in apparent digestibility for most of the amino acids.

As expected, the ileal digestibility of dietary P was increased when P was added to the diets. Phosphorus apparent digestibility values of the high-ash meat and bone meal diets were greater than for the low-ash meal diets, which is a different result than that observed in the first experiment.

Objective 2 - Determine the ileal digestibility of amino acids, phosphorus, and calcium in meat and bone meal processed at different processing conditions for pigs.

Two experiments were conducted under this objective to assess the effects of processing conditions of meat and bone meal on nutrient availability.

Experiment 9817A. This experiment was a finishing pig balance study with five treatments and three replications per treatment. Diets were as follows:

1. Low P basal diet (.32% P)
2. Basal + .125% added P from monosodium phosphate
3. Basal + .125% added P from meat and bone meal (control, no additional processing)
4. Basal + .125% added P from meat and bone meal (30 psi product)
5. Basal + .125% added P from meat and bone meal (60 psi product)

The basal diet was formulated to contain 14.7% crude protein, .80% lysine, .31% Ca, and .31% P. Calcium carbonate was added to provide .26% additional Ca to Diet 2, the same level of Ca as provided by the meat and bone meal in Diets 3-5; therefore, the Ca level was the same (.57%) in Diets 2-5. Feces and ileal digesta were collected from all pigs. The procedures were the same as those described previously.

Adding supplemental P in the form of monosodium phosphate or meat and bone meal to the basal diet tended to reduce the apparent crude protein and ileal amino acid digestibility values for most of the amino acids. Phosphate source tended ($P<.10$) to affect the ileal digestibility of histidine, lysine, isoleucine, valine, and some nonessential amino acids, with diets containing monosodium phosphate tending to have higher values than did diets containing meat and bone meal for these amino acids. Of the essential amino acids, only isoleucine and valine had significantly ($P<.10$) reduced ileal digestibilities when additional processing pressure was increased from 0 to 60 psi of pressure for 20 min. This same trend occurred for several other amino acids including histidine, threonine, and especially tryptophan, but the reductions were not significant ($P=.15$).

Ileal digestibility of P in the meat and bone meal diets increased linearly (P<.05) with increasing processing pressure. However, these trends were not apparent when fecal digestibility of P was determined.

Experiment 9823A. This was a 35-day feeding trial involving 36 crossbred pigs. The pigs were individually penned in an environmentally controlled room and allowed to consume their diets on an ad libitum basis. There were six diets with six replications per treatment. Diets were as follows:

1. Low P basal diet (.32% P)
2. Basal + .10% added P from monosodium phosphate
3. Basal + .20% added P from monosodium phosphate
4. Basal + .20% added P from meat and bone meal (control, no additional processing)
5. Basal + .20% added P from meat and bone meal (additional processing at 30 psi)
6. Basal + .20% added P from meat and bone meal (additional processing at 60 psi)

The basal diet was formulated to contain 16.4% crude protein, .95% lysine, .70% Ca, and .34% P. Calcium level was maintained at .70% in all diets. Fecal and ileal digesta samples were collected from all pigs receiving Diets 1, 3, 4, 5, and 6. All procedures were the same as those described previously.

For most of the amino acids, supplementing the low-P basal diet with additional P from either monosodium phosphate or meat and bone meal had little effect on apparent ileal amino acid digestibility. Also, processing pressure did not seem to influence amino acid digestibility.

As in the previous experiments, apparent ileal digestibility of dietary P was increased (P<.01) when supplemental P was added to the basal diet. The digestibility of dietary P tended to be higher (P<.10) for the monosodium phosphate diet compared with the meat and bone meal diets, especially those with 0 and 30 psi of additional pressure.

Objective 3 - Determine phosphorus bioavailability and ileal digestibility of amino acids, phosphorus, and calcium in meat and bone meals with different ash contents, particle size, and processing temperatures for broiler chicks.

An experiment was conducted with broiler chicks to evaluate a number of processing variables that had previously been assessed in experiments with pigs. The meat and bone meals used in this project are the same products that had been used in previous pig experiments and reported to the Fats and Protein Research Foundation in our final report in 1999.

Experiment 9906. This study utilized male, broiler-type chicks with an initial BW of 30 grams. The chicks were kept in temperature controlled batteries and fed a common diet for 3 days. The chicks were then weighed and 420 were allotted to treatments on the basis of weight. The chicks were housed in wire-floored Petersime batteries in the basement of the Animal Sciences Building and allowed to consume diets and water on an ad libitum basis. There were 12 dietary treatments and five replicate pens of seven chicks per treatment. Diets were as follows:

1. Low P basal diet (.52% total P, .25% non-phytate P)
2. Basal + .05% P from monosodium phosphate
3. Basal + .10% P from monosodium phosphate
4. Basal + .15% P from monosodium phosphate
5. Basal + .15% P from low-ash meat and bone meal
6. Basal + .15% P from low and high ash meat and bone meal (50:50 blend)
7. Basal + .15% P from high-ash meat and bone meal
8. Basal + .15% P from 6-mesh meat and bone meal
9. Basal + .15% P from 12-mesh meat and bone meal
10. Basal + .15% P from 0 psi meat and bone meal
11. Basal + .15% P from 30 psi meat and bone meal
12. Basal + .15% P from 60 psi meat and bone meal

The basal diet (21.1% crude protein) consisted of 52.8% corn and 33.9% dehulled soybean meal. This diet was fortified with vitamins, minerals, corn oil, DL-methionine, L-threonine, and an antibiotic. This diet was adequate or above current NRC (1994) estimated requirements for all nutrients except P for the growing chick. Monosodium phosphate, technical grade calcium carbonate, and meat and bone meal were substituted for corn starch on an equal weight basis. Chromic oxide was included in all diets at .25%.

Growth rate, feed intake, and feed:gain data were obtained for the 15-day experiment. At the end of the study, the chicks were killed and tibias were removed for breaking strength determinations as previously described in the general procedures section of this report. Ileal digesta was collected according to previously described methods.

All of the performance and bone traits were linearly ($P<.01$) improved by the level of P provided by the monosodium phosphate. In some cases, the responses were also quadratic ($P<.01$). Addition of .15% phosphorus from meat and bone meal (averaged across all sources) produced responses that were inferior ($P<.03$) to that from the addition of .15% phosphorus from monosodium phosphate for all traits except growth rate. The only significant differences among meat and bone meal treatments were a particle size effect ($P<.03$) in favor of the coarser particle size on performance and all bone traits, and a linear effect of processing pressure ($P<.02$) in favor of the highest pressure on growth rate.

Based on slope-ratio of tibia strength and ash, the P in meat and bone meal was, on average, 81.5% as bioavailable as the P in monosodium phosphate. The bioavailability of P in meat and bone meal was not affected by ash content of the meal (79% for high-ash vs 82% for low-ash) nor by processing pressure (82% for control vs 85% for 60 psi additional pressure); however, P bioavailability did seem to be influenced by particle size of the meat and bone meal. The higher bioavailability of P in the coarser product (90 vs 73%) may have been due to a longer retention time in the crop and gizzard, a characteristic of coarse particle sized products.

In this experiment, the apparent ileal digestibility of amino acids was not improved with P supplementation of the low-P basal diet. There were slight numerical differences ($P<.15$) in the digestibility of certain amino acids between the two sources of P, with the diet supplemented with monosodium phosphate having higher values; however, most of this effect was due to the lower digestibilities of amino acids in the low-ash and the blended meat and bone meals compared with the other meat and bone meal treatments. There tended to be linear (P<.11) increases in apparent ileal digestibility for most of the essential amino acid as meat and bone meal ash content was increased (i.e., pork, 50:50 blend, beef). Amino acid digestibility was essentially unaffected by either processing pressure or particle size of the meat and bone meals.

As observed in the pig studies, adding P to the basal diet, regardless of whether it was supplied by monosodium phosphate or meat and bone meal, tended to improve (P<.10) the apparent ileal digestibility of dietary P. Ash content and particle size of meat and bone meal had no consistent effect of P digestibility, but greater P digestibility appeared to occur (though not significantly) as processing pressure increased (35, 40, 43% for 0, 30, and 60 psi, respectively).

Comparison of the Predicted and Observed Digestibility of Amino Acids

To compare the observed digestibility values in our experiments to those previously published, we calculated the predicted amino acid digestibilities in our diets based on the published values for the individual feed ingredients. The predicted values were calculated as the sum of the proportion of the feed ingredients in the diet multiplied by their respective amino acid digestibility coefficients. For the pig experiments, the digestibility coefficients were taken from the most current National Research Council publication, *Nutrient Requirements of Swine* (NRC, 1998). The digestibility coefficients used to calculate the predicted digestibility values for the chick experiment were obtained from Ravidran et al. (1999).

For the pig experiments, the predicted amino acid digestibility values (Table 2) were similar to the values that we obtained, though they were slightly lower. On average, the range for the percentage unit difference between the calculated and the observed values was –2.7 to 8.7 percentage units (Table 3). Similar results were observed in the chick experiment, with a range in values from .3 to 6.0 percentage unit difference (Table 4). Whether the higher values that we obtained in the blend of ingredients is due to associative effects from the blend of ingredients as compared to measures of the ingredients when fed alone is unknown. Several other researchers, however, have reported this same phenomenon in pigs (Imbeach et al., 1988; Hansen et al., 1991) and chicks (Angkanaporn et al., 1996; Ravindran et al., 1999).

Overall Summary of Apparent Ileal Digestibility of Nutrients

A summary of the apparent ileal digestibility values that we obtained for the four most important amino acids in swine and poultry diets (lysine, threonine, tryptophan, and methionine) is shown in Table 5. In the pig studies, the overall digestibility means for the diets containing meat and bone meal as the source of supplemental P were 87.0% for lysine, 79.7% for threonine, 85.4% for tryptophan, and 87.0% for methionine. The values were approximately 99% of the digestibility values for these same amino acids in the diets containing monosodium phosphate as the source of supplemental P. Similar values were obtained in the chick study except for methionine, which was higher than for the pig studies (93.5 vs 87.0%), but this may have been due to a greater proportion of methionine being supplied as highly available DL-methionine in the chick diets. In the chick diets, the relative digestibility values in meat and bone meal diets were 95 to 98% of those of the monosodium phosphate diets.

Ileal and total tract apparent digestibilities of dietary Ca in pigs fed the meat and bone meal diets averaged 53.5 and 37.2%, respectively (Table 6). Ileal and total tract apparent digestibilities of dietary P in the meat and bone meal diets averaged 41.6 and 28.0%, respectively. These digestibility values were 92, 93, 97, and 99% of the values for diets with monosodium phosphate as the P source. For chicks, the apparent ileal digestibility of Ca and P in the meat and bone meal diets were 111 and 87% of the digestibility values of diets containing monosodium phosphate.

These results confirm our previous work and indicate that meat and bone meal is an excellent source of Ca and P for both growing pigs and chicks. Furthermore, the digestiblities of amino acids in diets containing meat and bone meal as the source of supplemental P are within 99% of the digestibility of amino acids in corn-soybean meal diets in which supplemental inorganic P is used as a supplemental source of P. In chicks, the digestibilities of amino acids in diets containing meat and bone meal were 95 to 99% of the digestibilities of amino acids in corn-soybean meal diets.

Conclusions

The results of the research with meat and bone meal that was conducted at the University of Kentucky over the past three years indicate that meat and bone meal is an excellent source of amino acids, calcium and phosphorus for swine. Although the research was less extensive with poultry than with swine, similar conclusions can be drawn from this research.

Averaged across all of the studies, the P in meat and bone meal was 87% (based on slope-ratio studies of bone traits), 90% (based on total tract, true digestibility studies), and 97 to 99% (based on ileal and total tract apparent digestibility studies) as bioavailable as the P in monosodium phosphate for pigs. For chicks, these values for meat and bone meal were 82% (based on slope ratio) to 87% (based on ileal apparent digestibility) of the availability of P in monosodium phosphate, but they were based on only one study. In the pig studies, the lysine, threonine, tryptophan, and methionine (the four most limiting amino acids) in diets in which meat and bone meal supplied all of the supplemental Ca and P were 99% as digestible as the amino acids in corn-soybean meal diets in which the P and Ca were supplied by monosodium phosphate and calcium carbonate. For chicks, these amino acids were 95 to 99% as digestible in the diets containing meat and bone meal as in the corn-soybean meal diets.

Particle size of meat and bone meal did not consistently affect the bioavailability of P for swine, but chicks appeared to utilize the P better in the large vs small particle sized product. In pigs, the P in high-ash meat and bone meal of cattle origin seemed to be more bioavailable than that in low-ash meat and bone meal of pork origin. Subjecting meat and bone meal to excessive processing pressure did not negatively affect the bioavailability of P, and may have actually improved it. Particle size, source, or processing pressure of meat and bone meal had little effect on ileal digestibility of dietary amino acids in either pigs or chicks.

The new information generated from these studies and the studies summarized in our 1999 report to the Fats and Proteins Research Council gives us a better understanding of the nutritional value of meat and bone meal in nonruminant feeding. This new information is available to the scientific community as a result of abstracts published in the Journal of Animal Science, shown at the end of this report, and oral presentations given at the Midwestern Section and Annual Meetings of the American Society of Animal Science.

Information generated from this research should be of benefit to the swine, poultry, and feed industries. Greater quantities of meat and bone meal and other animal by-products are likely to be available for use in swine and poultry feeds because of the recent ruminant-to-ruminant feeding ban. The use of meat and bone meal in swine and poultry diets could increase as this new information is made available to nutritionists, who can now formulate diets that will more precisely meet the animal's requirement without having excessive nutrients. Excesses in dietary nutrients cause excessive nutrient excretion that ultimately contributes to environmental pollution.

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References

Angkanaporn, K., V Ravindran, and W.L. Bryden. 1996. Additivity of apparent and true ileal amino acid digestibilities in soybean meal, sunflower meal, and meat and bone meal for broilers. Poult. Sci. 75:1098-1103.

Burnell, T.W., G.L. Cromwell and T.S. Stahly. 1989. Bioavailability of phosphorus in meat and bone meal for pigs. J. Anim. Sci. 67(Suppl. 2):38.

Coffey, R.D. and G.L. Cromwell. 1993. Evaluation of the biological availability of phosphorus in various feed ingredients for growing pigs. J. Anim. Sci. 71 (Suppl. 1):66.

Coffey, R.D. and G.L. Cromwell. 1995. Phosphorus bioavailability in selected feedstuffs for chicks. Poult. Sci. 74(Suppl. 1):108.

Cromwell, G. L. 1979. Availability of phosphorus in feedstuffs for swine. Proc. Distillers Feed Res. Conf. Distillers Feed Research Council, Cincinnati, OH 34:40.

Cromwell, G.L., T.S. Stahly and H.J. Monegue. 1991. Amino acid supplementation of meat meal in lysine-fortified, corn-based diets for growing-finishing pigs. J. Anim. Sci 69:4898.

Cromwell, Gary L. 1998. Precision feeding to economically reduce excreted nutrients and odor. Proc. Intl. Symp. Animal Production Systems and the Environment, Des Moines, IA.

Cromwell,Gary L. and Richard D. Coffey.1993. An assessment of the bioavailability of phosphorus in feed ingredients for nonruminants. Proc. Maryland Nutr. Conf., Baltimore, MD pp 146-158.

Donkoh, A., P. J. Moughan, and W. C. Smith. 1994. Comparison of the slaughter method and simple T-piece cannulation of the terminal ileum for determining ileal amino acid digestibility in meat and bone meal for the growing pig. Anim. Feed Sci. Technol. 49:43-56.

Evans, D.F. and J. Leibholz. 1979. Meat meal in the diet of the early-weaned pig. Anim. Feed Sci. Technol. 4:33.

Hansen, I., T. Larsen, K.E. Bach Knudsen, and B.O. Eggum. 1991. Nutrient digestibilities in ingredients fed alone or in combinations. Br. J. Nutr. 66:27-35.

Huang, K.C. and G.L. Allee. 1981. Bioavailability of phosphorus in selected feedstuffs for young chicks and pigs. J. Anim. Sci. 53(Suppl. 1):248.

Imbeach, W., W.C. Sauer, and R. Mosenthin. 1988. The prediction of the digestible amino acid supply in barley-soybean meal or canola meal diets and pancreatic enzyme secretion in pigs. J. Anim. Sci. 66:1409-1417.

Kadim, I. T. and P. J. Moughan. 1977. Development of an ileal amino acid digestibility assay for the growing chicken-effect of time after feeding and site of sampling. Br. J. Nutr. 38:89-95.

Knabe, D. A. 1989. Apparent ileal digestibility of amino acids in meat and bone meal. Final Report. Fats and Protein Research Foundation., Inc Bloomington, IL.

Knabe, D. A., D. C. LaRue, E. J. Gregg, G. M. Martinez, and T. D. Tanksley. 1989. Apparent digestibility of nitrogen and amino acids in protein feedstuffs by growing pigs. J. Anim. Sci. 67:441-458.

NRC. 1988. Nutrient Requirements of Swine (9th Ed.). National Academy Press, Washington, DC.

NRC. 1994. Nutrient Requirements of Poultry (9th Ed.). National Academy Press, Washington, DC.

NRC. 1998. Nutrient Requirements of Swine (10th Ed.). National Academy Press, Washington, DC.

Poe, E. R., Jr, and D. B. Hudman. 1962. Effect of levels of meat and bone scraps on growth rate and feed efficiency of growing-finishing swine. J. Anim. Sci. 21:787.

Puchal, F., V.W. Hays, V.C. Speer, J.D. Jones, and D.V. Catron. 1962. The free blood plasma amino acids of swine as related to the source of dietary proteins. J. Nutr. 76:11.

Ravindran, V., L.I. Hew, G. Ravindran, and W.L. Bryden. 1999. A comparison of ileal digesta and excreta analysis for the determination of amino acid digestibility in food ingredients for poultry. Br. Poult. Sci. 40(2):266-274.

SAS. 1985. SAS Users Guide: Statistic (Version 5 Ed.). SAS Inst., Inc., Cary, NC.

Sell, J. L., and M. J. Jeffrey. 1996. Availability for poults of phosphorus from meat and bone meals of different particle sizes. Poult. Sci. 75:232.

Snedecor, G.W. and W.G. Cochran. 1989. Statistical Methods (8th Ed.). Iowa State University Press, Ames.

Waldroup, P.W. and M.H. Adams. 1994. Evaluation of the phosphorus provided by animal proteins in the diet of broiler chickens. J. Appl. Poultry Res. 3:209.

Wang, X. and C. M. Parsons. 1998. Effect of raw material source, processing systems, and processing temperatures on amino acid digestibility of meat and bone meals. Poult. Sci. 77:834-841.

Scientific Articles Resulting from this Research.

Traylor, S.L., G.L. Cromwell, and M.D. Lindemann. 1998. Bioavailability of phosphorus in meat and bone meal for growing pigs. J. Anim. Sci. 76(Suppl. 2):55.

Traylor, S.L., G.L. Cromwell, and M.D. Lindemann. 1998. Bioavailability of phosphorus in meat and bone meal of varying particle sizes for growing pigs. J. Anim. Sci. 76(Suppl. 1):172.

Traylor, S.L., G.L. Cromwell, and M.D. Lindemann. 1999. Bioavailability of phosphorus in low- and high-ash meat and bone meal of pork and beef origin for pigs. J. Anim. Sci. 77(Suppl. 1):60.

Traylor, S.L., G.L. Cromwell, and M.D. Lindemann. 1999. Evaluation of meat and bone meal as the sole source of supplemental Ca and P for finishing pigs. J. Anim. Sci. 77(Suppl. 1):66.

Traylor, S.L., G.L. Cromwell, and M.D. Lindemann. 1999. Bioavailability of phosphorus in meat and bone meal subjected to varying processing pressures for pigs. J. Anim. Sci 77(Suppl. 1):176.

Traylor, S.L., G.L. Cromwell, and M.D. Lindemann. 2000. Bioavailability of phosphorus in meat and bone meal varying in origin, particle size, and processing pressures for chicks. Abstract No. 123, Midwestern Section Meeting of the American Society of Animal Science, Des Moines, IA, March 13-15, 2000.

Table 1. Composition of meat and bone meal used in the experiments

Item, %	Particle size 6- and 12-mesh	Low-Ash Pork	Hi-Ash Beef	Processing Pressure 0 psi	30 psi	60 psi
Crude protein	44.8	59.7	40.0	49.8	49.5	50.0
Crude fat	9.0	9.8	9.6	7.7	7.4	7.2
Ash	32.3	23.1	42.7	35.1	34.0	33.4
Ca	10.9	7.4	14.3	12.3	12.0	10.9
P	5.5	3.7	7.1	5.8	5.7	5.2
Amino acids						
Arginine	3.13	4.01	2.91	3.53	3.57	3.42
Histidine	.75	1.19	.60	.79	.80	.78
Isoleucine	1.10	1.70	.94	1.26	1.29	1.27
Leucine	2.48	3.66	2.03	2.73	2.78	2.77
Lysine	2.15	3.07	1.86	2.30	2.28	2.21
Methionine	.58	.84	.47	.54	.54	.52
Cysteine	.35	.61	.27	.54	.44	.38
Met + Cys	.93	1.45	.74	1.08	.98	.90
Phenylalanine	1.75	2.03	1.17	1.54	1.54	1.55
Tyrosine	1.06	1.44	.67	1.02	.97	1.02
Phe + Tyr	2.81	3.47	1.84	2.56	2.51	2.57
Threonine	1.59	1.99	1.04	1.44	1.46	1.44
Tryptophan	.25	.37	.22	.31	.29	.29
Valine	2.26	2.52	1.57	1.88	1.92	1.93

Table 2. Calculated apparent ileal digestibility (%) of amino acids in meat and bone meal diets for pigs[a]

		Experiment											
		9813		9816			9817			9823			MBM
Amino acid	MSP[b]	Low-ash	Hi-ash	Low-ash	Blend	Hi-ash	0 psi	30 psi	60 psi	0 psi	30 psi	60 psi	Average
Thr	74.7	74.9	74.2	75.6	74.5	74.8	74.0	74.0	74.0	74.6	74.5	74.5	74.9
Cys	77.5	76.0	77.1	75.2	76.2	76.9	76.6	76.8	76.8	76.1	76.3	76.4	76.4
Val	80.2	80.0	79.9	80.1	79.7	79.9	79.8	79.8	79.8	79.8	79.8	79.7	79.8
Met	86.0	82.8	85.0	81.5	83.1	84.5	84.6	84.5	84.5	83.9	83.9	83.9	83.8
Ile	85.3	85.1	85.2	84.8	84.5	84.8	85.0	85.0	85.0	84.6	84.6	84.6	84.8
Leu	81.5	81.4	81.1	81.7	81.1	81.4	81.0	81.1	80.9	81.2	81.4	81.1	81.2
Tyr	84.3	83.8	84.0	83.8	83.5	84.0	83.7	83.7	83.6	83.6	83.6	83.5	83.7
Phe	83.6	83.5	83.4	83.6	83.1	83.4	83.2	83.2	83.2	83.2	83.2	83.1	83.3
His	84.4	84.1	84.0	84.2	83.7	84.2	83.8	83.8	83.8	83.9	83.9	83.9	83.9
Lys	80.3	80.3	79.6	81.3	80.2	80.5	79.3	79.3	79.3	80.2	80.2	80.2	82.0
Arg	85.1	85.4	84.8	85.7	84.7	84.9	84.7	84.7	84.7	84.8	84.8	84.7	84.9
Trp	76.6	75.9	75.8	76.7	76.1	76.6	75.4	75.4	75.4	76.1	76.1	76.1	78.4

[a]Based on ingredient ileal digestibility values from NRC (1998).
[b]Average of the MSP diets for the four experiments.

Table 3. Percentage unit differences between observed minus calculated apparent ileal digestibility of amino acids in meat and bone meal diets for pigs[a]

		Experiment											
		9813		9816			9817			9823			MBM
Amino acid	MSP[b]	Low-ash	Hi-ash	Low-ash	Blend	Hi-ash	0 psi	30 psi	60 psi	0 psi	30 psi	60 psi	Average
Thr	5.6	9.8	9.1	2.1	4.8	11.2	4.1	4.7	-1.5	4.7	11.5	11.5	5.2
Cys	3.4	10.2	9.2	-1.4	-0.5	7.8	2.6	-0.6	-5.6	-0.4	8.4	8.3	2.9
Val	4.3	7.8	6.7	1.0	2.7	9.8	2.3	2.7	-3.5	2.6	9.9	10.0	4.0
Met	1.6	7.1	5.3	3.4	1.0	7.3	2.6	2.2	0.8	0.2	7.9	7.9	3.5
Ile	-0.5	3.0	2.5	-2.2	-0.4	5.9	-4.1	-4.5	-9.8	-0.5	6.1	6.1	.2
Leu	5.4	9.2	8.7	0.9	3.0	9.3	5.0	5.2	1.6	2.9	9.3	9.6	5.0
Tyr	0.9	4.8	3.9	-1.3	-0.3	6.3	-1.5	-1.8	-6.8	-0.4	6.7	6.8	1.3
Phe	3.4	6.4	5.8	0.9	1.7	7.6	2.5	2.6	-1.9	1.6	7.8	7.9	3.3
His	3.7	6.3	5.3	0.3	2.3	6.7	2.9	3.6	-1.3	2.1	7.0	7.0	3.3
Lys	5.0	5.9	6.2	3.9	5.6	10.3	3.6	4.3	1.8	5.5	10.6	10.6	5.3
Arg	5.9	7.2	7.3	3.7	4.3	8.5	4.4	4.2	0.5	4.2	8.6	8.7	4.7
Trp	9.8	13.4	10.2	7.0	8.2	9.5	5.5	5.7	-6.3	8.2	9.9	10.0	6.3
Average	4.0	7.5	6.6	1.5	2.7	8.4	2.4	2.3	-2.7	2.6	8.6	8.7	

[a]Based on the ingredient ileal digestibility values from NRC (1998).
[b]Average of the MSP diets for the four experiments.

Table 4. Calculated and percentage unit difference between the observed minus the calculated ileal digestibility of amino acids in meat and bone meal diets for broiler chicks

		Meat and bone meal								
	MSP	Low-ash	Blend	Hi-ash	6-mesh	12-mesh	0 psi	30 psi	60 psi	Average
Calculated ileal digestibility, %[a]										
Thr	73.4	71.9	71.9	72.7	72.0	72.0	72.2	72.1	72.0	72.1
Val	81.0	80.0	79.7	80.3	79.8	79.8	80.0	80.0	79.9	79.9
Met	95.3	94.2	94.3	94.8	94.5	94.5	94.6	94.6	94.6	94.5
Ile	81.3	80.4	80.2	80.8	80.5	80.5	80.4	80.4	80.3	80.5
Leu	84.6	83.7	83.4	84.0	83.7	83.7	83.7	84.1	83.5	83.7
Tyr	84.5	83.6	83.4	84.0	83.5	83.5	83.6	83.7	83.5	83.6
Phe	85.3	84.7	84.6	84.9	84.6	84.6	84.7	84.7	84.6	84.7
Lys	84.4	82.9	82.5	83.4	82.9	82.9	82.9	82.9	82.8	82.9
Arg	88.1	86.6	86.4	87.1	86.7	86.7	86.6	86.6	86.5	86.7
Percentage unit differences[b]										
Thr	11.0	2.4	9.6	10.3	11.7	10.2	3.6	6.0	8.0	7.7
Val	5.7	2.4	5.9	4.9	7.7	6.4	2.4	3.6	5.0	4.8
Met	.3	-2.0	-.7	-.3	.7	-.8	-2.4	.6	-.9	-.9
Ile	15.3	2.1	6.3	4.6	7.4	6.3	2.1	4.0	5.2	4.7
Leu	4.3	-.7	3.5	3.3	4.8	3.3	-.7	.8	2.6	2.1
Tyr	3.6	-3.5	1.9	2.0	3.5	1.4	-3.5	-1.4	.7	.1
Phe	3.5	-1.7	3.0	1.8	3.9	2.6	-1.7	-.3	2.2	1.2
Lys	6.0	2.7	6.1	5.4	7.0	6.2	2.7	3.2	4.8	4.8
Arg	4.2	1.4	4.0	3.8	5.2	4.3	1.4	1.9	3.7	3.2
Average	6.0	.3	4.4	4.0	5.8	4.4	.4	1.9	3.5	3.1

[a]Based on the ileal digestibility values reported by Ravindran et al., 1999. Ileal digestable values for histidine, cystine, and tryptophan were not given by Ravindran.
[b]Calculated as the difference between the observed minus the predicted ileal digestibility values.

Table 5. Summary of selected ileal amino acid digestibilities

	Amino acid							
	Lysine		Threonine		Tryptophan		Methionine	
Diet:	MSP	MBM	MSP	MBM	MSP	MBM	MSP	MBM
Pig Exp.								
9813	87.5	87.8	83.4	84.0	89.8	90.3	89.9	90.1
9816	87.5	89.2	78.7	81.0	86.6	86.9	86.3	86.9
9817	87.4	84.4	80.7	76.4	87.0	79.7	88.4	86.4
9823	87.4	86.4	78.1	77.4	82.0	84.5	85.1	84.5
Average	87.5	87.0	80.2	79.7	86.4	85.4	87.4	87.0
% of MSP		99		99		99		99
Chick Exp.								
9906	88.0	87.3	84.4	79.8	89.7	86.5	95.6	93.5
% of MSP		99		95		96		98

Table 6. Summary of ileal and total tract digestibility (%) of calcium and phosphorus in diets

	Ileal Calcium		Total tract Calcium		Ileal Phosphorus		Total tract Phosphorus	
	MSP	MBM	MSP	MBM	MSP	MBM	MSP	MBM
Pig Exp.								
9813	55.6	58.2	39.7	39.3	33.6	34.5	28.9	29.0
9816	68.0	56.9	41.2	36.7	46.2	42.1	24.5	27.6
9817	41.1	39.2	28.2	28.6	35.1	41.5	23.3	26.1
9823	68.4	59.5	51.3	44.1	55.9	48.2	36.5	29.3
Average	58.3	53.5	40.1	37.2	42.7	41.6	28.3	28.0
% of MSP		92		93		97		99
Chick Exp.								
9906	42.7	47.2	-	-	50.7	44.0	-	-
% of MSP		111				87		