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ASSESSMENT OF THE BIOAVAILABILITY OF PHOSPHORUS IN MEAT AND BONE MEAL FOR GROWING-FINISHING PIGS

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Background

Rendering and meat packing by-products, such as meat and bone meal have long been considered good sources of protein and are commonly used at low levels in commercial swine feeds. In addition to their high lysine content, they are also good sources of calcium (Ca), phosphorus (P), and B-complex vitamins (NRC, 1998).

A number of the early studies with meat and bone meal indicated that performance of weanling and growing-finishing pigs was linearly depressed as increased levels of meat and bone meal replaced soybean meal in corn-based diets. (Peo and Hudman, 1962; Puchal et al., 1962; Evans and Leibholz, 1979). At that time, it was thought that the reduction in performance may have been due to reduced palatability, excessive Ca and P intakes, or a poorer balance of amino acids in the meat and bone meal-supplemented diets.

More recent studies conducted at the University of Kentucky in the early 1990s indicated that the reduction in performance that researchers have consistently observed when meat and bone meal was included at high dietary levels is most likely due to a deficiency of the amino acid, tryptophan, in meat and bone meal supplemented diets (Cromwell et al., 1991). In three large studies, we clearly demonstrated that optimal performance of growing-finishing pigs could be achieved, even with relatively large amounts of meat and bone meal in the diet, if the diets were supplemented with tryptophan. We concluded that for every 10% meat and bone meal in the diet, .03% tryptophan also was required to optimize performance of pigs.

Meat and bone meal is a good source of Ca and P. Although the Ca and P is variable, most products contain between 7 to 10% Ca and 3.5 to 5.0% P. Because of its high levels of these minerals, diets containing 3 to 5% meat and bone meal may contain ample Ca and P to meet the pigs requirements for total Ca and P. However, this is true only if the Ca and P are highly available.

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 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). More recent 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).

The reason for this major 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 the our area. Particle size of meat and bone meals did not affect its utilization by poults (Sell and Jeffrey, 1996), but research is needed to establish the effects of particle size of meat and bone meal on its bioavailability of P in pigs.

A better understanding of the bioavailability of P in meat and bone meal, especially for pigs, is of paramount importance for several reasons:

First, the BSE (bovine spongiform. encephalopathy) or "mad cow" scare is very likely to result in a ban on feeding ruminant-derived, animal protein source back to ruminants in the USA, much like the ban that was imposed in the United Kingdom in 1988. This would mean that meat meal, meat and bone meal, and other animal derived protein sources will be available in greater supply for feeding of pigs and poultry;

Second, tryptophan is now available as a supplement (TryptazineO) that can be added rather inexpensively to diets which will permit the use of even higher levels of meat and bone meal and other meat byproducts in swine diets;

Third, greater usage of meat and bone meal in swine diets will 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 meat and bone meal is essential in order for this byproduct to be effectively utilized in swine and poultry feeds.

Objectives

1.To determine the bioavailability of phosphorus in meat and bone meal for pigs.

2.To assess the effects of particle size and other factors on the bioavailability of phosphorus in meat and bone meal for pigs.

3.To assess high levels of meat and bone meal as a source of protein, calcium, and phosphorus in diets for growing-finishing pigs.

Experimental Procedures

General Procedures. A total of ten experiments were conducted over a 2-year period. Crossbred pigs (originating from Hampshire e x Yorkshire-Landrace ?) were used in the studies. They were randomly allotted to treatments from outcome groups of weight and gender.

In each experiment, the sources of meat and bone meal were obtained based upon consultation with the 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.

Three types of experiments were conducted to assess the bioavailability and nutritional value of meat and bone meal for pigs.

Slope-Ratio Experiments. This procedure was developed in our laboratory and we have used it for over 20 years to determine P bioavailability in feedstuffs for pigs (Cromwell, 1979; Cromwell and Coffey, 1993). The procedure utilizes crossbred pigs initially averaging 30 to 40 1b. They are individually penned in slatted floor pens in a temperature controlled building. Generally, there are five or more replications per treatment. Feed and water are provided on an ad libitum basis and the pigs are weighed weekly.

Dietary treatments include a low P basal diet consisting of corn, soybean meal, and a dextrose-starch mixture, fortified with adequate levels of all nutrients except P. In this diet, all of the P is supplied by the corn and soybean meal; thus, it is largely in the form of phytate and the P is poorly available. Other diets include several levels of meat and bone meal, substituted for the dextrose-starch, that provide graded levels of P to the diet. Another set of diets include graded additions of monosodium phosphate added to provide the same levels of P as supplied by the meat and bone meal. Calcium is maintained at a constant level (generally .65%) in all diets, using calcium carbonate. Tryptophan is added to provide 3 grams of tryptophan for every 1,000 grams of meat and bone meal.

After a 5-6 week feeding period, the pigs are killed, the femurs are removed from the hams, and the 3rd and 4th metacarpals and metatarsals are removed from the feet. The bones were cleaned, then subjected to breaking strength determinations with an Instron machine. Breaking strength is defined as the amount of force applied at the center of the fresh bone when placed horizontally on two supports spaced 7.0 cm (femurs) or 3.2 cm (metacarpals and metatarsals) apart. The metacarpals or metatarsals are then dried, extracted with ether, and ashed.

The bone strength and ash data are statistically analyzed to determine the slope of the responses when regressed on dietary P intake of the pigs. The basal diet is used in calculating the regressions of each P source. A comparison of the two slopes gives the relatively bioavailability of the P in meat and bone meal (relative to the bioavailability of P in monosodium, phosphate, which is given a value of 100). The bioavailabilities based on the (1) femurs, (2) mean of metacarpalsmetatarsals, and (3) ash content in grams of the metacarpals or metatarsals are then averaged to give an overall estimate of the relative bioavailability of the meat and bone meals.

Digestibility Experiments. These experiments are designed to determine the apparent digestibility (or absorption) and apparent retention of Ca and P in meat and bone meal compared with monosodium phosphate. In addition, a basal diet is used and calculations are made to correct for the digestibility of the basal ingredients along with the endogenous P in order to estimate the true digestible Ca and P in meat and bone meal, according to the following procedure. The apparent absorbed Ca and P of pigs fed the basal diet is subtracted from the apparent absorbed Ca and P of pigs fed the experimental diets. This calculation of net absorption of Ca and P then allows one to estimate the percentage of the Ca and P in the meat and bone meal and in the calcium carbonate-monosodium phosphate combination that was absorbed, in that it corrects for endogenous P and the undigested P in the basal ingredients (corn and soybean meal). This process allows one to estimate the true digestion (or absorption) of the P and Ca in meat and bone meal.

Twelve stainless steel metabolism crates designed for separate collection of feces and urine are used in the balance experiments. They are in a temperature controlled room. Crossbred barrows are placed in the crates, fed a common diet, and allowed to adjust for a 1-2 week period. They are then fed their experimental diets for 4 days followed by a 5-day experimental (collection) period. Feeding level are equalized within each replication. Carmine indigo (.5%) or ferric oxide (.75%) is included in the morning feed of day I and of day 6 to mark the beginning and end of the 5-day collection period. Urine is collected daily and feces is collected twice daily and frozen for later analysis of Ca and P.

At the end of the collection period, the pigs are switched, within each replication, to a different diet and the process is repeated. This results in six to twelve replications for each treatment.

Growing-Finishing Experiment. Growing-finishing experiments involve the feeding of practical corn-soybean meal diets with graded levels of added P provided by meat and bone meal or by mono-dicalcium phosphate. All diets are fortified with salt, vitamins and trace minerals, and calcium carbonate is added to keep the Ca:P ratio at 1.2: 1. Lysine is maintained at a common level across all diets, and tryptophan is added to supply 3 grams for every 1,000 grams of meat and bone meal. Each diet is fed to a minimum of four pens of five pigs per pen from approximately 50 to 240 lb body weight.

Pigs are weighed and feed intake determined biweekly. From these measurements, daily gain, daily feed intake, and feed:gain are calculated. At the end of the test, the barrows are slaughtered at a commercial packing plant and the front feet are recovered. The third and fourth metacarpals are removed and breaking strength is determined as previously described.

Processing and Presentation of Data. All of the data in each experiment were subjected to statistical analysis using standard analysis of variance procedures (stat reference, 1989) and utilizing the Statistical Analysis System (SAS, 1986). A summary of each experiment, including a title page with pertinent information on the study, and the composition of the diets is included with this report.

Experimental Results Obtained for Each Objective

Objective 1 - Determine the bioavailability of phosphorus in meat and bone meal for pigs. Three experiments were conducted. The first experiment was a balance study to determine the best type of diet to use in subsequent balance experiments. The second experiment was a balance study to assess the effects of meat and bone meal as a source of supplemental P and Ca on P and Ca digestibility and retention in finishing pigs. The third experiment was a growth study to determine the bioavailability of P in meat and bone meal relative to that in bioavailability of P in monosodium phosphate.

Experiment 9712. In this experiment, two types of diets were evaluated for subsequent balance trials; a starch-dextrose-soybean meal diet and a corn-soybean meal diet. The starchdextrose-soy diet is the type of diet that we have previously used in most of our P bioavailability experiments. The corn-soy diet is a practical type diet that we think would be appropriate to use in experiments where high-P ingredients such as meat and bone meal are evaluated. Both basal diets were low in P (starch-dextrose-soy diet was . 18% P; corn-soy diet was .3 1 % P). Treatments I and 3 were the basal diets. Meat and bone meal was added to supply .15% supplemental P in diets 2 and 4. The meal used in this study analyzed 57% crude protein, 6.8% Ca and 3.8% P, so it would actually be classified as meat meal rather than meat and bone meal.

Each diet was fed to eight finishing pigs penned in stainless steel metabolism cages for a 5day fecal and urine collection period to determine Ca and P balance. The initial and final weights of the pigs were 120 and 167 lb. Diets were switched within replication such that there were eight replications per treatment.

The apparent absorption of P in the starch-dextrose-soy diet was 45% compared with 33% in the corn-soy diet. Apparent absorption of Ca was 65 and 57%, respectively. The corrected (true) absorption of P in meat meal was 58% in the starch-dextrose-soy diet and 62% in the corn-soy diet. Corresponding values for true Ca absorption was 65 and 63%, respectively. True retention (expressed as % of absorbed) of P was 100% and of Ca was 100 to 106%. Because the true absorption of Ca and P were very similar for the two types of diets, we decided to use the cornsoy basal diet in subsequent balance experiments.

Experiment 9715. The second experiment was a balance trial involving 12 pigs from 119 to 184 lb body weight. Three diets were evaluated: (1) a low P, corn-soybean meal basal diet, (2) the basal with .125% added P and .25% added Ca from meat and bone meal, and (3) the basal diet with the same levels of P and Ca from monosodium phosphate and calcium carbonate. After each collection period, diets were switched within replications such that there were 12 replications per treatment; however one replication was discarded due to abnormal results. The meat and bone meal analyzed 5 1 % protein, 10.0% Ca and 5. 0% P.

The true absorption estimates of both P and Ca in the meat and bone meal were unusually high for some unknown reason in this experiment. The true absorption was 104% for meat and bone meal and 102% for monosodium phosphate. Corresponding values for Ca were 123 and 118%. True retention (% of absorbed) of P was 99 and 100% for P and 113 and 102% for Ca, respectively.

Even though the estimated absorption and retention values were high in this experiment, the data indicate that there was very little difference between the two sources of P and Ca with respect to P and Ca availability to the animal.

Experiment 9716. This experiment was a growth study that assessed the relative bioavailability of P in meat and bone meal compared with the P in monosodiurn phosphate. Pigs initially averaging 38 lb were individually penned and fed seven diets: (1) a low P (.34% P) basal diet with no supplemental P, the basal diet with three graded levels of meat and bone meal to supply (2) .067%, (3) .133%, and (4) .20% added P, and the basal diet with three graded levels of monosodiurn phosphate to supply the same levels of added P as in the meat and bone meal diets (Treatments 5, 6, and 7). The level of Ca was held constant (.70%) in each diet. The meat and bone meal source was the same as used in Exp. 2. There were five replications per treatment. Pigs were on test for approximately 6 weeks, then they were killed and metatarsal, metacarpal, and femur bones were collected for breaking strength and ash determmiations.

Performance and bone mineralization improved with increasing level of dietary P, regardless of source. The bone breaking strength data and the bone ash data were subjected to slope-ratio analysis, and two methods of calculating slope-ratio were used (forced vs unforced intercept). Based on an average of the two methods and on both bone strength and ash, the bioavailability of P in the meat and bone meal averaged 91%, relative to the bioavailability of P in monosodium phosphate.

Objective 2 - Assess the effects of particle size and other factors on the bioavailability of phosphorus in meat and bone meal for pigs.
Several experiments related to this objective were conducted to determine the effects of particle size of meat and bone meal, source (beef vs pork, representing high and low ash content) of meat and bone meal, and processing temperature of meat and bone meal on the bioavailability of P.

Experiments on Particle Size of Meat and Bone Meal

With assistance from Steve Thomas, Griffin Industries, we identified a source of meat and bone meal for the particle size studies. The meat and bone meal analyzed 44.8% protein, 10.9% Ca and 5.5% P. Cracks were ground in a hammer mill to various degrees of fineness in the Grain Science

Department at Kansas State University in cooperation with Dr. Keith Behnke. Three particle sizes were selected based on the amount that passed through 6, 8, or 12-mesh screens (representing coarse, medium and fine) for subsequent determination of P bioavailability using both balance and slope-ratio procedures.

Experiment 9727. This was a balance study involving 12 barrows. Four treatments included a low-P, low-Ca basal diet and three diets with .125% added P and .25% added Ca from the coarsest (6-mesh) and finest (12-mesh) particle sizes of meat and bone meal and from highly available sources of P (monosodium. phosphate) and Ca (calcium carbonate). After each collection period, diets were switched within replications such that there were nine replications per treatment. Average weight of the barrows were 116 and 189 lb at the beginning and end of the study.

The true absorption of P was 53 and 56% in the 12-mesh and 6-mesh meat and bone meals,respectively, compared with 78% for the monosodium. phosphate. Corresponding values for Ca were 58, 58, and 60%, respectively. True retention, as percent of absorption was similar for the two sources of meat and bone meal vs monosodium phosphate (98 and 96 vs 88% for P; 111 and 110 vs 119% for Ca). The results indicate that particle size had no effect of P or Ca absorption, and both were slightly less than the absorption of the P and Ca from monosodium. phosphate and calcium carbonate.

Experiment 9728. A growth study was conducted. Thirty-six pigs averaging 36 lb were fed a low-P (.34% P) basal diet (similar to that used in Experiment 9716), the basal diet with two levels of added P (.10 and .20%) from monosodium phosphate, or the basal with .20% added P from the three particle sizes of meat and bone meal. The Ca level was maintained at .70% in all diets. Diets were fed for 35 days, then all pigs were killed.

Performance and bone traits were improved by increasing the dietary P level, and there were no differences among the sources of P (monosodium phosphate or the three particle sizes of meat and bone meal) at the highest level of added P. The bioavailability of P averaged 86, 94, and 90% for the 6-mesh, 8-mesh, and 12-mesh particle sizes, with an overall average of 90%. The results indicate that particle size within the range tested has very little effect on the bioavailability of P in the meal.

Experiments on Source of Meat and Bone Meal

Meat and bone meal originating from swine is considerably higher in protein content and considerably lower in ash content that meat and bone meal originating from cattle. We obtained two sources of meat and bone meal for this study; one originating from packing plants that killed only hogs and one from a plant that killed only cattle. The analysis for the pork and beef sources were: crude protein, 59.7, 40.0%; ash, 23.1, 42.7%; Ca, 7.4, 14.3; P, 5.5, 7. 1 %. Particle size was similar for the two sources.

Experiment 9813. This was a balance study involving 12 barrows. Four treatments included a low-P, low-Ca basal diet and three diets with .125% added P and .25% added Ca from the pork (low-

ash) and beef (high-ash) sources of meat and bone meal and from highly available sources of P (monosodium phosphate) and Ca (calcium carbonate). Diets were switched within replication after each collection period such that there were six replications per treatment. Average weight of the barrows were 126 and 191 lb at the beginning and end of the study.

The true absorption of P was 81 and 83% in the low-ash and high-ash meat and bone meals, respectively, compared with 86% for the monosodium phosphate. Corresponding values for Ca were 76, 79, and 64%, respectively. True retention, as percent of absorption was similar for the two sources of meat and bone meal vs monosodium phosphate (98 and 99 vs 97% for P; 103 and 89 vs 112% for Ca). The results indicate that source of meat and bone meal (pork vs beef representing low-ash vs high-ash) had no effect of P or Ca absorption, and both were slightly less than the absorption of the P and Ca from monosodium phosphate and calcium carbonate.

Experiment 9816. Thirty-six pigs averaging 28 lb were fed a low-P (.34% P) basal diet (similar to that used in Experiments 9716 and 9728), the basal diet with two levels of added P (.10 and .20%) from monosodium phosphate, or the basal with .20% added P from the three sources meat and bone meal. The three sources were pork (low ash), beef (high ash), and a 50:50 blend of pork and beef meat and bone meal (intermediate ash). Diets were fed for 35 days, then all pigs were killed.

Performance and bone traits were improved by increasing the dietary P level, and there were no differences among the sources of P (monosodium phosphate or the three particle sizes of meat and bone meal) at the highest level of added P. The bioavailability of P averaged 72, 82, and 89% for the low-ash pork, blend, and high-ash beef meat and bone meal. The bioavailability of P increased linearly ($P<.02$) with increasing ash content of the meat and bone meal. The overall average of P bioavailability was 81%. The results indicate that ash content of meat and bone meal had an effect on the bioavailability of P in the meal, with high-ash meat and bone meal of bovine origin being more highly available than the P in low-ash meat and bone meal of pork origin.

Experiments on Processing Temperature/Pressure of Meat and Bone Meal.

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 analyzing 50% crude protein, 12.0% Ca, and 5.7% P 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.

Experiment 9817. This was a balance study involving 10 barrows. Five treatments included a low-P, low-Ca basal diet and diets with .125% added P and .26% added Ca from monosodium phosphate and calcium carbonate or from the three sources of meat and bone meal that had been subjected to 0, 30, or 60 psi additional pressure. Diets were switched within replication after each collection period such that there were eight replications per treatment. Average weight of the barrows were 139 and 212 lb at the beginning and end of the study.

The true absorption of P was 85, 76, and 81% for the 0, 30, and 60 psi meat and bone meals, respectively, compared with 88% for the monosodium. phosphate-calcium carbonate diet. Corresponding values for Ca were 72, 56, and 68% for the three psi meat and bone meals compared with 70% for the monosodium phosphate-calcium carbonate diet. The results indicate that excessively high processing pressure did not have any consistent negative effect on true digestion and absorption of P or Ca absorption. True absorption of both P and Ca were slightly less than the absorption of the P and Ca from monosodium phosphate and calcium carbonate.

Experiment 9823. Thirty-six pigs averaging 34 lb were fed a low-P (.34% P) basal diet (similar to that used in Experiments 9716, 9728, and 9816), the basal diet with two levels of added P (. 10 and .20%) from monosodium phosphate, or the basal with .20% added P from the meat and bone meal subject to additional processing of 0, 30, or 60 psi. The Ca level was maintained at .70% across all diets. Diets were fed for 35 days, then all pigs were killed and bones were collected.

Performance and bone traits were improved by increasing the dietary P level. There were no differences in performance traits among pigs fed the various sources of P (monosodium phosphate or the three processing pressures of meat and bone meal) at the highest level of added P; however, breaking strength of bones were greater ($P<.05$) in pigs fed monosodium phosphate as compared with the meat and bone meals. The bioavailability of P averaged 80,81, and 91% for the control, 30, and 60 psi meat and bone meals, with an overall average of 84%.

The results indicate that excessively high processing temperature/pressure of meat and bone meal, which it may negatively impact amino acid bioavailability, has no negative effects on the bioavailability of P in the meat and bone meal.

Objective 3 - Assess high levels of meat and bone meal as a source of protein, calcium, and phosphorus in diets for growing-finishing pigs.

Experiment 9807. The purpose of this experiment was to assess the use of meat and bone meal as a source of P and Ca, as well as amino acids, in practical corn-based diets for finishing pigs. The study was conducted at the UK swine research farm and involved 100 finishing pigs initially averaging 99 lb body weight. There were four treatments and five replications of five pigs per pen. The pigs were housed in an open-front building with concrete floors in 4 ft x 22 ft pens. Each pen was equipped with a 2-hole wooden feeder and an automatic watering fountain. The experiment was conducted during the summer.

Four diets were fed during two phases (Phase 1 from 99 to 172 lb; Phase 2 from 172 to 242 lb. Diets 1 and 2 were fortified corn-soybean meal diets with feed grade mono-Dicalcium phosphate as the source of supplemental P. These diets were formulated to contain .45 and .40% (Diet 1) or .55 and .50% (Diet 2) total P during the two phases, respectively. The Ca levels were .50 and .45% (Diet 1) and .65 and .55% (Diet 2), during the two phases. Diets 3 and 4 contained meat and bone meal as the source of Ca and P at the same levels of Ca and P as in Diets I and 2, respectively. These lower levels of Ca and P represent diets containing NRC (1998) estimated Ca and P requirements, and the high levels of Ca and P represent a slight overage of Ca and P that is somewhat typical of the levels recommended by many universities and feed companies.

Adjustments were made in the amounts of corn and soybean meal such that all diets contained .76 and .65% lysine during the two phases.

All pigs were scanned by real-time ultrasound at approximately 230 lb, and all pigs were killed at the end of the study in a commercial packing plant. The front feet were collected and the third and fourth metacarpal bones were subjected to breaking strength measurements.

Growth rate was slightly greater for the meat and bone meal treatments during Phase 2 and over the entire test, but the difference was not significant. Feed:gain was improved during these periods (P<. 10) in the meat and bone meal fed pigs. Performance was not affected by Ca and P levels and there was no evidence of an interaction between source and level of Ca and P.

Carcass traits were not affected by source of levels of Ca and P. However, bone breaking strength was greater (P<.Ol) in pigs fed the higher levels of Ca and P. Bone strength tended to be slightly higher for pigs fed meat and bone meal as a source of Ca and P, but the differences were not significant.

The results indicate that meat and bone meal can be used as the sole source of supplemental Ca and P in practical, corn-soybean meal diets for finishing pigs.

Conclusions

The results of these studies clearly show that the bioavailability of P in meat and bone meal is relatively high for the growing pig. Based on digestibility studies, the estimated true digestibility (or true absorbability) of the P in meat and bone meal averaged 80% of the consumed P, as summarized in Table 2. This value compares with a true digestibility of the P in monosodium. phosphate of 89%. Therefore the true digestibility of P in meat and bone meal was 90% relative to that of monosodium phosphate. Similar conclusions can be reached from the slope-ratio procedures of bone traits obtained from in the growth experiments, as is also summarized in Table 2. The overall average for P bioavailability in meat and bone meal was 87% of that of monosodium. phosphate.

The results of these studies also indicated that particle size of meat and bone meal and subjecting the meal to excessive temperature had little effect on the bioavailability of P. Ash content of meat and bone meal did seem to have some effect on P bioavailability with high-ash meal originating from cattle appearing to have higher P bioavailability estimates than low ash meal originating from swine.

Some of these new data were used as the basis for the estimated P bioavailability of 90% for meat and bone meal in the feed composition table in the 1998, 10th edition of Nutrient Requirements of Swine, the most widely used nutrition guide in the world. Without these data, the estimated would likely have been listed as 60 to 70%, as concluded from earlier studies (Cromwell and Coffey, 1993).

Because of the new information generated from this research, we now have a much better understanding of the nutritional value of meat and bone meal in nonruminant feeding. This new information is readily available to the scientific community as a result of papers presented at

sectional meetings and at annual meetings of the American Society of Animal Science, and as a result of the publications listed at the end of this report.

The more accurate estimate of 88-90% bioavailability of P should allow feed manufacturers of swine feed to utilize more meat and bone meal in their formulas. This new information will allow nutritionist to more accurately meet the available P requirements of swine without running the risk of having marginal deficiencies or without overfortifing diets with excessive P that contributes to environmental pollution.

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Table 1. Composition of Meat and Bone Meal Used in the Experiments

	Experiment No.								
		9715	9727		9813 and 9816		9817 and 9823		
Item, %	9712	9716	9728	9807	Pork	Beef	0 psi	30 psi	60 psi
Crude protein	57.1	50.7	44.8	54.0	59.7	40.0	49-.8	49.5	50.0
Crude fat	10.0	6.4	9.0	10.5	9.8	9.6	7.7	7.4	7.2
Ash	25.0	34.7	32.3	27.9	23.1	42.7	35.1	34.0	33.4
Ca	6.8	10.0	10.9	9.6	7.4	14.3	12.3	12.0	10.9
P	3.8	5.0	5.5	4.4	3.7	7.1	5.8	5.7	5.2
Amino acids									
Arginine	3.95	3.49	3.13	3.84	4.01	2.91	3.53	3.57	3.49
Histidine	1.06	.82	.75	.80	1.19	.60	.79	.80	.78
Isoleucine	1.80	1.39	1.10	1.65	1.70	.94	1.26	1.29	1.27
Leucine	3.62	3.01	2.48	3.32	3.66	2.03	2.73	2.78	2.77
Lysine	2.85	2.26	2.15	2.29	3.07	1.86	2.30	2.28	2.21
Methionine	.82	.57	.58	.63	.84	.47	.54	.54	.52
Cysteine	.90	.69	.35	1.07	.61	.27	.54	.44	.38
Met + Cys	1.72	1.26	.93	1.70	1.45	.74	1.08	.98	.90
Phenylalanine	2.04	1.75	1.41	1.89	2.03	1.17	1.54	1.54	1.55
Tyrosine	1.36	1.06	.92	1.18	1.44	.67	1.02	.97	1.02
Phe + Tyr	3.40	2.81	2.33	3.07	3.47	1.84	2.56	2.51	2.57
Threonine	1.98	1.59	1.33	1.75	1.99	1.04	1.44	1.46	1.44
Tryptophan	.40	.25	.26	.30	.37	.22	.31	.29	.29
Valine	2.61	2.26	1.70	2.64	2.52	1.57	1.88	1.92	1.93

Table 2. Summary of Overall Estimates of True P Digestibility and P Bioavailability of Meat and Bone Meal Relative to Monosodium Phosphate as Determined by Digestibility and Slope-Ratio Experiment[ab]

	Based on Digestibility			Based on Slope-Ratio	
Experiment No.	True digest-ability of P in MSP (%)	True digest-ability of P in MBM (%)	NMM relative to MSP	Experiment No.	Bioavail ability of Pmi MBM
9712		60			
9715	102	104	102	9716	91
9727	78	54	69	9728	90
9813	86	82	95	9816	81
9817	88	81	92	9823	84
Average [d]	89	80	90		87

[a]Average of the various meat and bone meals evaluated in the variou p men .
[b]NMM = meat and bone meal; MSP = monosodium phosphate.
[c]Relative to monosodium. phosphate which is considered 100%.
[d]The value from Experiment 9712 is not included in the average because monosodium phosphate was not included in that experiment.