RENDERED PRODUCTS IN POULTRY NUTRITION

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Summary

The poultry industry in the United States has a long history of using rendered products in its rations. Rendered fats are generally lower in cost than vegetable oils such as soybean oil, which is used substantially in other countries. This allows for higher inclusion rates of fat and thus higher energy diets. These higher energy diets provide faster growth and improved feed conversion, providing a competitive advantage to the U.S. poultry industry. Rendered protein sources are also a boon to the poultry industry. A variety of high quality products are available including meat and bone meal (MBM), poultry by-product meal (PBM), and feather meal (FeM). Each of these is an excellent source of specific nutrients and generally provides a cost-effective source of protein. MBM provides an excellent source of amino acids and phosphorus. PMB provides even higher levels of protein and energy as well as acting as an excellent source of phosphorus. FeM is very high in sulfur amino acids. Combined, these products can be used to provide a substantial cost savings to the poultry industry and use of the products is quite high by the industry. Use of these products is estimated to save the industry as much as $10 for each ton of feed produced in the United States. Strong utilization of these products by the poultry industry is the norm and is expected to continue into the future.

The Poultry Industry

The poultry industry in the United States and worldwide has seen major changes in the past 50 years. While consumption of poultry and poultry products has increased dramatically over this time period, the changes in industry structure are perhaps more dramatic. The industry has gone from a small-scale producer of products for specialty meals to a provider of a major source of animal protein consumed in the United States. Worldwide, there has also been an explosion of poultry production. In developed countries, poultry industries function similarly to the United States. In less developed countries, while smaller in scale, the U.S. model is a goal for their industry development. Chicken production and slaughter in the United States was 8.9 billion birds in 2004 (Watt poultry, 2004) and continues to rise. World slaughter of chickens is also at an all-time high at over 46 billion birds yearly. The evolution of the industry has resulted in advances in diet formulation as new products and technology have become available. As this evolution took place, formulations became more sophisticated, moving from hand to computer formulation, from a total protein basis to a digestible amino acid basis, and incorporating of a variety of micronutrient sources. All of this has led to reduced cost and maximum bird performance for the U.S. poultry industry. The availability of a variety of rendered by-products has been of great benefit to the modern poultry industry.

Use of Rendered Products in Poultry Feeds

There has been a long history of use of animal proteins and a variety of recycled fats in the poultry industry worldwide. Essentially all sources of proteins and fats have been and continue to be used in significant quantities in the United States with the primary issue being relative values compared to other protein sources such as soybean meal. Products currently being utilized include meat meals from ruminant origin, swine origin, and poultry origin as well as the blood products from each of these, fat products from each of these, and FeM. Additionally, there is now some limited production of whole hen meal used as a disposal method for spent laying hens. Each of these products has been used successfully at various levels in the rations of poultry of all types with the higher levels going into broilers and turkeys due to their higher relative protein needs in comparison with layers.

These products of animal origin provide nutrients needed by poultry at reasonable prices relative to competing products, and in fact, prices tend to fluctuate based on prices of competing products. There has also been some interest in replacement of a portion of the soybean meal in poultry rations with animal products to improve performance. The oligosaccharide portion of soybean meal has been shown to produce some detrimental effects to poultry. This is thought to be due to a substance in the undigested portion of the product that irritates the footpad. The addition of animal protein sources may improve performance over standard diets. While these results may be due to high levels of limiting amino acids, it may also be explained by the reduction of poorly digested carbohydrates in the soybean meal. Previous work in the lab has suggested that up to half of the protein source can be provided with mixed by-products if one formulates correctly. While each product has different nutrient contents and potential values, most are excellent sources of energy or high quality protein, highly available phosphorus, and other minerals.

The goal of this chapter is to provide the information needed to utilize these products in ration formulation, methodology for their use, and limitations on their use as well as the economics of their use. Additionally, a review of the pertinent literature will be provided if more in-depth information is needed. Ultimately with this information in hand, proper decisions about the use of these products can be made, and money saved.

Use of Rendered Fats

Use of fats for animal feed has many advantages. Some of the benefits of fat addition:

- Concentrated source of energy and the main method of increasing the energy content of diets
- Increased growth rates

- Increased feed efficiency
- Decreased feed intake
- Source of linoleic acid
- Decreased dustiness of feeds and reduced dust losses
- Lubricant for equipment in feed mills
- Increased palatability of feeds
- Increased rate of gain can decrease age at market and increased throughput of housing systems
- Lower heat increment during heat stress keeps caloric intake up
- May slow gut transit of other feeds, resulting in increased digestibility
- May show an "extra caloric" effect
- May be more cost effective than other energy sources
- Concentrated feeds can decrease transportation costs for feed delivery

Some concerns that should be noted with fat utilization:

- Use of higher levels of fat may negate the effects of pelleting
- Measurement of metabolizable energy (ME) content can be difficult
- Potential for rancidity
- Equipment needs relative to fat additions must be adequate
- Poor digestibility of saturated fats by the young bird

A number of different fat sources are available for poultry from the rendering industry. The primary sources are poultry fat, tallow, yellow grease, lard, and blends. In other countries, there is considerable use of vegetable fats such as sunflower oil, soybean oil, or palm oil. Generally, these fats are relatively expensive when compared to rendered products, resulting in lower fat utilization and thus lower ME diets than in the United States. One of the major concerns relative to fat usage is the actual ME value that should be assigned to each fat source. This number is often difficult to determine in a practical sense and may have little practical value in diet formulation. When analyzing energy content of fat, it is generally done indirectly, by substitution of a portion of the ration fed in the ME determination. Additionally, fat may have an extra caloric effect (Jensen et al., 1970; Horani and Sell, 1977), whereby it affects the nutrient availability of other ingredients. This was noted in the lab where it was found that fat additions resulted in digestibility of MBM being increased (Firman and Remus, 1994). This would explain why some ME values reported are greater than the gross energy values possible for fat as well.

Early work on use of fat in poultry rations generally indicated a higher ME value for unsaturated vegetable oils when compared to animal products or products with high free fatty acid content (Seidler et al., 1955; Young, 1961; Waldroup et al., 1995). However, when fed as a portion of a complete ration, most experiments indicated no difference in performance parameters when different fat sources were fed (Seidler et al., 1955; Young, 1961; Fuller and Rendon, 1979; Fuller and Rendon, 1977; Pesti et al., 2002; Quart et al., 1992). Several reasons may be postulated why the differences seen in energy value in an ME analysis do not translate into differences in actual performance when added to complete diets. One of these is that the improvement in utilization of other dietary components is equally enhanced by different sources regardless of ME content. A more obvious answer may be the relatively small difference in ME content of a total ration at typical fat inclusion levels. In other words, if two fats of 7,000 and 8,000 kcal/kg ME are fed at three percent of the diet, the difference in ME content of the complete ration is only 30 kcal/kg, or less than one percent, of the total dietary energy. This type of difference is very small and would be very difficult to pick up experimentally. In a study by Pesti and coworkers (2002), a variety of fat sources were fed and differences of more than 4,000 kcal/kg were seen. However, when these same fats were fed to birds in a floor pen trial, no differences in gain or feed-to-gain ratio were observed, indicating that the net energy available to the bird was similar (Leeson and Ateh, 1995). Similar results were found in a recent study from the lab and are shown in Tables 1 and 2 (Leigh and Firman, 2005 unpublished).

Table 1. Average Broiler Growth for Birds Fed a Variety of Fat Sources.

Fat Source	0-3 Week (kg/bird/phase)	0-5 Week (kg/bird/phase)	0-7 Week (kg/bird/phase)
Soybean Oil	0.77	1.92	2.85
Yellow Grease	0.76	1.96	2.95
Poultry Fat	0.76	1.93	2.92
Tallow	0.75	1.92	2.99
Ani-veg Blend	0.74	1.89	2.96
Lard	0.75	1.88	2.97
Palm Oil	0.75	1.95	2.94

No statistical differences between treatments.

Table 2. Adjusted Feed-to-Gain Ratios for a Variety of Fat Sources in Broilers.

Fat Source	0-3 Week	0-5 Week	0-7 Week
Soybean Oil	1.38	1.60	1.87
Yellow Grease	1.38	1.56	1.85
Poultry Fat	1.38	1.58	1.85
Tallow	1.40	1.61	1.83
Ani-veg Blend	1.42	1.63	1.86
Lard	1.40	1.52	1.77
Palm Oil	1.42	1.56	1.88

Generally, fats are thought to be more digestible in the older bird relative to the young bird. Renner and Hill (1960) found poor utilization of tallow (highly saturated fat) by the young chick. Carew and coworkers (1972) showed that fat digestibility was compromised in the young chick, but increased rapidly as the chick aged. Similar results were obtained in the turkey as well (Sell et al., 1986). While this period of poor digestion of fats appears to be real, from a practical standpoint, it is less significant since the bird shows improved utilization of fat quite rapidly.

Increasing the level of energy in diets through fat addition may have a beneficial effect on performance (Fuller and Rendon, 1979). Much of the older data on changing energy levels were with diets not fully balanced, making data interpretation difficult. Addition of fats may result in increased body weight in some cases (Sell et al., 1986), although in many cases body weight gain is similar, but with improved feed efficiency (Pesti et al., 2002). Increasing dietary fat improved feed efficiency, but also may result in increased fat deposition (Salmon and O'Neil, 1971; Rivas and Firman, 1994). When turkeys were fed energy from 88 to 112 percent of the National Research Council (NRC) suggested levels, birds showed increased growth rate (25.3 to 29.4 lb) and dramatic changes in feed efficiency (3.41 versus 2.41 feed-to-gain ratio). While birds decreased feed intake in response to the higher energy diets in these studies, energy intake still increased with increased energy intake from fat additions (Firman, 1995).

Additions of fat beyond those required for linoleic acid have had mixed results in layer diets. Careful control of energy consumption in laying hens is required to assure that birds do not become overly finished (high in body fat). Orr and coworkers (1958) found no benefit to 2.5 or 5 percent fat additions in layers. Reid and Weber (1975) found no changes in egg production of caged layers when fed diets as high as 15 percent added fat although feed efficiency was improved. Supplementing fat (one to two percent) early in the laying cycle improved egg size and production (Jensen, 1983), although this was not seen in a trial with two to six percent added fat (Bohnsack et al., 2002).

Fat may also be used in the diet to reduce the heat increment, the heat produced when a diet is digested. The heat increment for protein is highest followed by carbohydrate with fat at the lowest heat increment. Thus it would be logical that if one could increase the proportion of the energy from fat, the animal would be able to handle heat stress more easily. One is cautioned that the total heat load may increase if the energy content of the diet is increased, although generally birds under heat stress will eat less to reduce the heat load from digestion. Broilers presented with a choice of high fat or high carbohydrate diets preferred high fat diets and performed better under high ambient temperatures (Dale and Fuller, 1978). Growth depression due to cycling heat stress was less in broilers fed high fat diets as well (Dale and Fuller, 1980).

Practical Use of Fat in Poultry Rations

The practical use of fat in poultry rations is straightforward, with the effects of fat addition well understood. A minimum level of fat (usually one percent) is generally fixed into the diet. This is for several reasons, but is generally done to assure sufficient quantities of linoleic acid. It also helps reduce dust levels of feed, lubricates equipment, and improves palatability of feed. This one percent addition level is generally done without regard for cost of addition. Levels beyond one percent of the diet are generally used to improve growth rate and feed efficiency and are far more related to cost of the total diet relative to performance gains achieved. In the United States, where relatively speaking, cheap fat is the norm due to the advanced rendering industry, additions of high levels of fat are common. Fat in the United States generally ranges from $200 to 400/ton while in many countries fat can easily be two to five times this price. A typical corn – soybean meal ration with one percent fat will have an energy value of approximately 3,000 kcal/kg ME. Each one percent addition of fat will add approximately 50 kcal of energy. Thus many U.S. rations will include fat at one to three percent in a starter ration and higher levels in the finisher rations of broilers. Higher fat additions generally result in better performance up to the maximum levels that can be physically added to diets (eight to 10 percent is generally considered the maximum in a pelleted or mash poultry ration). In many cases, nutritionists use a calorie-cost calculation to determine the most cost effective energy addition. In many countries corn is less available and soybean meal is quite expensive, leading to use of some lower quality ingredients and subsequently lower energy diets. These lower energy diets (sometimes less than 2,700 kcal/kg ME) result in poor growth rates, high feed-to-gain ratios, and a high cost structure. It is not uncommon to see 20 to 30 percent lower overall performance from the same broiler strain in many cases. Inexpensive fat would substantially improve performance of these birds. Utilization of fat in turkey rations is generally somewhat higher than broiler rations due to the high protein levels fed and the low energy found in soybean meal, which is a substantial component of these diets.

A number of concerns are expressed relative to fat utilization in a practical sense. These primarily revolve around the relative quality of the fat source and include rancidity, free fatty acid levels, and MIU (moisture, insolubles, and unsaponifiables). Many of these concerns can be allayed through the purchasing process where the maximum levels of these can be specified. Rancidity is routinely dealt with through addition of an antioxidant. Free fatty acids below 20 percent are not considered a problem, and MIU is quite low in most cases. The relative number of instances of actual problems from fat is quite small.

Use of Rendered Protein Sources

Use of rendered protein sources for animal feed has many advantages:

- Generally, very cost competitive relative to vegetable protein sources
- Use will reduce total diet costs in most cases
- Source of high quality protein
- In most cases, highly digestible
- May help balance the amino acid needs

- In many cases, will provide slightly faster growth rates than vegetable protein-only diets
- Excellent source of highly available phosphorus and other minerals

Some concerns should be noted with using rendered protein products:

- Poor quality control could result in decreased amino acid digestibility
- Proper formulation methods must be used to make most effective use
- Potential for microbial contamination if improperly handled
- Variation in product due to material mix, processing methodology

Use of rendered protein products has been limited in the past for a variety of reasons. Older research indicated a growth depression if use exceeded certain limits such as 7.5 percent of the diet. This depression in growth occurred primarily due to the reduced digestibility of many products relative to soybean meal. Older data from the lab indicated almost 10 percent less digestible lysine in MBM than in soybean meal (Firman, 1992). Thus, as the levels of MBM increased in the diet, the level of lysine available for use by the bird decreased. While the routine safety factor covered this deficit to a point, an amino acid deficiency eventually developed and growth rate was depressed. Formulation on a digestible basis eliminated this problem, and inclusion rate has become less of an issue. Additionally, more recent product tested has approached soybean meal in terms of amino acid digestibility. The maximum inclusion rate is more likely to be due to the high levels of calcium and phosphorus that occur at higher inclusion rates although cost issues usually dictate levels below this.

Available Products

Meat and Bone Meal

There has been considerable work done with MBM, particularly in the area of protein and amino acids. Firman (1992) found that the amino acid digestibility of meat meal does not differ in turkeys of different age or sex and is similar to the rooster model commonly used. Lysine and methionine are highly available for metabolism, but a significant amount of the cystine is not bioavailable (Wang and Parsons, 1998a). This is of importance because tryptophan and total sulfur amino acids (TSAA) are most limiting in MBM, followed by threonine, isoleucine, phenylalanine + tyrosine, lysine, valine and histidine (Wang et al., 1997). Several reports have found that the protein quality of MBM varies greatly. Parsons and co-workers (1997) found that the ash content is correlated to the protein quality. It is thought to be a caused by the ratio of protein to ash in a ration. As ash increases, protein decreases. The amino acid digestibility is probably not actually decreased (Shirley and Parsons, 2001). The method of determining digestibility can also have an effect, often yielding differing results (Johns et al., 1987). Fat additions to rations have also proved to be a factor as increased digestibility has been shown in the presence of high levels of fat. Increasing the fat component of a diet can slow gut motility, leaving more time for absorption. The micelles themselves may also help transport amino acids to the gut wall (Firman and Remus, 1994). Digestibility can also be affected by the presence of other ingredients, like soybean meal (Angkanaporn et al., 1996). It has been shown that formulating rations based on digestible or bioavailable amino acid levels provides better results than on a total amino acid basis (Wang and Parsons, 1998b).

One of the most important factors determining the nutritional quality of MBM is the processing procedure. With recent concerns over bovine spongiform encephalopathy (BSE), feeding mammalian-derived MBM to ruminants is banned in the United States and the European Union (EU) has banned the feeding of all products of animal origin to livestock. This leaves the poultry and swine industry as the major consumers of ruminant MBM. When a meal is rendered, the time, pressure, and temperature of rendering may vary. The European Union has mandated that animal by-product meals must be processed at 133ºC and 3 atmospheres (43.5 psi) for 20 minutes. Unfortunately, pressure may reduce the availability of nutrients for the bird (Shirley and Parsons, 2000). Temperature also has proven to affect the availability of nutrients. Temperature has the same inverse relationship to nutrient availability as seen with pressure (Johnson et al., 1998), as does the processing time (Karakas et al., 2001). Constant improvement in processing technology has recently resulted in improved nutrient availability, but variation in quality is still an issue for the industry (Elkin, 2002).

Several other studies have estimated the ideal amount of MBM to add to a ration. The level of inclusion of MBM to usual rations has been debated because of variations in metabolizable energy, protein quality, and available phosphorus. It is often included at five percent or less of the ration. However, Sell (1996) found that MBM can be added successfully to diets at up to 10 percent for turkeys.

As given in the name, bone is a component of MBM. This provides an excellent source of calcium and phosphorus. Drewyor and Waldroup (2000) noted that inclusion of MBM must be monitored to ensure phosphorus levels are not so high that environmental issues arise. Others have found that the phosphorus in MBM is highly available to turkey poults (Sell and Jeffrey, 1996). Fortunately, prediction equations for phosphorus content have been developed similar to those used to predict the metabolizable energy of a feedstuff. This rapid determination will aid in the formulation of rations utilizing MBM (Mendez and Dale, 1998).

Of primary concern is the metabolizable energy of MBM. As mentioned previously, the variability of the feedstuff makes it difficult to precisely determine a standard value. Waring (1969) found an ME of 1,988 kcal/kg, lower than many estimates. The National Research Council (1994) uses a value of 2,150 kcal/kg. However, early papers tended to underestimate the ME of MBM, with it probably being between 2,300 and 2,500 kcal/kg (Martosiswoyo and Jensen, 1988a; 1988b; Dolz and de Blas, 1992). Species may also have an effect. Dale (1997) found a ME of 2,449 kcal/kg for beef MBM and 2,847 kcal/kg for pork MBM, while others found no differences in species (Karakas et al., 2001). There has been considerable discussion of the methodologies used in determination of ME of MBM products as well. Robbins and Firman (2005) tested a variety of the common methods currently employed and found few differences due to methodology.

Poultry By-product Meal

This is the by-product of the poultry processing industry and may consist of the offal and other inedible parts of the chicken. Original data on PBM use showed very positive results for the time as a replacement of soybean meal or fish meal, although diet formulations were not very sophisticated (Gerry, 1956; Fuller, 1956; Wiseman et al., 1958). Data also were collected on measures of protein efficiency (Escalona et al., 1986) although this is less useful today given the ability to computer balance amino acid profiles. The main cause for differentiation between PBM and poultry meal is based on the processing source. One plant may include portions of the chicken such as the de-boned carcass from further processing while another may sell primarily whole birds and not render this portion of the bird and thus the meal will have different levels of ash content. This product has become more expensive in some cases as the high quality has led to use by the pet food industry in the United States, with the higher quality product designated as pet food grade. Pet food grade product is generally thought to be more consistent with energy values found in a much narrower range than those of feed grade PBM (Escalona et al., 1986; Dozier and Dale, 2005). More information is provided in the pet food chapter of this book.

Table 3. Percent Digestibility of Poultry By-product Meal.

Amino Acid	Chicken	Turkey
Arg	93.2	91.2
Ser	85.7	85.0
His	80.8	83.4
Ile	90.6	86.6
Leu	91.1	87.3
Lys	90.9	89.3
Met	92.1	89.3
Cys	77.8	78.1
Phe	90.4	86.8
Tyr	93.9	85.5
Thr	86.6	87.3
Trp	95.0	94.8
Val	88.1	85.2
Asp	73.3	82.0
Glu	87.6	87.5
Pro	80.9	85.1
Ala	86.5	87.0
Average	87.3	86.5

Nutrient composition of PBM varies widely depending on sample source (Dozier et al., 2003) with protein contents varying from 49 to 69 percent. Energy content also varies (Pesti et al., 1986) and can be predicted from proximate values using the following equation from Dale et al. (1993): TMEn = (kcal/kg) = 2904 +

65.1(percent fat)- 54.1 (percent ash). Digestibility of PBM also varies, but is generally between 80 to 90 percent. Average digestibilities for a variety of samples can be found through commercial sources, but a representative product for turkeys and chickens is shown in Table 3 (Firman and Remus, 1993).

Feather Meal

FeM is the ground and hydrolyzed feathers from chicken and turkey processing. Generally, FeM is considered to be low in digestibility and to have a poor amino acid balance and is thus not heavily used in the poultry industry. It is generally economically priced, and will normally be used at one to three percent of the ration. Higher levels can be fed when careful formulations are used. FeM usage by poultry was demonstrated to be effective in older trials when amino acid balance was taken into account as long as total inclusion rate was low (Gerry and Smith, 1954; Harms and Goff, 1957; Lillie et al., 1956; McKerns and Rittersporn, 1958; Moran et al., 1968; Sullivan and Stephenson, 1957; Wilder et al., 1955). More recent data indicate FeM is an excellent source of several amino acids most notably cystine and although the overall quality of the protein is low, FeM can often spare the use of synthetic methionine (Wessels, 1972).

Table 4. Digestibilities of Amino Acids in Feather Meal.

Amino Acid	Chicken	Turkey
Arg	84.2*	89.5
Ser	76.4*	89.3
His	84.2	74.4
Ile	82.3	86.8
Leu	76.8*	85.0
Lys	73.3	76.2
Met	77.5	80.3
Cys	58.8*	86.8
Phe	79.6	85.8
Tyr	79.8	85.9
Thr	72.9*	84.9
Trp	77.0*	87.4
Val	77.5*	85.3
Asp	58.0*	74.0
Glu	71.8*	82.4
Pro	63.1*	88.5
Ala	72.3	80.0
Average	73.6	83.7

[A] Mean digestibility coefficient * Significant differences compared to turkeys.

More recent work has looked at processing methodology and how this contributes to the digestibility of the amino acids in FeM. Morris and Balloun (1971) found a processing time of 60 minutes at 50 psi produced the best results while others (Papadopaulos et al., 1985; Moritz and Latshaw, 2001) found that time and pressure were negatively correlated to produce a high quality FeM. However, Wang and Parsons (1997) found no significant relationships between temperature and processing time. Availability of amino acids (Baker et al., 1981; Han and Parsons, 1991; Bielorai et al., 1983; Firman and Remus, 1993) and energy (Dale, 1992) of FeM have been evaluated. The amino acid digestibilities of an example FeM for chickens and turkeys are shown in Table 4. FeM additions of four to six percent to turkey diets were the maximum inclusion that did not negatively affect performance, especially when in combination with other by-products (Eissler and Firman, 1996). It was noted that a set inclusion rate results in an increasing proportion of the total protein coming from FeM as protein levels are decreased in turkey rations.

Phosphorus Utilization

Phosphorus is one of the most valuable nutrients in the rendered proteins of animal origin. The highly available content of phosphorus in products is, in many cases, what makes the product economically viable when compared to other protein sources. Early work on phosphorus utilization indicated that phosphorus was highly available from animal products (Waldroup et al., 1965). Orban and Roland (1992) found phosphorus from bone meal sources slightly less available than from dicalcium phosphate. However, more recent data indicate no differences in utilization of phosphorus from animal products and dicalcium phosphate (Waldroup and Adams, 1994). Most nutritionists today assume 100 percent availability of phosphorus from rendered by-products.

Use of Animal Proteins in Rations

Products of the rendering industry are heavily used in most rations for broilers and turkeys in the United States. While products may be utilized individually, in most cases the most cost effective additions result from allowing the computer to select from a variety of available sources. MBM of ruminant origin is generally the most cost-effective source, followed by feed grade PBM and FeM. FeM is generally added at very low levels to help offset costs of sulfur amino acids. MBM and PBM are added as protein and phosphorus sources, with the latter generally being higher in energy and thus commanding a higher value. Addition rates of FeM are generally less than two percent while additions of the MBM and PBM can be substantially higher. When formulated on a digestible basis, the upper limit of these additions can easily exceed 10 percent from a growth standpoint, but are generally more based on a cost efficiency standpoint. If not formulating on a digestible amino acid basis, one should still look at digestibility of the product and set a maximum inclusion rate if there are substantial differences in digestibility from soybean meal. Given the quantity of data available, all poultry diets should be formulated on a digestible basis in the future.

The most significant problem in use of rendered products is variation of the product. Formulators are encouraged to maintain a database of product analyses and make every attempt to use the same suppliers to reduce product variation.

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. *Poultry Sci*. 75:1098-1103.

Baker, D.H., R.C. Blitenthal, K.P. Boebel, G.L. Czarnecki, L.L. Southern, and G.M Willis. 1981. Protein-amino acid evaluation of steam-processed feather meal. *Poultry Sci*. 60:1865-1872.

Bielorai, R., Z. Harduf, B. Iosif, and E. Alumot. 1983. Apparent amino acid absorption from feather meal by chicks. *British Journal of Nutrition* 49:395-399.

Bohnsack, C.R., R.H. Harms, W.D. Merkel, and G.B. Russell. 2002. Performance of commercial layers when fed diets with four levels of corn oil or poultry fat. *J. Appl. Poultry Res.* 11:68-76.

Carew, L.B., Jr., R.H. Machemer Jr., R.W. Sharp, and D.C. Foss. 1972. Fat absorption by the very young chick. *Poultry Sci*. 51:738-742.

Dale, N. 1997. Metabolizable energy of meat and bone meal. *J. Appl. Poultry Res*. 6:169-173.

Dale, N. 1992. True metabolizable energy of feather meal. *J. Appl. Poultry Res*. 1:331-334.

Dale, N., B. Fancher, M. Zumbado, and A. Villacres. 1993. Metabolizable energy content of poultry offal meal. *J. Appl. Poultry Res*. 2:40-42.

Dale, N.M., and H.L. Fuller. 1978. Effect of ambient temperature and dietary fat on feed preference of broilers. *Poultry Sci*. 57:1635-1640.

Dale, N.M., and H.L. Fuller. 1980. Effect of diet composition on feed intake and growth of chicks under heat stress. II. Constant vs. cycling temperatures. *Poultry Sci*. 59:1434-1441.

Dolz, S., and C. de Blas. 1992. Metabolizable energy of meat and bone meal from Spanish rendering plants as influenced by level of substitution and method of determination. *Poultry Sci*. 71:316-322.

Dozier, W.A., and N.M. Dale. 2005. Metabolizable energy of feed-grade and pet food-grade poultry by-product meals. *J. Appl. Poultry Res*. 14:349-351.

Dozier, W.A. III, N.M. Dale, and C.R. Dove. 2003. Nutrient composition of feed-grade and pet-food-grade poultry by-product meal. *J. Appl. Poultry Res*. 12:526-530.

Drewyor, M.A., and P.W. Waldroup. 2000. Utilization of high levels of meat and bone meal in broiler diets. *J. Appl. Poultry Res*. 9:131-141.

Eissler, C.R., and J.D. Firman. 1996. Effects of feather meal on the performance of turkeys. *J. Appl. Poultry Res*. 5:246-253.

Elkin, R.G. 2002. Nutritional components of feedstuffs: a qualitative chemical appraisal of protein. *Poultry Feedstuffs: Supply, Composition and Nutritive Value*. CAB International, Wallingford. UK.

Escalona, R.R., G.M. Pesti, and P.D. Vaughters. 1986. Nutritive value of poultry by-product meal. 2. Comparisons of methods of determining protein quality. *Poultry Sci*. 65:2268-2280.

Firman, J.D. 2003. Diet Formulation Strategies for the Future in Poultry. National Renderers Assn. Johannesburg, South Africa.

Firman, J.D. 1995. Protein and energy utilization by the turkey. Proceedings of the "Maximizing profits for the poultry and swine industries," conference, Cincinnati, OH, Griffin Industries.

Firman, J.D. 1992. Amino acid digestibilities of soybean meal and meat meal in male and female turkeys of different ages. *J. Appl. Poultry Res.* 1:350-354.

Firman, J.D., and J.C. Remus. 1994. Fat additions increase digestibility of meat and bone meal. *J. Appl. Poultry Res*. 3:80-82.

Firman, J.D., and J.C. Remus. 1993. Amino acid digestibilities of feedstuffs in female turkeys. *J. Appl. Poultry Res*. 2:171-176.

Fuller, H.L. 1956. The value of poultry by-products as sources of protein and unidentified growth factors in broiler rations. *Poultry Sci*. 35:1143-1144.

Fuller, H.L., and M. Rendon. 1977. Energetic efficiency of different dietary fats for growth of young chicks. *Poultry Sci*. 56:549-557.

Fuller, H.L. and M. Rendon. 1979. Energetic efficiency of corn oil and poultry fat at different levels in broiler diets. *Poultry Sc*i. 58:1234-1238.

Gerry, R.W., and J.R. Smyth. 1954. The value of feather meal in rations for poultry. *Poultry Sci*. 33:1089.

Gerry, R.W. 1956. The use of poultry by-products in poultry rations. Poultry Sci. 35:1144.

Han, Y., and C.M. Parsons. 1991. Protein and amino acid quality of feather meals. *Poultry Sci*. 70:812-822.

Harms, R.H., and O.E. Goff. 1957. Feather meal in hen nutrition. *Poultry Sci*. 36:358-361.

Horani, F. and J.L. Sell. 1977. Effect of feed grade animal fat on laying hen performance and on metabolizable energy of rations. *Poultry Sci*. 56:1972-1980.

Jensen, L.S. 1983. *Feedstuffs* 55(25):15.

Jensen, L.S., G.W. Schumaier, and J.D. Latshaw. 1970. Extra caloric effect of dietary fat for developing turkeys as influenced by calorie-protein ratio. *Poultry Sci*. 49:1697-1704.

Johns, D.C., C.K. Low, J.R. Sedcole, M.P. Gurnsey, and K.A.C. James. 1987. Comparison of several *in vivo* digestibility procedures to determine lysine digestibility in poultry diets containing heat treated meat and bone meals. *Br. Poultry Sci*. 28:397-406.

Johnson, M.L., C.M. Parsons, G.C. Fahey Jr., N.R. Merchen, and C.G. Aldrich. 1998. Effects of species raw material source, ash content, and processing temperature on amino acid digestibility of animal by-product meals by cecectomized roosters and ileally cannulated dogs. *J. Anim. Sci*. 76:1112-1122.

Karakas, P., H.A.J. Versteegh, Y. van der Honing, J. Kogut, and A.W. Jongbloed. 2001. Nutritive value of the meat and bone meals from cattle or pigs in broiler diets. *Poultry Sci*. 80:1180-1189.

Leeson, S., and J.O Atteh. 1995. Utilization of fats and fatty acids by turkey poults. *Poultry Sci*. 74:2003-2010.

Leigh, H., and Firman, J.D. 2005. Comparison of fat sources in diets of broilers. Unpublished.

Lillie, R.J., J.R. Sizemore, and C.A. Denton. 1956. Feather meal in chick nutrition. *Poultry Sci.* 35:316-318.

Martosiswoyo, A.W., and L.S. Jensen. 1988a. Available energy in meat and bone meal as measured by different methods. *Poultry Sci.* 67:280-293.

Martosiswoyo, A.W., and L.S. Jensen. 1988b. Effect of formulating diets using differing meat and bone meal energy data on broiler performance and abdominal fat content. *Poultry Sci*. 67:294-299.

McKerns, K.W., and E. Rittersporn. 1958. The nutritional significance of processed keratin in poultry feeding. *Poultry Sci*. 37:433-436.

Mendez, A., and N. Dale. 1998. Rapid assay to estimate calcium and phosphorus in meat and bone meal. *J. Appl. Poultry Res*. 7:309-312.
Moran, E.T., Jr., J.D. Summers, and S.J. Slinger. 1966. Keratin as a source of protein for the growing chick. *Poultry Sci*. 45:1257-1266.
Moritz, J.S., and J.D. Latshaw. 2001. Indicators of nutritional value of hydrolyzed feather meal. *Poultry Sci*. 80:79-86.
Morris, W.C., and S.L. Balloun. 1971. Effect of processing methods on the utilization of hydrolyzed feather meal by broilers. *Poultry Sci*. 50:1609-1610.
National Research Council. 1994. *Nutrient Requirements of Poultry*. 9th rev ed. National Academy Press, Washington, DC.
Orban, J.I., and D.A. Roland Sr. 1992. The effect of varying bone meal sources on phosphorus utilization by 3-week old broilers. *J. Appl. Poultry Res*. 1:75-83.
Orr, H.L., E.S. Snyder, and S.J. Slinger. 1958. Effect of animal fat, arsonic acid and range *vs.* confinement rearing on egg quality. *Poultry Sci*. 37:212-214.
Parsons, C.M., F. Castanon, and Y. Han. 1997. Protein and amino acid quality of meat and bone meal. *Poultry Sci.* 76:361-368.
Pesti, G.M., L.O. Faust, H.L. Fuller, N.M. Dale, and F.H. Benoff. 1986. Nutritive value of poultry by-product meal. 1. Metabolizable energy values as influenced by method of determination and level of substitution. *Poultry Sci.* 65:2258-2267.
Pesti, G.M., R.I. Bakalli, M. Qiao, and K.G. Sterling. 2002. A comparison of eight grades of fat as broiler feed ingredients. *Poultry Sci*. 81:382-390.
Quart, M.D., B.L. Damron, F.G. Martin, R.B. Christmas and D.R. Sloan. 1992. Effects of poultry fat and yellow grease on broiler performance and profitability. *Poultry Sci.* 71:821-828.
Reid, B.L., and C.W. Weber. 1975. S upplemental dietary fat and laying hen performance. *Poultry Sci*. 54:422-428.
Renner, R., and F.W. Hill. 1960. The utilization of corn oil, lard and tallow by chickens of various ages. *Poultry Sci*. 39:849-854.
Rivas, F, and J.D.0 Firman. 1994. Performance and carcass traits of turkeys fed diets varying energy and protein content during a three week finisher period. *J. Appl. Poultry Res*. 4:327-335.
Robbins, D.H., and Firman, J.D. 2005. Evaluation of the metabolizable energy of meat and bone meal for chickens and turkeys by various methods. *International J. Poultry Sci*. 4 (9): 633-638.
Salmon, R.E., and J.B. O'Neil. 1971. The effect of the level and source of dietary fat on the growth, feed efficiency, grade and carcass composition of turkeys. *Poultry Sci*. 50:1456-1467.
Sell, J.L. 1996. Influence of dietary concentration and source of meat and bone meal on performance of turkeys. *Poultry Sc*i. 75:1076-1079.
Sell, J.L., and M.J. Jeffrey. 1996. Availability for poults of phosphorus from meat and bone meals of different particle sizes. *Poultry Sci.* 75:232-239.
Sell, J.L., A. Krogdahl, and N. Hanyu. 1986. Influence of age on utilization of supplemental fats by young turkeys. *Poultry Sci*. 65:546-554.
Seidler, A.J., H.E. Scheid, and B.S. Schweigert. 1955. Effects of different grades of animal fats on the performance of chicks. *Poultry Sci.* 34:411-414.
Shirley, R.B., and C.M. Parsons. 2000. Effect of pressure processing on amino acid digestibility of meat and bone meal for poultry. *Poultry Sci*. 79:1775-1781.
Shirley, R.B., and C.M. Parsons. 2001. Effect of ash content on protein quality of meat and bone meal. *Poultry Sci*. 80:626-632.

Sullivan, T.W., and E.L. Stephenson. 1957. Effect of processing methods on the utilization of hydrolyzed poultry feathers by growing chicks. *Poultry Sci*. 36:361-365.
Waldroup, P.W., C.B. Ammerman, and R.H. Harms. 1965. The utilization of phosphorus from animal protein sources for chicks. *Poultry Sci*. 44:1302-1306.
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*. 3:209-218.
Waldroup, P.W., S.E. Watkins, and E.A. Saleh. 1995. Comparison of two blended animal-vegetable fats having low or high free fatty acid content. *J. Appl. Poultry Res*. 4:41-48.
Wang, X., and C.M. Parsons. 1998a. Bioavailability of digestible lysine and total sulfur amino acids in meat and bone meals varying in protein quality. *Poultry Sci*. 77:1003-1009.
Wang, X., and C.M. Parsons. 1997. Effect of processing systems on protein quality of feather meals and hog hair meals. *Poultry Sci*. 76:491-496.
Wang, X., and C.M. Parsons. 1998b. Dietary formulation with meat and bone meal on a total versus a digestible or bioavailable amino acid basis. *Poultry Sci*. 77:1010-1015.
Wang, X., F. Castanon, and C.M. Parsons. 1997. Order of amino acid limitation in meat and bone meal. *Poultry Sci.* 76:54-58.
Waring, J.J. 1969. The nutritive value of fish meal, meat and bone meal and field bean meal as measured by digestibility experiments on the adult colostomised fowl. *Br. Poultry Sci*. 10:155-163.
Wessels, J.P.H. 1972. A study of the protein quality of different feather meals. *Poultry Sci*. 51:537-541.
Wilder, O.H.M., P.C. Ostby, and B.R. Gregory. 1955. The use of chicken feather meal in feeds. *Poultry Sci*. 34:518-524.
Young, R.J. 1961. The energy value of fats and fatty acids for chicks. I. Metabolizable energy. *Poultry Sci* 40:1225-1233.