Complete Replacement of Soybean Meal in Pig Diets with Hydrolyzed Feather Meal with Blood by Amino Acid Supplementation Based on Standardized Ileal Digestibility

by

Sean David Brotzge

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Approved by

Lee Chiba, Chair, Professor, Animal Sciences
Joseph Hess, Professor, Poultry Sciences
Daryl Kuhlers, Professor, Animal Sciences

ABSTRACT

The current study was conducted to examine the possibility of completely replacing soybean meal (SBM) with hydrolyzed feather meal with blood (FM) by supplementing with appropriate AA based on standardized ileal digestible (SID) AA in FM. Corn-SBM, positive control (POS) diets were formulated to contain 6.6 and 5.2 g true ileal digestible (TID) Lys/kg to satisfy the requirements during the finisher-1 and finisher-2 phases, respectively. Corn-FM negative control (NEG) diets were formulated to be iso-N and iso-caloric to the POS diets. The NEG diets were supplemented with Lys and Trp to alleviate AA deficiencies based on TID AA values in FM reported by the 1998 NRC (NRC). In addition, the NEG diets were supplemented with Lys and Trp to alleviate AA deficiencies based on the determined SID of AA in FM (SID). Thirty-two gilts and 32 castrated males were selected for the study. When they weighed 50.0 ± 2.9 kg, pigs (2 gilts or 2 castrated males/pen) were randomly assigned to 1 of 4 finisher-1 phase diets with 4 gilt pens and 4 castrated male pens/diet. When average pen weight was 79.0 ± 2.0 kg, pigs were switched to finisher-2 phase diets. Pigs had ad libitum access to feed and water throughout the study. At the end of the finisher-2 phase (107.7 ± 3.3 kg), blood samples were collected and analyzed for serum metabolites. Overall growth performance indicated that total Lys intake ($P = 0.029$) increased and ADFI tended to increase ($P = 0.083$) in pigs fed the POS diets compared with those fed the SID diets, which may have resulted in the tendency for POS pigs to have slightly greater ADG ($P = 0.094$). No differences were observed between the treatments in the efficiency of feed or Lys utilization for BW gain. Pigs fed the SID diets tended to have greater G:F ($P = 0.057$) and had greater gain:total Lys intake ($P < 0.001$) than those fed

the NRC diets. As expected, pigs fed the POS diets performed better than those fed the NEG diets in terms of ADG ($P < 0.001$) and G:F ($P < 0.001$), consumed more total Lys ($P < 0.001$), and tended to have greater ADFI ($P = 0.079$) than pigs fed the NEG diets. However, pigs fed theNEG diets had increased BW gain:Lys intake ($P < 0.001$) compared with pigs fed the POS diets. Dietary treatments had no effect on dressing percentage, last rib backfat, fat-free lean gain:Lys intake, or subjective meat quality scores. Pigs fed the POS diets had greater fat-free lean accretion ($P = 0.020$) than SID pigs, but there were no differences between the treatments for LM area, fat-free carcass %, or the efficiency of feed and Lys utilization for lean gain. Pigs fed the POS diets had increased LM areas ($P = 0.012$), rates ($P < 0.001$) and proportion ($P = 0.03$) of carcass lean, and lean gain:feed ($P < 0.001$) than those fed the NEG diets. Dietary treatments had no effect on serum glucose concentrations. Pigs fed the POS diets had greater urea-N ($P = 0.003$), but lower cholesterol ($P = 0.002$) concentrations than those fed the SID diets. Pigs fed the NEG diet had reduced total protein ($P < 0.001$), and increased urea-N ($P = 0.001$), triglycerides ($P < 0.001$), and cholesterol ($P < 0.001$) concentrations compared to those fed the POS diets. The results indicated that pigs fed the corn-FM diets supplemented with AA based on the SID of AA in FM utilized feed and Lys for BW gain as efficiently as pigs fed corn-SBM diets. However, pigs fed the SID diets had slightly reduced BW gain and lean gain compared with those fed the POS diets, perhaps because of slightly reduced feed and Lys intake.

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I. INTRODUCTION

Sustainability continues to be important in today's society. With ever increasing human populations, it is vitally important to explore all available sources of protein and amino acid sources for swine production (Chiba, 2001). The increase in population can lead to the competition between humans and food producing animals for viable sources of protein and amino acids. This competition is enhanced mainly due to the similarity in needs of humans and nonruminant species, especially swine. Both humans and pigs have requirements for specific amino acids, not crude protein. It has been pointed out that feedstuffs used in food producing animals could be used to feed the ever growing human population. Therefore, finding viable, alternative sources of amino acids that would lessen the competition has become an important issue. It has been clear that, as less economically developed countries attempt to industrialize and grow, the need for increased food production, especially through the animal food production, has also grown. Because of this, finding alternate amino acid (AA) sources has become necessary to increase food animal production in a non-competitive way with the human population.

This increase in competition between humans and animals has increased the prices for the protein and AA sources typically used for swine diets. It has been well documented that the inclusion of energy and protein sources can account for as much as 90% of total feed costs for swine production (SCA, 1987). In the industry, with continually shrinking profit margins,

it has become necessary to explore new, alternative feed ingredients to be included in swine diets as a source of AA (Chiba, 2001). It is important to keep in mind that while this need is great, it is crucial that performance of swine and utilization of nutrients not be sacrificed simply to cut costs. Any protein source that could cause a major decrease in performance would be counter-productive to the goals of producers and, therefore, not a viable alternative. Also, if the alternative source is AA rich, yet cannot be utilized efficiently by the animal, it will lead to increased nitrogen excretion in waste and could have an adverse effect on the environment. Both of these problems would be vastly detrimental to the sustainability of a successful swine industry. Therefore, as we explore new, alternative sources of AA, it is extremely important that they be utilized efficiently to eliminate the possibility of a reduction in performance and an increase in environmentally hazardous excretion.

The industry standard diet for swine production includes grains, mainly corn, as the energy source and soybean meal as the protein source. It is estimated that soybean meal accounts for 85% of the protein supplements fed to swine (Cromwell, 1998). Soybean meal is typically available in either 44 or 48% crude protein. The corn-soybean meal diet has become very popular because it provides a very good balance of amino acids (Aherne and Kennelly, 1985; Seerley, 1991; Cromwell, 1998).

Humans and swine share similar needs for AA in the correct balance. This has lead to an increase in the use of the soybeans after oil extraction. For human use, the soybeans have been used increasingly to produce protein-rich food products, such as protein isolate and soy protein concentrate, which have been widely marketed as health foods because of the high availability of protein in soybeans (Erdman and Fordyce, 1989; Young, 1991) and the potential health benefits of the product to reduce some risks for heart disease (Lichtenstein, 1998). As expected, this has

lead to a large increase in the demand for soy-proteins in the human population, further increasing the competition between humans and swine for the protein source. If the trend continues, it is feasible to predict that in the future the demand for the product could outpace the supply. This would lead to massive increases in product costs, rendering soybean meal a non-viable source of amino acids for swine production.

The trend has been noticed by the research community, and many alternative sources have been explored in the effort to find a viable, sustainable alternative source of AA for swine diets. The alternative sources include a wide range of products, and both animal and plant sources have been evaluated, to either partially or totally replace soybean meal in swine diets (Aherne and Kennelly, 1985; Church, 1986; Thacker and Kirkwood, 1990). It is always important to consider palatability, energy and nutrient composition, handling capacity, and economic implications when choosing alternative feedstuffs as a protein supplement. Because many of these issues, there has been extensive research examining the partial replacement of soybean meal with alternative sources; however, very few studies have examined a complete replacement of soybean meal with a viable alternative source of protein and amino acids (Shelton et al., 2001).

The number of broilers harvested each year in the United States is nearing 10 billion, producing a huge volume of feathers which may not be useful for human consumption or use. Hydrolyzed feather meal (FM), is an attractive alternative source of AA for growing swine diets, largely because of its high protein content. Unfortunately, feather meal is known to be low in Lys and other AA, which may have been responsible for relatively little research on feather meal in swine diets until fairly recently (Southern et al., 2000; van Heugten and van Kempen, 2002; Apple et al., 2003; Ssu et al., 2004).

Supplementation of feather meal with crystalline AA based on available or ileal digestible AA seems to be the most effective way to utilize feather meal for pig production. Therefore, determining the ileal digestibility of AA in feather meal would be the first step in utilizing feather meal for pig production in an environmentally friendly manner. In recent years, the use of standardized ileal digestible (SID) AA has become a common practice in describing the value of feed ingredients and formulating pig diets. The results of our previous studies indicated that FM produced from pure feathers may not provide a sufficient amount of available indispensible AA to support weight gain as well as soybean meal (SBM; Divakala et al., 2009). Contanch et al. (2007a) concluded that hydrolyzed feather meal (FM) with blood may be more digestible than those without blood, indicating that FM with blood may provide more digestible AA to animals than FM without blood. The present study was conducted to determine the possibility of replacing SBM in growing pig diets completely with FM with blood by AA supplementation based on SID coefficients. Specific objectives were to investigate the effects of corn-FM diets supplemented with AA based on SID AA in FM on: 1) growth performance 2) carcass traits 3) subjective meat quality scores, and 4) serum metabolites

II. LITERATURE REVIEW

Poultry Feathers

General. Feathers comprise somewhere between 5 to 7% of the total body weight of domestic fowl. Poultry feathers contain a high percentage protein, the majority of which (85 to 90%) exists in the form of keratin (Harrap and Woods, 1964). Feathers are one of the most abundant sources of keratin on earth, however, keratin is insoluble in aqueous solutions (Fruton and Simmons, 1960). Because of this, the potential value of feathers has not been fully explored (Onifade et al., 1998). However, because of the high protein content of feathers, it would be prudent to further explore all uses, including the possibility as an alternative feedstuff in livestock production.

Keratin. Keratin is the main protein in hair, wool, fingernails, hooves, as well as in feathers. An important distinction is that the surface area of feathers is larger than other keratinous substances because of the smaller fiber diameter. Keratin exists in a tightly packed β-conformation, with a polypeptide chain super coil (Parry and North, 1998). Keratin contains high concentrations of the sulfur-containing AA Cys (Block and Bolling, 1951). This high concentration of Cys is important for the structural conformation of keratin. The Cys residues tend to form disulfide bonds with one another, leading to the stabilization of the coiled structure. It is these disulfide bonds that make keratin poorly digestible in the nonruminant

system (Moran et al., 1966). Additionally, the structure of keratin is further stabilized through hydrogen bonding and hydrophobic interactions between the various polypeptides. The combination of these bonds and interactions culminates to make keratin resistant to many enzymatic processes in vivo.

Production of Feathers. The National Chicken Council (2008), estimated 8.8 billion broiler chickens were harvested for meat consumption in 2007. As the poultry industry has been increasing steadily over the years (average of 1.425%/year), it is estimated that over 9 billion broilers are currently (2012) being produced in the United States, which can produce about 3 billion pounds of feathers. It has been estimated that a typical broiler plant can generate feathers from harvest at a rate of around 4,000 pounds per hour and up to 65,000 pounds per day (McGovern, 2000). With such a huge volume of feathers being produced on a daily basis, if not handled properly it can become overwhelming. Globally this can have a substantial effect on the environment if the feathers are not properly disposed. It is important to find alternative markets for these feathers to alleviate environmental concerns associated with the production of broilers.

Recycling Feathers - A Benefit to Poultry and Swine Production

Production of broiler chickens and, thus, feathers will continue to increase every year. Although, currently, composting may be capable of keeping pace with the supply, it is clear that there will simply be too much produced for the current methods to keep up. From an environmental standpoint, this large volume of feathers can be overwhelming, not to mention the additional costs of proper handling and disposal of the feathers. Therefore, it seems vitally important for the poultry industry to find new ways of utilizing these feathers. By converting the feathers into products such as commercial fibers and feedstuffs, the value of this by-product of

poultry harvest can be increased (McGovern, 2000). In addition, with ever increasing world-wide populations, competition between humans and animals for sources of protein or AA will continue to increase (Chiba, 2001). The high protein content of feathers, thus, makes it an attractive source of AA for swine production. If feathers can be utilized efficiently, without decreasing performance or increasing production costs, it can be a viable source of AA in swine diets. Therefore, increased use of feather meal will be mutually beneficial for both the poultry and swine industries.

Disposal and Recycling Methods. The composting of feathers has been shown to be a recycling method that is both environmentally friendly and economical (McGovern, 2000). If properly composted, feathers will recycle themselves naturally, converting the N rich feathers into fertilizer. Although composting is a good way to dispose of feathers, it seems unrealistic to assume that composting will be able to keep pace with the ever increasing production of broilers and, thus, feathers. Other alternatives have been explored to deal with the poultry feathers produced. The most popular of these alternatives involves recycling the feathers to produce commercial fibers (McGovern, 2000). However, it is clear that converting feathers into hydrolyzed feather meal to be used in livestock production would help adding value to the feathers, as well as reducing environmental concerns and competition between species for sources of amino acids.

***Keratin as a Feedstuff*.** Although, feathers are composed of 80 to 85% crude protein, keratin provides little nutritive value to nonruminant species (Naber and Morgan, 1956). Nonruminant animals lack the enzyme keratinase, which is capable of breaking down the disulfide bonds that arise from the high concentration of sulfur containing AA. Thus, for the

protein to be utilized by the animals, these bonds must broken through hydrolysis at high temperature and pressure (Latshaw, 1990).

Hydrolyzed Feather Meal

General. As previously stated, feathers are very high in protein and, therefore, have a potential for use as a substitute for other expensive feed protein sources (Han and Parsons, 1991). Again, the large amount of disulfide bonds contribute greatly to the insolubility and indigestibility of keratin, and those bonds must be cleaved before this protein can be digested and utilized efficiently by animals (McCasland and Richardson, 1966; Moran et al., 1966). Feather protein has been shown to be only moderately susceptible to trypsin (Routh and Lewis, 1938), and the nutritive value can be improved by subjecting them to heat (Draper, 1944). In early studies, chickens fed feather meal exhibited a positive correlation between growth rate and degree of keratin breakdown by heating (Naber and Morgan, 1956), which may have led to the production of hydrolyzed feather meal (FM).

Feather Meal Processing Methods. It is possible to process raw feathers in many different ways that may cause a difference in the nutritive value of the feathers, in terms of protein and AA digestibility (Sullivan and Stephenson, 1957; Moran et al., 1966; Morris and Balloun, 1973b; Papadopoulos, 1984). When determining which method to use, it is important to keep in mind which method is most cost effective and environmentally friendly (Dalev, 1994; Kherrati et al., 1998; Coward-Kelly et al., 2006). The most efficient method used currently is hydrolysis via hydrothermal treatments or autoclaving (Papadopoulos, 1985). The resulting product is of a higher quality feather meal. This method is widely used in the industry today to produce FM. It has also been reported that availability of protein and AA in FM can be

improved by using enzymatic treatment prior to the hydrolysis (Barbour et al., 2002). Other research has demonstrated that FM digestibility can be improved by treatment with microbial keratinases (Odetallah et al., 2003). Hydrothermal treatment of feathers involves three main steps to produce the final product of FM: hydrolysis, drying, and grinding. Hydrolysis involves subjecting the feathers to a combination of temperature, pressure, and time to break down the keratin protein bonds (McCasland and Richardson, 1966). Next, the drying process reduces the moisture content in FM to a pre-determined content. After drying, the FM is ground to a certain size depending on the target species and stage of development (e.g. ruminants vs. pigs and starter vs. finisher). Although this method is efficient and most popular in the industry today, it is not without drawbacks. The high heat and pressure to which the feathers are exposed can lead to the destruction of certain AA, causing a decrease in the nutritive value of the FM. For instance, it has been show that during FM production, treatments such as alkali or thermal processing of feathers will destroy mainly the sulfur-containing amino acids (Steiner et al., 1983; Papadopoulos et al., 1986; Kim and Patterson, 2000). Thus, many studies are continually conducted to determine the optimal time, temperature, and pressure in to minimize the counter-productive destruction of valuable AA.

As mentioned previously, the using of microbial keratinases to break down keratin disulfide bonds has been of recent interest as an alternative to hydrothermal treatments of feathers (Grazziotin et al., 2006). A few selected microbes have been in focus for their potential use as a source of keratinases. Those are *Bacillus licheniformis* (Williams et al., 1990; Lin et al., 1992), *Streptomyces fradiae* (El mayergi and Smith, 1971; Young and Smith, 1975), *Kochuria rosea* (Vidal et al., 2000; Bertsch and Coello, 2005), and the kr2 strain of certain *Vibrio* species (Sangali and Brandelli, 2000a, 2000b). Although some work has demonstrated that FM

digestibility can be increased by treatment with microbial keratinases (Odetallah et al., 2003), further research is still necessary to determine the best method of application and which microbial keratinases are optimal for large scale FM production. However, the early research indicates that this may be an economically and environmentally feasible new approach for producing FM.

Feather Meal Quality

Factors Influencing Feather Meal Quality. A combination of several factors influences the quality of FM. For example, the processing methods used, as well as the composition of the raw materials (e.g., raw feather composition; Moritz and Latshaw, 2001). The composition of the raw feathers can be affected by age, breed, and species of the bird from which the feathers originate, thus affecting the quality of FM. Processing methods will greatly influence the final quality and nutritional value of the FM (Papadopoulos et al., 1985; Han and Parsons, 1991, Mortiz and Latshaw, 2001). For example, one study showed that the processing pressure greatly affected the AA Cys; with increasing hydrolysis, Cys was decreased in FM, while lanthionine was increased. Lanthionine is a non proteinogenic AA formed during the hydrolysis of Cys (Baker et al., 1981; Wang and Parsons, 1997). It has also been reported that in this case, the high lanthionine concentrations can cause a decrease in AA availability in FM (Baker et al., 1981; Han and Parsons, 1991; Papadopoulos, 1985). The AA digestibility has also been shown to be negatively affected by increasing hydrolysis, with the exception of lanthionine and Arg. In this study, Arg was unaffected by increasing hydrolysis, while lanthionine increased along with increasing hydrolysis (Moritz and Latshaw, 2001). However, in vitro levels of lanthionine within a certain range seem to be a good indicator of the in vivo protein or AA quality (Han and Parson, 1991). It has also been shown that Lys, under hydrolysis conditions, can form a

nonproteinogenic AA called lysinoalanine (Wang and Parsons, 1997). In essence, when processing feathers to produce FM, it is important to remember the possibility of the formation of antinutritional factors, such as nonproteinogenic AA, lysinoalanine. If the conditions cause high concentrations of these substances, the product will lose a considerable value because decreased digestibility or availability of AA.

Evaluating FM. When analyzing FM for quality, two approaches are generally used. The first is in vitro analysis of FM using an enzyme such as pepsin. Pepsin concentration of 0.002 or 0.2 % is typically used to analyze protein digestibility. It is important to remember that, depending on the concentration used, the digestibility values can be substantially affected. For example, it has been demonstrated that using the concentration of 0.002% pepsin for in vitro analysis correlates more closely with in vivo assays than use of 0.2% pepsin (Bielorai et al., 1982; Han and Parsons, 1991). In addition, the digestibility values for the 0.2% pepsin were substantially greater than when using 0.002% pepsin, but this is to be expected because of the use of a higher concentration of enzyme. Despite these findings, both concentrations are still being used and obviously, it would be important to set a standard concentration for this assay. The main benefit of this assay is that the process is quick, easy, and cost effective. The second approach widely used to determine AA bioavailability of protein sources are growth assays. There are, however, some problems with using growth assays. The problem lies with the fact that these assays are far from ideal when assessing feedstuffs that are deficient in one or more indispensible AA, such as FM. For example, the estimates for Lys bioavailability in FM are extremely variable and imprecise when using growth assays (Han and Parsons, 1991), and the results of those assays generally do not correlate well with the results of in vitro studies (Bielorai et al., 1982). Selecting an appropriate method to determine the nutritive value of FM is

important as it will directly affect the results of any study (Mortiz and Latshaw, 2001). Therefore, it is essentially to select an appropriate, yet standardized, procedure to determine the nutritional quality of FM.

Amino Acid Content of Hydrolyzed Feather Meal

Amino Acid Content of FM. As it exists in the current market, FM has two forms, with or without coagulated blood. As expected, there are some differences in protein and the AA profile of FM with blood and FM without blood. The FM with blood contains greater concentrations of Asp, Ala, Met, Leu, Tyr, Phe, His, and Lys as a percentage of the total amino acids than the FM without blood. But, FM without blood contained significantly greater concentrations of Ser, Pro, Gly, Arg, and Trp (Contanch et al., 2007a). Despite those differences, it is clear that FM is relatively low in Lys content. As Lys is the first limiting AA in most pig diets, it seems that relatively little research has been conducted to explore its use in swine diets until recently (Southern et al., 2000; van Heugten and van Kempen, 2002; Apple et al., 2003; Ssu et al., 2004). It is important to remember that FM, as is the case with other animal protein sources, can have highly variable compositions of AA (Wang and Parsons, 1997).

Limitations of FM. As a source of protein or AA, FM has several limitations, especially for nonruminant species such as pigs and chickens. Because of its low concentration of certain valuable, indispensible AA (Lys, Met, His, and Trp), it has not been used much in nonruminant diets (Routh, 1942; McCasland and Richardson, 1966; Moran et al., 1966; Wessels, 1972; Luong and Payne, 1977). The FM has also been shown to have low N and AA digestibility values (Bielorai et al., 1982; Knabe et al., 1989).

Enhancement of FM. Recent research seems to indicate that the addition of FM supplemented with blood can increase the indispensible AA content of FM (Contanch et al., 2007a). The CP values are similar for FM with and without blood (85.4 vs. 86.0%), although the soluble protein as a percent of the CP values is greater for FM with blood than without (8.3% vs. 5.8%; Contanch et al., 2007a). Blood is an ideal complementary feedstuff for FM because FM is high in sulfur-containing AA, such as Cys, and low in Lys, while blood is low in sulfur-containing AA and high in Lys (Blasi et al., 1991; Gibb et al., 1992). It has been shown that by supplementing FM without blood with Lys, carcass quality can be maintained (Chiba et al. 1996).

Comparison of FM with SBM. When examining the potential for using FM, instead of SBM, for swine diets, the major consideration is the content and availability of the first limiting AA, Lys. The FM has been shown to contain similar availability of indispensible AA, with the obvious exception of Lys, with SBM (Bielorai et al., 1983; Knabe et al., 1989; Han and Parsons, 1991). This alone gives FM the potential to be used as a substitute for SBM in swine diets. In addition, FM has been found to have a superior content of certain AA, such as Cys, Val, and Thr compared to SBM (Bielorai et al., 1983). Again, the drawback in including FM in nonruminant diets is the low Lys content, but, as previously mentioned, supplementation of FM with Lys has shown some promise to potentially replace SBM completely in swine diets by AA supplementation (Chiba et al., 1996).

Hydrolyzed Feather Meal as a Feedstuff for Ruminants

General. The FM is high in CP and has been shown to be a good source of CP for ruminants. For ruminant species, the nutritive value of FM lies with the amount of rumen

undegradable protein (RUP) present in the FM (Thomas and Beeson, 1977; Daugherty and Church, 1982). It has been suggested that FM might contain nearly twice the amount of RUP to that of SBM (Goedecken et al., 1990). The value of protein sources which are high in RUP, such as FM, has been repeatedly shown to increase the flow of N and AA to the small intestine, thereby, improving nutrient utilization and animal performance (Cecava and Parker, 1993; Comer et al., 1993; Sindt et al., 1993; Zinn and Owens, 1993). The RUP, however, can result in decreased digestibility, possibly limiting its usefulness in feedstuffs extremely high in RUP content. Through a comparative study of feedstuffs and digestibility, RUP digestibility in FM was similar to that of cottonseed meal (Aderibigbe and Church, 1983), but lower than soybean meal, even though FM contains a greater portion of RUP than SBM (Thomas and Beeson, 1977; Church et al., 1982). Despite the lower digestibility associated with high-RUP protein sources, FM remains a promising source of CP for ruminant species' diets.

Dairy Cattle. As the average milk produced per cow in the United States has increased over the years, the requirements for absorbed proteins have also increased, thus, necessitating more dietary protein that can escape rumen degradation (NRC, 1989). To achieve this goal, a protein source with a high RUP content is required. In this respect, FM is a potential candidate to fill this need (Kellems et al., 1989). The high content of RUP in FM is thought to be able to improve the flow of N and certain indispensible AA to the small intestine, possibly affecting the quantity and quality of milk produced by the lactating cow. Supplementation of this RUP should be used primarily during periods when the synthesis and the flow of microbial protein to the intestine is insufficient to meet the needs of the cow, such as during the early and peak lactation phases (Cunningham et al., 1994). It has been shown that inclusion of FM at certain amounts can lead to an increase in milk production, which may be a result of a more favorable balance of

RUP in the system (Harris et al., 1992). In that particular study, a low rate of FM inclusion was used. Moss and Holliman (1990), however, found that milk production tended to decrease numerically as dietary FM increased. Harris et al. (1992) also demonstrated that milk protein decreased linearly with increased FM inclusion rates. These results have been supported by some studies (Moss and Holliman, 1990) but refuted by others (Kellems et al., 1989).

It is possible that the decrease is a direct result of certain AA deficiencies in FM (Goedecken et al., 1990). To combat these indispensible AA deficiencies of FM, the possibility of including FM supplemented with blood meal has been examined (Waltz et al., 1989; Johnson et al., 1994). Flows of microbial N tend to decrease, but flows of non-ammonia and non-microbial N increased as a result of the addition of FM supplemented with blood meal in increasing amounts. However, a coinciding decrease in duodenal Ile, Lys, Met, and Thr did occur with the increase in FM plus blood meal (Cunningham et al., 1994). The viability of FM use in dairy diets has increased because an interaction between the CP content and the inclusion rate of FM in lactating cow diets has been found, (Harris et al., 1992). The FM inclusion, in spite of the results of some studies, shows the potential to influence both the quality and quantity of milk produced by dairy cattle when fed in the optimal amounts (Harris et al., 1992).

Beef Cattle. Studies conducted with steers have displayed greater levels of fecal N excretion in cattle fed feather and hair meals compared to those cattle fed SBM diets. This is, perhaps, the direct result of the greater apparent N digestibility in SBM for cattle (Thomas and Beeson, 1977). However, cattle fed SBM did excrete greater levels of urinary N, indicating that steers fed feather and hair meals did have greater percentages of absorbed N. The lower levels of rumen ammonia and plasma urea N in steers fed feather and hair meals indicate that they may have lower protein solubility in the rumen; this may have a depressing effect on dry matter and

gross energy digestibility. These digestibility results are variable, however, and do not provide definitive results (Church et al., 1982). In a feedlot trial using three different test groups of cattle fed different diets, the data on nutrient composition, protein solubility, digestibility, and feedlot performance strongly indicated that FM or hair meals are satisfactory sources of N for ruminants, particularly when fed in combination with urea in high roughage finishing diets (Church et al., 1982). It has been shown that *in vitro* rumen dry matter digestibility values of FM are generally low, indicating that FM has some reticulo-rumen bypass potential, and the addition of urea to FM increased the utilization of FM protein (Aderibigbe and Church, 1983). This, once again, displays the large amount of RUP present in FM, which allows for an increase in flows of N and AA to the primary site of absorption, the small intestine. Feather and hair meals have also been proven to be superior, when properly processed, to cottonseed meal (on a per unit N basis) when it is fed as the only protein supplement in diets for ruminant species (Aderibigbe and Church, 1983). Other *in vitro* studies have shown that, by supplementing FM with blood or blood meal, it is possible to increase the total N digestibility in the rumen, irrespective of processing conditions (Contanch et al., 2007). These results indicate great promise for the future inclusion of FM in ruminant diets as a good source of RUP and non-microbial N for the animal.

***Sheep and Lambs*.** Many studies, with varying results, have been conducted on the use of FM in sheep and lamb diets. Some research has shown that the use of FM caused a decrease in growth performance when it supplied all of the supplemental protein in growing-fattening lamb diets (Huston and Shelton, 1971). Conversely, it has been shown that body weight gains in fattening lambs fed FM were equally as good when compared to lambs fed plant protein sources on a protein-equivalent basis (Jordan and Jordan, 1955; Jordan and Croom, 1957). It has been reported that replacing half of the SBM protein with FM in lamb finishing diets resulted in lamb

performance similar to that achieved with the use of SBM as the only source of supplemental protein (Ely et al., 1991). In another study, linear increases in body weight gain and serum total protein concentration were observed as FM replaced SBM in increasing amounts (Thomas et al., 1994). These data indicate that FM can be substituted for SBM fed to sheep consuming low-quality roughages at a maintenance ME level (Thomas et al., 1994). In the same study, FM inclusion had no effect on sheep wool fiber length, diameter, or sulfur content.

Hydrolyzed Feather Meal for Fish, Shrimp, and Fowl

Fish and Shrimp. The main source of CP and AA in fish diets comes from fish meal. Because of this, fish meal is a product in extremely high demand for its use in the aquaculture industry today, thus, increasing the price. To lessen the demand and the burden of high price, it would be important to explore the use of other viable sources of CP and AA (Rumsey, 1993). The FM has emerged as an alternative to supplement fish diets, or possibly even replace fish meal use in some diets. Particularly, replacement of fish meal with FM has shown positive effects on performance in several species of fish such as tilapia (Viola and Zoher, 1984; Bishop et al., 1995), rainbow trout (Hughes, 1991; Bureau et al., 2000), Indian major carp (Hasan et al., 1997), chinook salmon (Fowler, 1990), and Japanese flounder (Kikuchi et al., 1994). The recurring issue with the use of FM is the decrease in digestibility in nonruminant species like shrimp and fish. However, positive results on fish performance have been reported. For instance, a study with Pacific White Shrimp indicated that AA supplementation of FM in diets fed to these species increased growth performance, and, thus, increased product yield (Cheng et al., 2002).

Chickens and Turkeys. When used to replace limited quantities of various protein feedstuffs in practical diets, FM has been shown to be of value as a source of CP (Wilder et al.,

1955; Lillie et al., 1956; Naber and Morgan, 1956; Sullivan and Stephenson, 1957; Wisman et al., 1958; McKerns and Rittersporn, 1958; Naber et al., 1961; Poppe, 1965). At high dietary CP levels (20 to 30%), FM has been shown to be a good replacement for chicks, but is poor when included at low levels (15%). This indicates that FM is a good source of non-specific nitrogen for the chick (Sibbald et al., 1962; Moran et al., 1966). However, Naber et al. (1961) found that, when using FM as the primary protein source, chicks never performed as well as those fed comparable corn-soybean meal diets, regardless of AA supplementation. However, this result could be inaccurate, because His was only supplemented at one half of the requirement for the chick, which have been determined after the study was conducted. The limiting AA in FM for chick growth are Met, Lys, His, and Trp (Moran et al., 1966). For broilers, FM was effective in lowering the calorie to protein ratio, thereby reducing the size of the fat pad (Griffith et al., 1977a). This is because the quality of the dietary protein source is less of a concern than the total amount of protein in relation to carcass fat. Similar research has also indicated that FM inclusion, regardless of assumed AA availability, lowered levels of abdominal fat (Cabel et al., 1987). It should be noted that these results were not accompanied any by negative effects such as decreased rate of gain, feed efficiency, and carcass dressing percentage. In a later study (Cupo and Cartwright, 1991) researchers found that there were interactions between dietary FM and calorie to protein ratio in carcass weight, protein, and fat. This further confirmed the ability of FM to reduce fat deposition during the broiler finishing phase. Limited studies have been conducted using FM for turkeys. Some data indicate that FM could be incorporated in turkey grower diets up to 6% without affecting growth performance (Eissler and Firman, 1996). As previously stated, although FM is not ideal for use in growing chick diets because of the deficiencies in certain indispensible AA required for chick growth, it does have a possible role in

broiler diets. The FM is better suited for the broiler finisher diets, and feeding FM for a short periods before harvest has been shown to be useful in decreasing fat deposition, thereby increasing lean gain.

Hydrolyzed Feather Meal Inclusion in Swine Diets

General. Possibly because of the low lysine content of FM, there has not been much research on FM until fairly recently (Southern et al., 2000; van Heugten and van Kempen, 2002; Apple et al., 2003; Ssu et al., 2004, Divakala et al., 2009). Because of the high protein content, FM can be an attractive source of AA for growing pigs (Han and Parsons, 1991). The results of the research indicate that FM is a good source of non-specific N to improve carcass quality of finisher pigs (Chiba et al., 1995).

Inclusion Rates in Swine Diets. Early studies (e.g., Hall, 1957) to evaluate the use of FM in swine diets were unsuccessful in determining the potential value of this product as a protein source for growing-finishing pigs. This is most likely due to the fact that FM was simply substituted for other protein sources on the basis of weight. After those initial studies, the role that FM could potentially play in swine diets was largely ignored until the mid 1990's. One study indicated that FM can be used as a source of specific N to increase the leanness of finisher pigs, as mentioned before (Chiba et al., 1995). In a subsequent study, it was determined that FM can be included up to 90 g/kg of corn-SBM diets (Chiba et al., 1996). More recent reports indicated an optimum inclusion rate of 60 g/kg (Apple et al., 2003) or 80 g/kg (van Heugten and van Kempen, 2002). The FM is high in protein and a very attractive source of AA for swine production, as mentioned before, but it is noticeably deficient in Lys and certain other indispensible AA (Chiba, 2005a,b). Because of the deficiencies, it is necessary to incorporate

FM into the swine diets based on AA content. Unfortunately, this method can increase the CP content of diets, thus. potentially increasing some environmental problems associated with swine production (Chiba, 2000). Thus, supplementation with appropriate crystalline AA based on AA availability would be the most effective way to incorporate FM into swine diets. Unfortunately, although the NRC (1998) provides digestibility values for FM, those estimates are based on rather limited data (Chiba, 2001).

Justification for the Research Project

The sheer volume of poultry feathers generated on a daily basis can be overwhelming, and, for the competitive and sustainable poultry industry, it is essential to find viable ways to manage one of its major waste product. Increasing market demand for FM can contribute greatly to such an effort. Because of the competition between humans and animals for quality sources of AA, it is important to find alternative AA sources for future pig production. The effort to increase market demand for FM by increasing its use in pig production i, therefore, mutually beneficial for successful and sustainable poultry and pig production.

Although FM is ich in many AA and can be an attractive source of AA for pig diets, it is deficient in Lys and certain other indispensible AA. Therefore, FM must be incorporated into diets based on the AA content. This method can, however, increase the dietary protein content, which can lead to environmental problems. Supplementation of FM diets ith appropriate AA based on AA availability, thus, would be the most plausible and effective way to utilize FM in pig diets. This approach is consistent with two concepts, "ideal protein and available nutrients", which can contribute greatly to the development of environmentally friendly, optimum feeding strategies for successful and sustainable pig production.

Considering the AA profile, it might be possible to replace SBM, which is a standard protein supplement, in pig diets completely with FM by supplementing only Lys. The results of our earlier study indicated that Lys supplementation was effective in maintaining carcass quality of pigs, but weight and lean gains were depressed by feeding such a diet, indicating that the availability of not only Lys, but other AA in FM may be lower than other protein sources. In our recent study, finisher pigs fed the FM diet supplemented with all necessary AA based on the assumed AA availability utilized feed and A for weight and lean gains as effectively as those fed the corn-SBM control diet. The FM was, however, not as effective as the control diet in supporting weight gain, implying that FM did not provide a sufficient amount of available AA. It is possible that FM with a small amount of blood, which is an excellent source of indispensible AA, may provide more available AA for pigs than those without blood, thus, avoiding growth depression. Obviously, further research is needed, and determining the ileal digestibility of FM might be the first step in utilizing FM for pig production in a more effective and environmentally friendly manner.

Our hypothesis underlying this project is that pigs fed the corn-FM diet supplemented with appropriate AA based on the available AA concept would support growth performance and carcass quality similar to those fed a corn-SBM diet. Our effort will not only increase the market demand for FM, which is crucial for the competitiveness of the poultry industry, but also contribute greatly to the development of environmentally friendly, optimum feeding strategies for successful and sustainable pig production.

III. Complete Replacement of Soybean Meal in Pig Diets with Hydrolyzed Feather Meal with Blood by Amino Acid Supplementation Based on Standardized Ileal Digestibility

Running head: Hydrolyzed feather meal with blood for growing pigs

Complete Replacement of Soybean Meal in Pig Diets with Hydrolyzed Feather Meal with Blood by Amino Acid Supplementation Based on Standardized Ileal Digestibility[1,2]

S. D. Brotzge,* L. I. Chiba,*[3] C. K. Adhikari,* H. H. Stein,† S. P. Rodning,* and E. G. Welles‡

*Department of Animal Sciences, College of Agriculture, Auburn University, Auburn, AL 36849; †Department of Animal Sciences, University of Illinois, Urbana 61801; and ‡Department of Pathobiology, College of Veterinary Medicine, Auburn University, Auburn, AL 36849

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[3]Corresponding author: chibale@auburn.edu

ABSTRACT: The current study was conducted to examine the possibility of completely replacing soybean meal (SBM) with hydrolyzed feather meal (FM) with blood by supplementing with appropriate AA based on standardized ileal digestible (SID) AA in FM. Corn-SBM, positive control (POS) diets were formulated to contain 6.6 and 5.2 g true ileal digestible (TID) Lys/kg to satisfy the requirements during the finisher-1 and finisher-2 phases, respectively. Corn-FM negative control (NEG) diets were formulated to be iso-N and iso-caloric to the POS diets. The NEG diets were supplemented with Lys and Trp to alleviate AA deficiencies based on TID AA values in FM reported by the 1998 NRC (NRC). In addition, the NEG diets were supplemented with Lys and Trp to alleviate AA deficiencies based on the determined SID of AA in FM (SID). Thirty-two gilts and 32 castrated males were selected for the study. When they weighed 50.0 ± 2.9 kg, pigs (2 gilts or 2 castrated males/pen) were randomly assigned to 1 of 4 finisher-1 phase diets with 4 gilt pens and 4 castrated male pens/diet. When average pen weight was 79.0 ± 2.0 kg, pigs were switched to finisher-2 phase diets. Pigs had ad libitum access to feed and water throughout the study. At the end of the finisher-2 phase (107.7 ± 3.3 kg), blood samples were collected and analyzed for serum metabolites. Overall growth performance indicated that total Lys intake ($P = 0.029$) increased and ADFI tended to increase ($P = 0.083$) in pigs fed the POS diets compared with those fed the SID diets, which may have resulted in the tendency for POS pigs to have slightly greater ADG ($P = 0.094$). No differences were observed between the treatments in the efficiency of feed or Lys utilization for BW gain. Pigs fed the SID diets tended to have greater G:F ($P = 0.057$) and had greater gain:total Lys intake ($P < 0.001$) than those fed the NRC diets. As expected, pigs fed the POS diets performed better than those fed the NEG diets in terms of ADG ($P < 0.001$) and G:F ($P < 0.001$), consumed more total Lys ($P < 0.001$), and tended to have greater ADFI ($P = 0.079$) than pigs fed the NEG diets.

However, pigs fed the NEG diets had increased BW gain:Lys intake ($P < 0.001$) compared with pigs fed the POS diets. Dietary treatments had no effect on dressing percentage, last rib backfat, fat-free lean gain:Lys intake, or subjective meat quality scores. Pigs fed the POS diets had greater fat-free lean accretion ($P = 0.020$) than SID pigs, but there were no differences between the treatments for LM area, fat-free carcass %, or the efficiency of feed and Lys utilization for lean gain. Pigs fed the POS diets had increased LM areas ($P = 0.012$), rates ($P < 0.001$) and proportion ($P = 0.03$) of carcass lean, and lean gain:feed ($P < 0.001$) than those fed the NEG diets. Dietary treatments had no effect on serum glucose concentrations. Pigs fed the POS diets had greater urea-N ($P = 0.003$), but lower cholesterol ($P = 0.002$) concentrations than those fed the SID diets. Pigs fed the NEG diet had reduced total protein ($P < 0.001$), and increased urea-N ($P = 0.001$), triglycerides ($P < 0.001$), and cholesterol ($P < 0.001$) concentrations compared with those fed the POS diets. The results indicated that pigs fed the corn-FM diets supplemented with AA based on the SID of AA in FM utilized feed and Lys for BW gain as efficiently as pigs fed corn-SBM diets. However, pigs fed the SID diets had slightly reduced BW gain and lean gain compared with those fed the POS diets, perhaps, because of slightly reduced feed and Lys intake.

Key words: amino acid, growing pigs, hydrolyzed feather meal, standardized ileal digestibility

INTRODUCTION

The competition between humans and animals, especially nonruminant species, for quality sources of AA is likely to increase continuously in the future (Chiba, 2001) because of the ever-increasing world population and an increase in the economic development of both newly industrialized and less economically developed countries (Aherne and Kennelly, 1985). As a result, finding new quality sources of AA for pig production is paramount to the

sustainability of the future swine industry. Because of its high protein content, feather meal has been of interest in nutritional research (Han and Parsons, 1991) and can be an attractive source of AA for growing pig diets. Unfortunately, feather meal is known to be low in Lys and other AA, which may have been responsible for relatively little research on feather meal in swine diets until fairly recently (Southern et al., 2000; van Heugten and van Kempen, 2002; Apple et al., 2003; Ssu et al., 2004).

Supplementation of feather meal with crystalline AA based on available or ileal digestible AA seems to be the most effective way to utilize feather meal for pig production. Although the NRC (1998) publication includes both apparent and true ileal digestible (**TID**) AA in feather meal, those estimates may not be universally applicable simply because those estimates are based on limited data. Therefore, determining the ileal digestibility of AA in feather meal would be the first step in utilizing feather meal for pig production in an environmentally friendly manner. In recent years, the use of standardized ileal digestible (**SID**) AA has become a common practice in describing the value of feed ingredients and formulating pig diets.

The results of our previous studies indicated that FM produced from pure feathers may not provide a sufficient amount of available indispensible AA to support weight gain as well as soybean meal (**SBM**; Chiba et al., 1996; Divakala et al., 2009). Contanch et al. (2007a) concluded that hydrolyzed feather meal (**FM**) with blood may be more digestible than those without blood, indicating that FM may provide more digestible AA to animals than FM without blood. The present study was conducted to determine the possibility of replacing SBM in growing pig diets completely with FM with blood by AA supplementation based on SID coefficients. Specific objectives were to investigate the effects of corn-FM diets supplemented

with AA based on SID AA in FM on: 1) growth performance 2) carcass traits 3) subjective meat quality scores, and 4) serum metabolites.

MATERIALS AND METHODS

The protocol for this study was approved by the Auburn University Institutional Animal Care and Use Committee.

Animals and Facilities

A total of 32 gilts and 32 castrated males approaching 50 kg were selected based on BW and ancestry and moved to adjacent, open-sided, grower-finisher units. Pigs were allocated to 32 pens (>1.35 m^2/pig) with 2 gilts or 2 castrated males per pen, and pens were randomly assigned to 4 diets with 4 gilt pens and 4 castrated male pens per diet. When the average pen weight reached the target weight (50.0 ± 2.9 kg), pigs were offered one of 4 finisher-1 diets. At an average pen weight of 79.0 ± 2.0 kg, pigs were switched to finisher-2 diets. Because of the number of pigs available at one time, the study was conducted in 2 trials. Each trial used 16 gilts and 16 castrated males, with the second trial beginning 5 wk after the start of the first trial. Pigs were offered ad libitum access to feed and water throughout the study. Pig BW and feed consumption were determined weekly. One pig was removed from the study for a reason unrelated to the treatment. The average minimum and maximum temperatures during the study were 17.7 and 29.0ºC, respectively.

Experimental Diets

One batch of FM was obtained from a member of the Poultry Protein & Fat Council (U.S. Poultry and Egg Association, Tucker, GA) and used for the entire study to ensure uniformity of

sample. The determined SID AA contents of FM (Sulabo et al., 2012) were used when formulating experimental diets. For corn and SBM, however, the TID AA values reported by the NRC (1998) were used because more than 1 batch of corn and SBM were used during the study. The analyzed composition of the ingredients used in the study are presented in Table 1. A corn-SBM, positive control (**POS**) diet was formulated to contain 6.6 g TID Lys/kg to satisfy the requirements during the finisher-1 phase. A corn-FM negative control (**NEG**) diet was formulated to be iso-N and iso-caloric to the POS diet. The NEG diet was then supplemented with Lys and Trp to alleviate AA deficiencies based on TID of AA in FM reported by the NRC (1998; **NRC**). In addition, the NEG diet was also supplemented with Lys and Trp to alleviate AA deficiencies based on the determined SID of AA in FM (**SID**). The finisher-2 diets were formulated with a similar approach but contained 5.2 g TID Lys/kg.

To supplement the diets with the appropriate crystalline AA, the amount of corn in the diet was adjusted. To avoid the possible confounding effects of energy density, poultry fat was included in the corn-FM diets to maintain a constant DE content across all diets. No attempt was made to maintain a constant AA balance, but the proportion of each indispensible AA relative to Lys in the corn-SBM and AA-supplemented FM diets were above the balanced protein (NRC 1998). Minerals and vitamins for all diets were provided in amounts calculated to meet or exceed the NRC (1998) recommendations. Feed samples were collected from each batch of feed mixed, and pooled sub-samples were analyzed for CP (AOAC, 2000).

Blood Samples

When the average pen weight reached the target BW (107.7 ± 3.3 kg), approximately 10 mL of blood was collected via vena cava puncture using a sterile syringe and needle. Pigs were

fasted overnight prior to sample collection (0800 to 1000 h). Blood samples were allowed to clot and serum samples were separated by centrifugation at 1,500 × *g* for 15 min at room temperature to obtain clean serum samples. An aliquot was stored frozen at -20ºC until analyzed for urea-N, albumin, total protein, glucose, triglyceride, and cholesterol using an automatic analyzer at the Auburn University Clinical Pathology Laboratory (Chiba et al., 2002; Mule et al., 2006).

Slaughter Procedures

When average pen BW reached the target weight (107.7 ± 3.3 kg), pigs were slaughtered at the Auburn University Meat Laboratory using conventional procedures. The eviscerated carcasses were split longitudinally through the vertebral midline, and HCW was recorded. After a chilling period of 24 h at 2ºC, cold carcass weight was measured and the right side of the carcass was cut perpendicularly between the 10th and 11th ribs to measure LM area and 10th rib backfat. Subjective meat quality scores (color, firmness, marbling, and muscling) were then assigned (NPPC, 1991). The rate and proportion of carcass lean were estimated using the equations reported by the NPPC (2000).

Statistical Analysis

Data were analyzed using the GLM procedure of SAS (SAS Inst. Inc., Cary, NC). Initially, treatment, sex, trial, building, and appropriate interactions, along with appropriate BW as a covariate, were included in the statistical model. Covariates considered for the analysis were initial and final BW for growth performance data and final BW for carcass and serum metabolite data. The results indicated that trial and trial × treatment interaction were not an important source of variation, thus the data for the 2 trials were combined and analyzed. Interactions and covariates that did not reach statistical significance ($P > 0.10$) were then

removed from the final model. To assess the effects of treatment, pre-planned contrasts were used: 1) POS vs. NEG, 2) POS vs. SID, and 3) SID vs. NRC. The pen was the experimental unit, and results were considered statistically significant if $P \leq 0.05$ and a trend if $P \leq 0.10$.

RESULTS

Growth Performance

Pigs fed the POS diet during the finisher-1 phase consumed ($P = 0.012$) more feed and total Lys and gained faster ($P = 0.013$) than those fed the SID diet (Table 4). But, there was no difference in G:F or gain:total Lys intake between pigs fed the POS and SID diets. Although there was no difference in ADFI or Lys intake, SID pigs gained faster ($P = 0.047$) and tended to utilize feed ($P = 0.061$) and utilized Lys ($P = 0.002$) more efficiently for BW gain than NRC pigs. Pigs fed the POS diet consumed more feed ($P = 0.002$) and Lys ($P < 0.001$), gained faster ($P < 0.001$), and had a greater G:F ($P < 0.001$) than those fed the NEG diet. As would be expected, however, gain:Lys intake was greater ($P < 0.001$) in pigs fed the NEG diet than those fed the POS diet.

During the finisher-2 phase, pigs fed the POS diet tended to consume more feed ($P = 0.087$) and total Lys ($P = 0.098$) than those fed the SID diet, but there were no differences in ADG, G:F, or gain:Lys intake between the 2 treatments. Pigs fed the SID diet utilized Lys more efficiently for ADG than those fed the NRC diet ($P = 0.049$). Pigs fed the POS diet had greater total Lys intake ($P < 0.001$), ADG ($P = 0.001$), and G:F ($P < 0.001$) than pigs fed the NEG diet. Similar to finisher-1 phase, pigs fed the NEG diet had greater gain:Lys intake ($P = 0.006$) compared to those fed the POS diet.

Overall, pigs fed the POS diets tended to consume more feed ($P = 0.083$) and consumed more total Lys ($P = 0.029$) than those fed the SID diets, which may have resulted in a tendency for pigs fed the POS diets to have slightly greater ADG ($P = 0.094$) than those fed the SID diets. However, there was no difference in G:F or gain:Lys intake between the 2 treatments. Although there were no differences in ADFI, Lys intake, or ADG, pigs fed the SID diets tended to have greater G:F ($P = 0.057$) and had greater gain:Lys intake ($P < 0.001$), than those fed the NRC diets. Pigs fed the POS diets tended to have greater ADFI ($P = 0.079$) and had greater Lys intake ($P < 0.001$), ADG ($P < 0.001$), and G:F ($P < 0.001$) than those fed the NEG diets. As observed in the finisher-1 and finisher-2 phases, pigs fed the NEG diets had greater gain:Lys intake ($P < 0.001$) than those fed the POS diets.

Carcass Traits and Subjective Meat Quality Scores

Dietary treatments had no effect on dressing percentage, last rib backfat, or fat-free lean gain to Lys intake (Table 5). Pigs fed the SID ($P = 0.10$) and NEG ($P = 0.099$) diets tended to have greater 10th rib backfat than those fed the POS diets. Pigs fed the POS diets had greater LM area ($P = 0.012$) than pigs fed the NEG diets, but there was no difference between pigs fed the POS and SID diets. Similarly, pigs fed the POS diets had greater fat-free lean percentage ($P = 0.030$) than those fed the NEG diets, but there was no difference between pigs fed the POS and those fed the SID diets. Although pigs fed the POS diets had greater fat-free accretion rate ($P = 0.020$) than those fed the SID diets, the efficiency of feed or total Lys utilization for lean accretion rate was not statistically different between those 2 treatments. Pigs fed the POS diets had greater fat-free lean accretion rate ($P < 0.001$) and efficiency of feed utilization for lean accretion rate ($P < 0.001$) than those fed the NEG diets, but there was no difference in the efficiency of Lys utilization for lean accretion. No differences were observed between the pigs

fed the SID and NRC diets in any of the carcass traits. Dietary treatments had no effect on meat color, firmness, marbling, or muscling scores.

Serum Metabolites

Serum urea-N concentration was greater in pigs fed the NEG diets than those fed the POS diets ($P < 0.001$), and it was less ($P = 0.003$) in pigs fed the SID diets than pigs fed the POS diets (Figure 1). There was no difference between pigs fed the SID and NRC diets in serum urea-N concentration. Pigs fed the NEG diets had reduced serum total protein ($P < 0.001$) and albumin ($P < 0.001$) concentrations than those fed the POS diets. However, no difference in serum total protein or albumin concentration was observed between the POS and SID pigs or the SID and NRC pigs.

Dietary treatments had no effect on serum glucose concentration in the present study (Figure 2). Serum triglyceride concentration was greater ($P < 0.001$) in pigs fed the NEG diets than those fed the POS diets, but there was no difference between pigs fed the POS and SID diets or the SID and NRC diets. Pigs fed the NEG diets had greater serum cholesterol concentration ($P < 0.001$) than those fed the POS diets, and it was also greater ($P = 0.002$) in those fed the SID dietss compared with pigs fed the POS diets. There was no difference in cholesterol concentration between pigs fed the SID and NRC diets.

DISCUSSION

For a competitive and sustainable poultry industry, it is imperative to find viable ways to manage the large volume of poultry feathers produced, mostly by broiler production. Increasing the market demand for feather meal can contribute greatly to such an effort. It is also important to find alternative sources of AA for future pig production because of the competition between

humans and pigs for quality sources of protein (Chiba, 2001). Therefore, finding ways to increase the use of feather meal in pig production is mutually beneficial for successful and sustainable poultry and pig production.

Because of the high protein content, feather meal can be an attractive source of AA for growing pig diets (Chiba, 2001). However, as mentioned before, feather meal is low in Lys and other indispensible AA, which may have been responsibe for little research on the use of feather meal in swine diets until fairly recently (Southern et al., 2000; van Heugten and van Kempen, 2002; Apple et al., 2003; Ssu et al., 2004). As a source of indispensible AA, feather meal must be incorporated into diets based on the AA content because, again, it is deficient in Lys and other AA (Chiba, 2010a,b). Unfortunately, such an approach can increase the dietary CP content, which can lead to environmental problems (Chiba, 2000). Thus, supplementation of feather meal diets with appropriate AA based on AA availability would be the most plausible and effective way to utilize feather meal in pig diets.

Although the NRC (1998) publication includes both apparent and TID values for feather meal, those estimates may not be universally applicable simply because those estimates are based on limited data (Chiba, 2001). Therefore, it is necessary to determine the digestibility of AA in hydrolyzed feather meal with blood (FM) before formulating diets to explore the possibility of completely replacing SBM with FM by AA supplementation of pig diets. Digestibility values adjusted for nonspecific endogenous losses of AA are termed SID coefficients. Although those values are not corrected for additional diet-specific endogenous losses because of, e.g., the presence of fiber or anti-nutritional factors as summarized by Stein et al. (2001), the SID of AA and protein in a wide range of feed ingredients have been reported over the years (Jondreville et al., 1995; Rademaker et al., 1999), and it is likely the use of such values would increase in the

future. Therefore, in the present study, SID coefficients in FM were determined first (Sulabo et al., 2012) and those values were used in the attempt to replace SBM completely with FM by appropriate AA supplementation.

The results of our recent study (Divakala et al., 2009) indicated that, although pigs were able to utilize feed and AA for BW gain and lean accretion as efficiently as those fed the corn-SBM diets, they were not able to maintain BW gain. Those results implied that, perhaps, the corn-feather meal diets supplemented with AA, based on the assumption that digestibility of all AA in feather meal was 40%, was not able to provide sufficient digestible AA. It is possible that FM may provide more digestible AA to animals than feather meal without blood (Contanch et al., 2007). Therefore, the effort was made to replace SBM completely with FM by AA supplementation.

Growth performance data in the present study indicated that pigs fed the POS diets tended to consume more feed and consumed more Lys and gained faster than pigs fed the SID diets. However, the pigs fed the SID diets were able to utilize feed and Lys for BW gain as efficiently as those fed the POS diets. It is likely that the tendency for decreased rate of BW gain in SID pigs is the result of the decreased feed and Lys intake (178 and 1.3 g/d, respectively). There were no differences between pigs fed the SID and NRC diets in ADFI, total Lys intake, or ADG. However, pigs fed the SID diets tended to utilize feed for BW gain more efficiently, and utilized Lys more efficiently than those fed the NRC diets. Based on these data, it seems that the diets based on SID coefficients were able to provide a more optimal balance of indispensible AA than those based on the TID values reported by the NRC (1998), thus resulting in the improved feed and Lys efficiency in pigs fed the SID diets.

As in previous studies (Chiba et al., 1996; Divakala et al., 2009), pigs fed the NEG diets tended to consume less feed than the POS pigs, and had reduced Lys intake, ADG, and G:F compared with pigs fed the POS diets. Sufficient amounts of necessary AA are required for protein synthesis (Everson et al., 1989) and the NEG diet was simply deficient in both the Lys and Trp needs for growing pigs. However, pigs fed the NEG diets had increased efficiency of Lys utilization for BW gain compared with pigs fed the POS diets. This is likely a result of the sparing effect of AA in pigs fed diets deficient in Lys and other AA as mentioned by Chiba et al. (1991).

Although there was no difference in LM area or fat-free lean percentage, pigs fed the POS diets had a greater fat-free lean accretion rate than those fed the SID diets, which may be associated with, again, the reduced feed or Lys intake or both. As observed in BW gain, there was no difference between pigs fed the SID and POS diets in the efficiency of feed or Lys utilization for fat-free lean accretion. No differences in carcass traits were observed between pigs fed the SID and NRC diets. Pigs fed the POS diets had increased LM area and a tendency for decreased 10th rib backfat compared with those fed the NEG diets. Thus, they had greater lean carcass percentage, fat-free lean accretion, and increased efficiency of feed and Lys utilization for lean accretion. The NEG diets were, again, simply deficient in Lys and Trp, which may explain the decreased lean accretion and efficiency and increased backfat. It has been reported (Castell et al., 1994; Cisneros et al., 1996; Blanchard et al., 1999) that pigs fed protein-deficient diets had increased intramuscular fat, however, in the present study, marbling scores did not differ between pigs fed the NEG and POS diets. In fact, no differences in any subjective meat quality scores were observed in the present study.

Serum metabolite data may provide insight into the effects of dietary manipulations on metabolic activities. Lowrey et al. (1962) suggested that serum total protein or albumin concentration can be used as an indicator of the adequacy of dietary protein content. Studies have shown that pigs fed protein-deficient or Lys-deficient diets exhibit decreases in both serum total protein and albumin concentrations (Atinmo et al., 1976; Pond et al., 1980; Divakala et al., 2009; and Kamalakar et al., 2009). The results of the present study are in agreement with these findings. Pigs fed the NEG diets had significant reduced total protein and albumin concentrations. No differences in total protein or albumin concentrations were observed between pigs fed the SID and POS diets, indicating that, perhaps, pigs fed the SID diets were provided with sufficient digestible AA and were able to use AA as efficiently as those fed the POS diets (Mule et al., 2006).

Urea-N is another important indicator of protein and AA adequacy and efficiency. Plasma urea-N levels seem to decrease in pigs fed the diets supplemented with AA to match levels of control diets (Gomez et al., 2002). In the present study, pigs fed the SID diets had reduced concentrations of serum urea-N compared with those fed the POS diets. This is likely due to the greater availability of crystalline AA compared with the intact protein (Izquierdo et al., 1988; Kerr and Easter, 1995; Ward and Southern, 1995; Knowles et al., 1998). Also, pigs fed the POS diets had decreased concentrations of urea-N compared to those fed the NEG diets.

Low AA intake may have a hypercholesterolemic effect, and it has been reported that there was a negative relationship between Lys intake and serum cholesterol concentration (Mule et al., 2006). In the present study, serum cholesterol concentrations decreased in pigs fed the POS diets compared with those fed the SID diets. As mentioned previously, pigs fed the POS diets consumed slightly more total Lys each day than those fed the SID diets, which may have

been responsible for the results observed. Also, pigs fed the NEG diets had increased concentrations of cholesterol compared with those fed the POS diets. This was to be expected because serum cholesterol is typically greatest in pigs fed a protein or AA deficient diet, which may be due to changes in the lipoprotein composition or transport, or both, which can have a hypercholesteremic effect, though the exact mechanism is unclear (Pond et al., 1986).

The magnitude of depression of overall BW gain associated with replacing SBM completely with feather meal seemed to be reduced by using FM with blood in the present study compared with the FM without blood used in our previous study (Divakala et al., 2009). The differences in BW gain between the control and the FM diet supplemented with appropriate AA were 140 and 57 g/d for the previous and current study, respectively. Unfortunately, as in the previous study, the rate of fat-free lean accretion was less in the pigs fed the AA-supplemented FM diets. However, as previously indicated, the efficiency of feed or Lys utilization for BW gain or lean accretion was not different between pigs fed the corn-SBM diets and the AA-supplemented FM diets based on SID AA values for FM.

In conclusion, although the depression in BW gain was alleviated by using FM with blood to a certain extent, the FM diet supplemented with appropriate AA based on SID AA values was not as effective as the corn-SBM diets in promoting growth. It is possible that this is associated with the reduced feed and Lys intake in pigs fed the FM diets. However, pigs fed the FM diets supplemented with appropriate AA based on SID AA utilized feed and AA for BW gain and lean accretion as efficiently as those fed the corn-SBM diets. Further research is warranted to investigate, e. g., how to minimize the differences in feed and Lys intake between pigs fed corn-SBM diets and FM diets, so that FM can be used for pig production in an environmentally friendly manner.

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Table1. Composition of hydrolyzed feather meal, soybean meal, and corn (%; as-fed basis)[1,2]

Item	Hydrolyzed feather meal with blood	SID[3] of CP and AA in FM with blood,%	Soybean meal	Corn
DM	-	-	94.89	88.01
CP	82.81	76.3	47.62	8.02
Arg	5.68	86.0	3.34	0.39
His	1.44	64.8	1.21	0.23
Ile	3.96	96.3	2.11	0.26
Leu	7.35	81.2	3.37	0.89
Lys	2.90	79.4	2.94	0.26
Met	0.69	77.3	0.68	0.18
Cys	3.60	61.0	0.69	0.18
Met + Cys	4.29	-	1.37	0.36
Phe	4.28	83.5	2.30	0.38
Tyr	2.49	78.9	1.18	0.08
Phe + Tyr	6.77	-	-	-
Thr	3.90	76.1	1.90	0.28
Trp	0.69	85.2	0.59	0.06
Val	6.40	83.0	2.14	0.35
Ala	4.27	80.0	2.04	0.58
Asp	5.78	57.1	5.04	0.53
Glu	8.94	73.0	7.75	1.37
Gly	6.02	78.9	2.02	0.32
Pro	7.20	67.7	2.22	0.66
Ser	8.07	81.0	2.30	0.38

[1]Hydrolyzed feather meal with blood (Sulabo et al., 2012) and corn and soybean meal were analyzed (Ajinomoto Heartland, Inc., Chicago, IL). Hydrolyzed feather meal with blood was hydrolyzed with discharge temperature of 21 to 24ºC with 517 to 586 kPa, and blood (approximately 10%) was added after hydrolyzation process.

[2]For corn and soybean meal, reported the average of several batches of samples; some AA values were not reported.

[3]SID = standardized ileal digestibility of hydrolyzed feather meal (FM) with blood (Sulabo et al., 2012).

Table 2. Composition of finisher-1 diets (as-fed basis)[1,2]

Item	POS[2]	NEG[3]	NRC[4]	SID[5]
Ingredient, g/kg				
Corn	792.86	858	854.05	854.49
Soybean meal (47.5% CP)	183.61	-	-	-
Hydrolyzed feather meal	-	98.76	98.76	98.76
Poultry fat	-	17.78	17.78	17.78
Dicalcium phosphate	10.88	14.09	14.09	14.09
Limestone	6.65	5.37	5.37	5.37
Salt	3.50	3.50	3.50	3.50
Vitamin-trace mineral premix[6]	2.50	2.50	2.50	2.50
Lys·HCl	-	-	3.767	3.314
Trp	-	-	0.186	0.191
Calculated composition				
DE, Mcal/kg	3.47	3.47	3.47	3.47
CP, g/kg	153	153	153	153
Ca, g/kg	6.00	6.00	6.00	6.00
P, g/kg	5.50	5.50	5.50	5.50
Ca:P	1.09	1.09	1.09	1.09
Lys, g/kg	6.60	3.66	6.60	6.60
Lys:DE, g/Mcal	1.902	1.055	1.902	1.902
Trp, g/kg	1.474	1.018	1.2	1.2
Thr, g/kg	4.842	5.2	5.2	4.973
His, g/kg	3.725	2.769	2.769	2.637
Ile, g/kg	5.464	5.535	5.535	5.859
Val, g/kg	6.356	8.218	8.218	8.155
Analyzed composition				
CP, g/kg	165.4	164.7	163.6	166.3

[1]All corn-hydrolyzed feather meal (FM) with blood diets were formulated to be iso-N and iso-caloric to the corn-soybean meal positive control diet. Supplemental AA replaced a portion of corn, and the amount was adjusted according to the product specifications. Finisher-1 diets were fed from 50.1 ± 2.7 to 79.1 ± 1.9 kg.

[2]POS = corn-soybean meal positive control diet; NEG = corn-FM negative control diet; formulated to be iso-N to the POS diet; NRC = NEG + Lys and Trp based on apparent ileal digestible (AID) AA in FM reported by NRC (1998); and SID = NEG + Lys and Trp based on standardized ileal digestible (SID) AA in FM with blood (Sulabo et al., 2012).

[3]Provided the following (unit/kg diet): Fe (ferrous sulphate), 150 mg; Zn (zinc oxide), 150 mg; Mn (manganous oxide), 37.5 mg; Cu (copper sulfate), 150 ppm; I (ethylenediamine dihydroiodide), 5 ppm; Se (sodium selenite), 3 ppm; vitamin A, 6,614 IU; vitamin D_3, 1,102 IU; vitamin E, 26 IU; vitamin B_{12}, 0.03 mg; menadione (menadione Na bisulfite complex), 1 mg; riboflavin, 6 mg; D-pantothenic acid (D-Ca pantothenate), 45 mg; niacin, 28 mg; and choline (choline chloride), 110 mg.

[4]Amino acid contents of the SID diet are based on the SID values for FM and TID values for corn (NRC, 1998), whereas other diets are based on TID values (NRC, 1998).

Table 3. Composition of finisher-2 diets (as-fed basis)[1,2]

Item	POS[2]	NEG[3]	NRC[4]	SID[5]
Ingredients, g/kg				
Corn	847.54	893	890.12	889.48
Soybean meal (48% CP)	128.02	-	-	-
Hydrolyzed feather meal	-	68.9	68.9	68.9
Poultry fat	-	12.34	12.34	12.34
Dicalcium phosphate	12.13	14.34	14.34	14.34
Limestone	6.32	5.42	5.42	5.42
Salt	3.50	3.50	3.50	3.50
Vitamin-trace mineral premix[6]	2.50	2.50	2.50	2.50
Lys·HCl	-	-	2.626	2.307
Trp	-	-	0.144	0.148
Calculated composition				
DE, Mcal/kg	3.459	3.459	3.459	3.459
CP, g/kg	131.2	131.2	131.2	131.2
Ca, g/kg	6.00	6.00	6.00	6.00
P, g/kg	5.50	5.50	5.50	5.50
Ca:P	1.09	1.09	1.09	1.09
Lys, g/kg	5.20	3.15	5.20	5.20
Lys:DE, g/Mcal	1.503	0.911	1.503	1.503
Trp, g/kg	1.176	0.859	1.00	1.00
Thr, g/kg	4.078	4.329	4.329	4.17
His, g/kg	3.187	2.52	2.52	2.429
Ile, g/kg	4.529	4.58	4.58	4.806
Val, g/kg	5.431	6.731	6.731	6.687
Analyzed composition				
CP, g/kg	141.9	139.4	140.2	140.7

[1]All corn-hydrolyzed feather meal (FM) with blood diets were formulated to be iso-N and iso-caloric to the corn-soy positive control diet. Supplemental AA replaced a portion of corn, and the amount included was adjusted according to the product specifications. Finisher-2 were fed from 79.1 ± 1.9 to 107.7 ± 2.8 kg.

[2]POS = corn-soybean meal positive control diet; NEG = corn-FM negative control diet; formulated to be iso-N to the POS diet; NRC = NEG + Lys and Trp based on apparent ileal digestible (AID) AA in FM reported by NRC (1998); and SID = NEG + Lys and Trp based on standardized ileal digestible (SID) AA in FM with blood (Sulabo et al., 2012).

[3]Provided the following (unit/kg diet): Fe (ferrous sulphate), 150 mg; Zn (zinc oxide), 150 mg; Mn (manganous oxide), 37.5 mg; Cu (copper sulfate), 150 ppm; I (ethylenediamine dihydroiodide), 5 ppm; Se (sodium selenite), 3 ppm; vitamin A, 6,614 IU; vitamin D_3, 1,102 IU; vitamin E, 26 IU; vitamin B_{12}, 0.03 mg; menadione (menadione Na bisulfite complex), 1 mg; riboflavin, 6 mg; D-pantothenic acid (D-Ca pantothenate), 45 mg; niacin, 28 mg; and choline (choline chloride), 110 mg.

[4]Amino acid contents of the SID diet are based on the SID values for FM and TID values for corn (NRC, 1998), whereas other diets are based on TID values (NRC, 1998).

Table 4. Effect of AA supplementation of corn-hydrolyzed feather meal with blood diets on growth performance of pigs during the finisher-1 and finisher-2 phases and overall[1]

	Diet[2]					*P*-value[4]		
Item	POS	NEG	NRC	SID	SEM[3]	POS vs. NEG	POS vs. SID	SID vs. NRC
Finisher-1 phase								
ADFI, g/d	2,661	2,401	2,403	2,477	40	0.002	0.012	0.309
Lys intake,[5] g/d	20.3	12.3	19.3	19.0	1.2	< 0.001	0.012	0.583
ADG, g/d	984	674	824	896	44	< 0.001	0.013	0.047
G:F, g/kg	370	278	343	361	14	< 0.001	0.299	0.061
Gain:Lys intake,[5] g/g	48.6	54.3	42.7	47.0	1.5	< 0.001	0.180	0.002
Finisher-2 phase								
ADFI, g/d	3,091	2,836	2,848	2,834	41	0.156	0.087	0.918
Lys intake, g/d	18.8	12.4	18.1	17.3	1.0	< 0.001	0.098	0.351
ADG, g/d	940	709	876	904	34	0.001	0.489	0.586
G:F, g/kg	304	244	307	317	11	< 0.001	0.187	0.313
Gain:Lys intake, g/g	50.0	56.3	48.3	51.9	1.1	0.006	0.299	0.049
Overall								
ADFI, g/d	2,822	2,604	2,626	2,644	33	0.079	0.083	0.860
Lys intake, g/d	19.4	12.3	18.7	18.1	1.0	< 0.001	0.029	0.278
ADG, g/d	952	688	843	895	37	< 0.001	0.094	0.137
G:F, g/kg	338	261	321	337	12	< 0.001	0.902	0.057
Gain:Lys intake, g/d	49.1	55.4	44.9	49.3	1.4	< 0.001	0.872	< 0.001

[1]Least square means based on 8 pens; finisher 1 : 50.1 ± 2.7 kg to 79.1 ± 1.9 kg; finisher 2 : 79.1 ± 1.9 kg to 107.7 ± 2.8 kg.

[2]POS = corn-soybean meal positive control diet; NEG = corn-hydrolyzed feather meal (FM) with blood negative control diet formulated to be iso N to the POS diet; NRC = NEG + Lys and Trp based on true ileal digestible AA in FM reported by NRC (1998); and SID = NEG + Lys and Trp based on standardized ileal digestible (SID) AA in FM (Sulabo et al., 2012).

[3]Pooled SEM.

[4]Preplanned contrasts.

[5]Based on total Lys.

Table 5. Effect of AA supplementation of corn-hydrolyzed feather meal with blood diets on carcass traits, and subjective meat quality scores at the end of the finisher phase[1]

	Diet[2]					*P*-value[4]		
Item	POS	NEG	NRC	SID	SEM[3]	POS vs. NEG	POS vs. SID	SID vs. NRC
Carcass traits								
Dressing percentage, %	74.9	75.8	75.5	75.4	0.1	0.319	0.460	0.952
10th rib backfat, mm	22.3	26.4	25.2	25.7	0.6	0.099	0.100	0.807
Last rib backfat, mm	25.4	24.7	27.4	27.2	0.4	0.764	0.339	0.907
LM area, cm^2	39.4	33.6	39.1	38.9	0.9	0.012	0.771	0.912
Fat-free lean, %	50.7	47.3	49.3	49.1	0.5	0.030	0.186	0.833
Fat-free lean gain, g/d	364	217	312	312	20	< 0.001	0.020	0.999
Fat-free lean gain:feed intake, g/kg	128.9	84.7	119.4	117.7	6.3	< 0.001	0.210	0.846
Fat-free lean gain:Lys intake,[5] g/g	18.7	17.9	16.7	17.2	0.3	0.576	0.226	0.655
Subjective meat quality scores								
Color	2.58	2.67	2.45	2.45	0.04	0.701	0.525	0.996
Firmness	1.05	1.05	1.00	1.00	0.01	0.994	0.346	0.999
Marbling	2.09	2.26	1.38	1.88	0.12	0.648	0.549	0.135
Muscling	2.03	2.02	2.00	2.06	0.01	0.900	0.771	0.529

[1]Least squares means based on 8 pens; final BW = 107.7 ± 2.8 kg.

[2]POS = corn-soybean meal positive control diet; NEG = corn-hyrdrolyzed feather meal (FM) with blood negative control diet designed to be iso-N to the POS diet; NRC = NEG + Lys and Trp based on true ileal digestible AA in FM reported by NRC (1998); and SID = NEG + Lys and Trp based on standardized ileal digestible (SID) AA in FM with blood.

[3]Pooled SEM.

[4]Preplanned contrasts.

[5]Based on total Lys.

Figure 1:

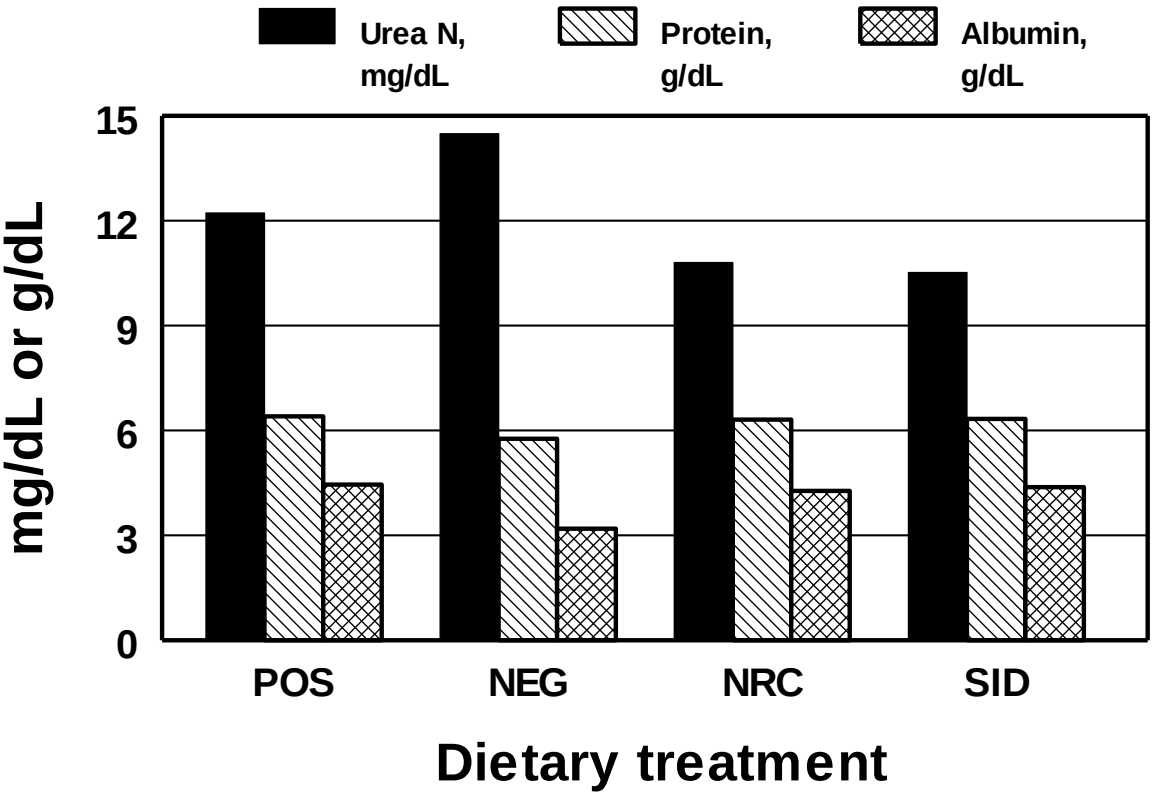
Urea N, mg/dL
Protein, g/dL
Albumin, g/dL
mg/dL or g/dL
15
12
9
6
3
0
POS
NEG
NRC
SID
Dietary treatment

Figure 1. Effect of Hydrolyzed feather meal with blood and amino acid supplementation on serum urea N, total protein (protein), and albumin at the end of the study (final BW = 107.7 ± 2.8 kg). Each least squares means was based on 8 pens. POS = corn-soybean meal positive control diet; NEG = corn-FM negative control diet formulated to be iso-N to the POS diet; NRC = NEG + Lys and Trp based on true ileal digestible AA in FM reported by NRC (1998); SID = NEG + Lys and Trp based on standardized ileal digestible AA in FM with blood reported by. Pooled SEM: 0.6 mg, 0.09 g, and 0.19 g/dL, for urea-N, total protein (protein), and albumin, respectively. Preplanned contrasts = urea-N: POS vs. NEG, $P < 0.001$, and POS vs. SID, $P = 0.003$; protein: POS vs. NEG, $P < 0.001$; and albumin: POS vs. NEG, $P < 0.001$.

Figure 2:

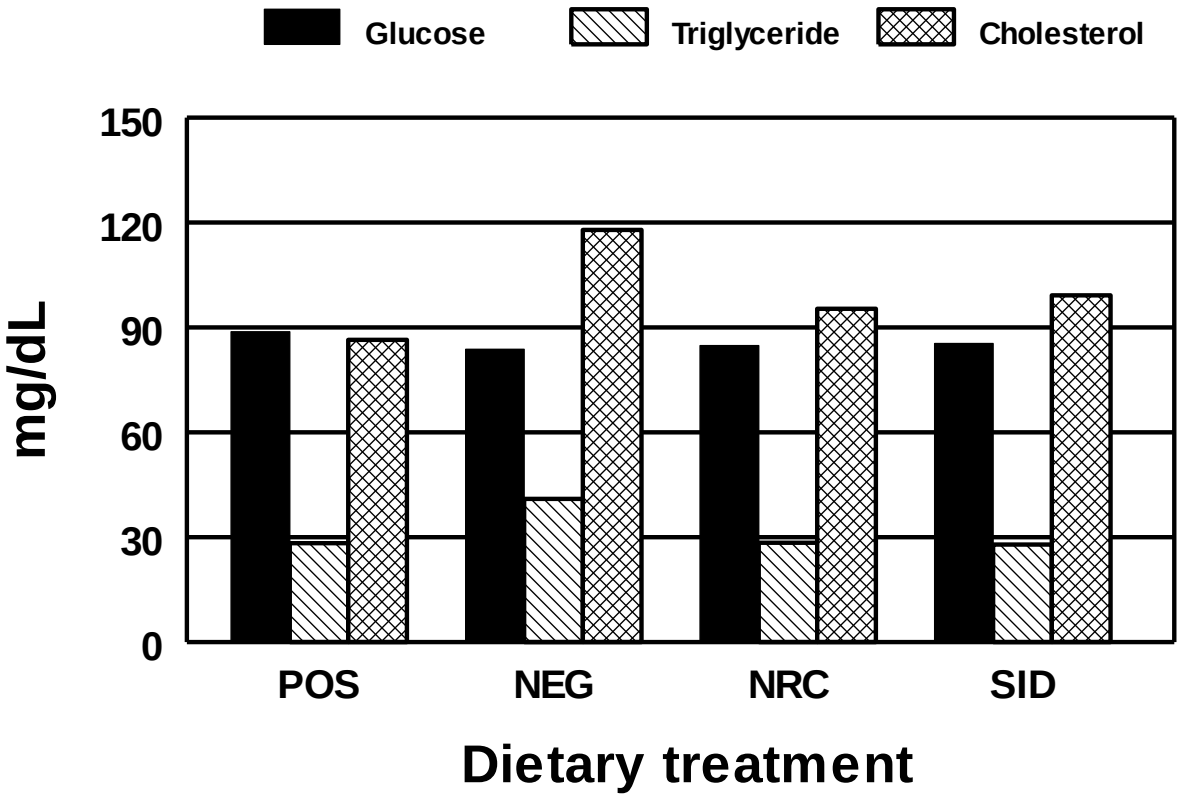
Glucose
Triglyceride
Cholesterol
150
120
90
60
30
0
mg/dL
POS
NEG
NRC
SID
Dietary treatment

Figure 2. Effect of Hydrolyzed feather meal with blood and amino acid supplementation on serum metabolites at the end of the study (final BW = 107.7 ± 2.8 kg). Each least squares means was based on 8 pens. POS = corn-soybean meal positive control diet; NEG = corn-FM negative control diet formulated to be iso-N to the POS diet; NRC = NEG + Lys and Trp based on true ileal digestible AA in FM reported by NRC (1998); and SID = NEG + Lys and Trp based on standardized ileal digestible AA in FM with blood reported by. Pooled SEM: 0.71, 2.1, and 4.3 mg/dL for glucose, triglyceride, and cholesterol, respectively. Preplanned contrasts = triglyceride: POS vs. NEG, $P < 0.001$; and cholesterol: POS vs. NEG, $P < 0.001$, and POS vs. SID, $P = 0.002$.

SUMMARY AND CONCLUSIONS

In the United States in 2008, more than 9.08 billion broiler chickens were slaughtered, generating an estimated 2.46 billion pounds of feathers. Globally, the sheer volume of feathers can be overwhelming, particularly in growing and recently industrialized nations. In order to maintain a sustainable, yet competitive, poultry industry, this major waste product must be managed properly. Inclusion of FM in swine diets not only provides an alternative use for the product to alleviate environmental concerns due to poultry slaughter, but also adds value to this major waste product. Additionally, the human population is ever growing, resulting in the demand for high quality sources of AA to increase. As a result, it has become necessary to find viable, alternative sources of quality AA for sustainable pig production. Increased FM use in the swine industry is, therefore, mutually beneficial to the poultry and swine industries.

Because of the high protein content, feather meal can be an attractive source of AA for growing pig diets (Chiba, 2001). However, as mentioned before, feather meal is low in Lys and other indispensible AA, which may have been responsibe for little research on the use of feather meal in swine diets until fairly recently (Southern et al., 2000; van Heugten and van Kempen, 2002; Apple et al., 2003; Ssu et al., 2004). As a source of indispensible AA, feather meal must be incorporated into diets based on the AA content because, again, it is deficient in Lys and other AA (Chiba, 2010a,b). Unfortunately, such an approach can increase the dietary CP content, which can lead to environmental problems (Chiba, 2000). Thus, supplementation of feather meal

diets with appropriate AA based on AA availability would be the most plausible and effective way to utilize feather meal in pig diets.

In order to formulate the diets to provide the correct amounts and proportions of AA required by the growing pig, the standardized ileal digestibility (SID) of FM was determined. These AA digestibility values were then used to formulate one of our experimental diets. The specific objectives of this study were to determine the effects of corn-FM diets supplemented with appropriate AA based on these SID values for FM on growth performance, serum metabolite profiles, carcass traits, and subjective meat quality scores on growing pigs. A corn-SBM positive control diet (POS) was formulated for finisher-1 and finisher-2 phases. The negative control diet (NEG), was a corn-FM diet formulated to be iso-nitrogenous and iso-caloric to the POS diet. The third dietary treatment was a NEG diet supplemented with appropriate AA based on true ileal digestibility values determined for hydrolyzed feather meal by the 1998 NRC (NRC = NEG + Lys and Trp). The fourth and final dietary treatment was designed as a NEG diet supplemented with appropriate AA based on our determined SID values for AA in FM (SID = NEG + Lys and Trp).

Thirty-two gilts and 32 castrated males (50.1 ± 2.7 kg; 2 gilts or 2 castrated males/pen) were randomly assigned to one of four finisher-1 phase diets. At an average pen weight of 79.1 ± 1.9 kg, pigs were switched to finisher-2 phase diets. Throughout the study pigs were offered ad libitum access to feed and water. When pen weight reached 107.7 ± 2.8 kg, serum samples were collected via vena cava puncture using a disposable needle and syringe following an overnight fast. After this target weight was reached, pigs were slaughtered at the Auburn University Meat Lab to collect standard carcass measurements and receive subjective meat quality scores.

Growth performance data in the present study indicated that pigs fed the POS diets tended to consume more feed and consumed more Lys and gained faster than pigs fed the SID diets. However, the pigs fed the SID diets were able to utilize feed and Lys for BW gain as efficiently as those fed the POS diets. It is likely that the tendency for decreased rate of BW gain in SID pigs is the result of the decreased feed and Lys intake (178 and 1.3 g/d, respectively). There were no differences between pigs fed the SID and NRC diets in ADFI, total Lys intake, or ADG. However, pigs fed the SID diets tended to utilize feed for BW gain more efficiently, and utilized Lys more efficiently than those fed the NRC diets. Based on these data, it seems that the diets based on SID coefficients were able to provide a more optimal balance of indispensible AA than those based on the TID values reported by the NRC (1998), thus resulting in the improved feed and Lys efficiency in pigs fed the SID diets. Pigs fed the NEG diets tended to consume less feed than the POS pigs, and had reduced Lys intake, ADG, and G:F compared with pigs fed the POS diets. However, pigs fed the NEG diets had increased efficiency of Lys utilization for BW gain compared with pigs fed the POS diets

Results from numerous previous studies indicated that subjective meat quality scores such as color, firmness, and marbling would be altered by the dietary treatments. However, the present study, while noticing a numerical increase in marbling scores for NEG pigs compared to other groups, found no significant differences in color, firmness, or marbling scores.

In conclusion, although the depression in BW gain was alleviated by using FM with blood to a certain extent, the FM diet supplemented with appropriate AA based on SID AA values was not as effective as the corn-SBM diets in promoting growth. It is possible that this is associated with the reduced feed and Lys intake in pigs fed the FM diets. However, pigs fed the FM diets supplemented with appropriate AA based on SID AA utilized feed and AA for BW

gain and lean accretion as efficiently as those fed the corn-SBM diets. Further research is warranted to investigate, e. g., how to minimize the differences in feed and Lys intake between pigs fed corn-SBM diets and FM diets, so that FM can be used for pig production in an environmentally friendly manner.

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APPENDICES

Appendix A: Principle of the Urea nitrogen Analysis (Roche Diagnostics, Indianapolis, IN)

Urea is hydrolyzed by urease to form CO_2 and ammonia:

$$\text{Urea} + H_2O \xrightarrow{Urease} 2\ NH_4^+ + CO_2$$

The ammonia then reacts with α-ketoglutarate and NADH in the presence of GLDH to yield glutamate and NAD^+:

$$\alpha\text{-ketoglutarate} + NH_4^+ + \text{NADH} \xrightarrow{GLDH} \text{L-glutamate} + NAD^+ + H_2O$$

The decrease in absorbance due to the consumption of NADH is measured kinetically.

Appendix B: Principle of the Total protein Analysis (Roche Diagnostics, Indianapolis, IN)

Under alkaline conditions, divalent copper in the biuret reagent reacts with protein peptide bonds to form the characteristic purple-colored biuret complex:

$$\text{Protein} + Cu^{2+} \xrightarrow{\textit{Alkaline solution}} \text{Cu-protein complex}$$

The color intensity of this complex is directly proportional to the protein concentration, which is measured photometrically.

Appendix C: Principle of the Albumin Analysis (Roche Diagnostics, Indianapolis, IN)

This is a colorimetric assay with the endpoint method. At a pH of 4.1, albumin displays a sufficiently cationic character to be able to bind with bromocresol green (BCG), an anionic dyestuff to form a blue-green complex:

$$\text{Albumin} + \text{BCG} \xrightarrow{pH\ 4.1} \text{albumin-BCG complex}$$

The color intensity is directly proportional to the concentration of albumin and is measured photometrically.

Appendix D: Principe of Glucose Analysis (Diagnostic Chemicals Ltd.)

Glucose is phosphorylated to hexokinase in the presence of adenosine triphosphate (ATP) and magnesium to for glucose-6-phosphate (G-6-P) and adenosine diphosphate (ADP):

$$\text{Glucose} + \text{ATP} \xrightarrow{Hexokinase,\, Mg^{2+}} \text{G-6-P} + \text{ADP}$$

G-6-P is then oxidized by glucose-6-phosphate dehydrogenase (G-6-PDH) in the presence of nicotidamide adenine dinucleotide (NAD^+) producing 6-phosphogluconate and NADH:

$$\text{G-6-P} + NAD^+ \xrightarrow{G\text{–}6\text{–}PDH} \text{6-phosphogluconate} + \text{NADH} + H^+$$

The formation of NADH causes an increase in absorbance at 340 nm which is directly proportional to the concentration of glucose in the sample.

Appendix E: Principle of Cholesterol Analysis (Roche Diagnostics, Indianapolis, IN)

Cholesterol is determined enzymatically using cholesterol esterase and cholesterol oxidase as follows. Cholesterol esters are cleaved via cholesterol esterase to yield free cholesterol and fatty acids:

$$\text{Cholesterol esters} + H_2O \xrightarrow{\textit{Cholesterol esterase}} \text{cholesterol} + \text{RCOOH}$$

Cholesterol is then converted by oxygen with the aid of cholesterol oxidase to cholest-4-en-3-one and hydrogen peroxide (H_2O_2):

$$\text{Cholesterol} + O_2 \xrightarrow{\textit{Cholesterol oxidase}} \text{cholest-4-en-3-one} + H_2O_2$$

The H_2O_2 then forms a red dyestuff by reacting with 4-aminophenazone and phenol, catalyzed by peroxidase:

$$2H_2O_2 + \text{4-aminophenazone} + \text{phenol} \xrightarrow{\textit{Peroxidase}} \text{4-(p-benzoquinone-monoimino)-phenazone} + 4H_2O$$

The color intensity of the red dyestuff is directly proportional to the concentration of cholesterol and is determined photometrically.

Appendix F: Principle of Triglyceride Analysis (Diagnostic chemicals Ltd., Oxford, CT)

Serum triglycerides are hydrolyzed to glycerol and free fatty acids by lipase:

$$\text{Triglycerides} + H_2O \xrightarrow{Lipase} \text{glycerol} + \text{fatty acids}$$

Glycerol is then phosphorylated to glycerol-1-phosphate in the presence of ATP and glycerol kinase (GK).

$$\text{Glycerol} + \text{ATP} \xrightarrow{GK,\ Mg^{2+}} \text{glycerol-1-phosphate} + \text{ADP}$$

Glycerol-1-phosphate is then oxidized by glycerol phosphate oxidase (GPO) in the presence of oxygen to yield H_2O_2 and dihydroxyacetone phosphate:

$$\text{Glycerol-1-phosphate} + O_2 \xrightarrow{GPO} H_2O_2 + \text{dihydroxyacetone phosphate}$$

The H_2O_2 then causes an oxidative coupling of p-chlorophenol and 4-aminoantipyrine, producing a red colored quinoeimine dye complex:

$$H_2O_2 + \text{p-chlorophenol} + \text{4-aminoantipyrine} \xrightarrow{Peroxidase} \text{quinoeimine dye} + H_2O$$

This causes an increase in absorbance at 520 nm and is directly proportional to the concentration of triglycerides in the sample.

Appendix G: Minimum and maximum daily temperatures (^{o}C) during the study[1]

Table 1. Daily minimum (Min) and maximum (Max) temperatures (T) inside the building during the study

Date	Max T	Min T	Date	Max T	Min T	Date	Max T	Min T
1-Mar	24.4	16.7	22-Apr	25.6	11.7	24-Jun	35	22.2
2-Mar	23.9	17.8	23-Apr	21.1	7.8	27-Jun	33.9	18.9
3-Mar	26.1	11.1	24-Apr	17.2	5	28-Jun	32.8	18.9
4-Mar	16.1	4.4	25-Apr	21.7	9.4	30-Jun	38.3	24.4
5-Mar	15	4.4	26-Apr	27.2	13.9	1-Jul	39.4	26.1
7-Mar	19.4	6.1	27-Apr	28.3	17.8	2-Jul	38.9	21.7
9-Mar	26.1	13.9	28-Apr	27.2	15.6	3-Jul	32.8	23.9
15-Mar	26.1	15	29-Apr	28.9	15	4-Jul	36.1	20
16-Mar	28.9	15.6	30-Apr	31.1	17.8	8-Jul	31.7	22.8
17-Mar	28.3	15	1-May	32.2	19.4	9-Jul	32.8	22.8
18-Mar	28.9	15	2-May	31.1	19.4	10-Jul	33.3	21.1
19-Mar	29.4	15	4-May	27.8	20	11-Jul	32.2	21.1
21-Mar	28.9	17.2	5-May	30	21.1	12-Ju;	32.2	21.7
22-Mar	27.2	17.8	6-May	31.1	20.6	17-Jul	33.9	23.3
24-Mar	21.7	16.7	7-May	30.6	17.2	18-Jul	33.9	21.7
25-Mar	24.4	11.7	8-May	27.8	19.4	19-Jul	32.2	22.2
26-Mar	23.9	12.8	12-May	26.7	17.8	20-Jul	31.7	22.8
27-Mar	27.8	14.4	13-May	23.9	17.2			
28-Mar	28.3	13.3	14-May	23.3	17.2			
29-Mar	27.8	15.6	23-May	27.2	15.6			
30-Mar	27.2	15	24-May	28.9	16.7			
31-Mar	24.4	16.7	25-May	31.7	19.4			
1-Apr	25	13.3	26-May	33.3	22.2			
2-Apr	28.3	16.7	27-May	34.4	23.9			
3-Apr	28.3	16.1	28-May	33.3	21.7			
5-Apr	26.1	15.6	29-May	32.2	21.7			
6-Apr	21.7	11.7	30-May	32.8	19.4			
7-Apr	21.7	10	6-Jun	30	20			
8-Apr	22.8	10	7-Jun	28.9	19.4			
9-Apr	25	13.9	8-Jun	29.4	18.9			
10-Apr	26.1	12.2	9-Jun	30.6	20			
11-Apr	26.1	12.2	10-Jun	26.7	20			
12-Apr	21.7	6.1	13-Jun	25.6	19.4			
13-Apr	20.6	7.2	17-Jun	29.4	18.9			
14-Apr	24.4	12.2	18-Jun	30	17.8			
18-Apr	27.2	15.6	19-Jun	31.1	18.9			
19-Apr	23.3	16.1	20-Jun	31.1	20			
20-Apr	20.6	16.1	22-Jun	32.2	20			
21-Apr	25.6	15.6	23-Jun	33.3	22.2			

Table 2. Mean minimum and maximum temperatures (ºC) during the study

Month	Minimum temperature	Maximum temperature
March	13.7	25.2
April	12.8	24.7
May	19.4	29.9
June	20.0	31.2
July	22.4	33.9
Mean	17.7	29.0