DIETARY CRUDE PROTEIN AND LYSINE IN BROILER CHICKEN NUTRITION

by

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(Under the Direction of Gene M. Pesti)

ABSTRACT

The effect of dietary crude protein (CP) and lysine on broiler chicken performance was investigated in this dissertation. Four studies were conducted to better understand the relationship between dietary CP and lysine with emphasis on dietary CP level and source on broiler chicken performance and the lysine requirement, dietary CP and lysine level and broiler genotype interactions, and the growth response of boiler chickens to cumulative dietary CP and lysine intakes. Increasing dietary CP from 17 to 26% was found to increase body weight gain (BWG) and improve feed conversion ratio (FCR) in male broiler chicks. Dietary CP level and/or source had significant effects on carcass composition. Males and females were found to have similar qualitative responses to increasing dietary CP and source.

The response of broiler chicks to graded levels of lysine at 17, 18.5, and 23% CP was measured in diets mixed by either the graded supplementation or diet dilution method. The requirement for lysine was estimated as a percentage of the diet and as a percentage of the dietary CP level. Results of a t-test show that the lysine requirement between dietary CP levels were significantly different on a percentage of diet basis but not as a percentage of dietary CP level. These results indicate that the lysine requirement is a direct proportion of the dietary CP level within a practical range. In addition, no differences were observed between the graded supplementation method and the diet dilution method in estimating the lysine requirement.

A three-way interaction between dietary CP, lysine and genotype was detected in broiler chicks during the starter and grower phases. Ross 308 and Cobb x Cobb broiler chicks were fed starter diets containing two dietary CP levels and three dietary lysine levels. Ross 508 and Arbor Acres broiler chicks were fed grower diets with similar dietary CP and lysine levels. Regression analysis showed differences due to genotype for BWG, feed intake and FCR for starter chicks, and BWG and carcass composition for grower chicks. The three-way interaction demonstrates that quantitative differences exist between genotypes in response to increasing dietary CP and lysine levels.

The response of broiler chicks to cumulative dietary CP and lysine intakes was determined to follow "the law of diminishing returns." Significant linear and quadratic responses were observed with chicks fed starter diets with four levels of dietary CP and lysine. BWG as a function of dietary CP and lysine intake was used to develop and demonstrate a quadratic feed formulation programming model. In general, as the price of crude protein sources increased, the level of dietary CP decreased. Maximum profit diets formulated using the quadratic program could significantly increase returns over the least-cost formulation models under some economic situations for the starter diet alone.

INDEX WORDS: Crude Protein, Lysine, Genotype, Cottonseed meal, Lysine requirement, Maximum profit feed formulation

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CHAPTER 1

INTRODUCTION

Dietary crude protein (CP) level has been shown to have significant effects on carcass composition (Smith and Pesti, 1998 and Smith et al., 1998). In general, increasing dietary CP improves feed conversion ratio (FCR), increases breast meat yield and decreases abdominal fat pad percentage. It is reasonable to assume that dietary feed formulations with higher dietary CP levels above industry standards would prove to be more profitable.

If increasing dietary CP levels proves to be more profitable then at what level should the indispensable amino acids be included in the diet? In the early 1950's Almquist noted that the lysine and methionine requirements versus dietary CP levels were not similar and that as the dietary CP increased the lysine and methionine requirements decreased as a proportion of CP. However, in the 1970's, this assumption was challenged (Boomgaardt and Baker, 1970 and 1973) and the lysine requirement was estimated to be a constant proportion of dietary CP. More recent studies have found the lysine (Abebe and Morris, 1990a; Surisdiarto and Farrell, 1991; Hurwitz et al., 1998) requirement as a percentage of CP to decrease as dietary CP increased, thus confirming Almquist's earlier conclusion. It is difficult to attribute differences in the materials and methods these researchers employed to create such equivocal results. Certainly, the comparison of experiments similar in their hypotheses is clouded by numerous differences in experimental design. In addition, it is known that the responses to amino acids, and therefore amino acid requirement estimates, can vary depending on the dietary protein source and quality, dietary energy level, experimental conditions, statistical evaluation, gender, and genotype. Researchers have realized the diverse production potentials offered by gender, genotype and genotype cross and how nutrition, particularly nutrient levels, can influence those potentials. Genetic differences in growth rate, feed intake, and feed efficiency have been reported between genotypes (Washburn et al., 1975; Malone et al., 1979; Holsheimer et al., 1991; MacLeod et al., 1998). In addition, genetic differences have been observed for breast meat yield and abdominal fat pad percentage (Holsheimer et al., 1991; Acar et al., 1991). Smith et al. (1998) concluded that a different profit maximizing feed formulation would be required for each genotype. However, determining nutrient requirements and different profit maximizing feeding programs for each genotype seems impossible and may result in redundancy. A simpler approach would be to first determine if differences in response to dietary CP and lysine exist between genotypes without determining a requirement.

Leclercq and Beaumont (2001) concluded, “because of the curvilinearity of performance responses to lysine concentration, determining the requirement is difficult.” That is, the response of broiler chicks as measured by body weight gain to increasing dietary lysine follows the “law of diminishing returns.” The concept of feeding economically optimal levels of nutrients based on diminishing returns functions is not new, but still has been rarely used in nutrition (Almquist, 1953). Pesti et al. (1986) used a quadratic polynomial to describe a response model with feed consumption and body wight gain as functions of two inputs (CP and ME). They observed quadratic growth responses to dietary energy and crude protein (CP) indicating diminishing marginal productivity.

The relationship between dietary lysine and CP levels is not unlike other substitution examples in nutrition such as phytin phosphorus and phytase, methionine, cystine, choline and betaine, phenylalanine and tyrosine, and tryptophan and niacin. It is reasonable to assume that with changing market prices for poultry meat and feedstuffs, varying combinations of dietary lysine and crude protein can prove to be the more profitable than simply formulating for the least-cost diet.

The research within this dissertation was conducted to determine the influence of dietary crude protein and lysine on broiler chicken performance. Emphasis was placed on dietary CP level and source on broiler chicken performance and the lysine requirement, dietary CP and lysine level and broiler genotype interactions, and the growth response of boiler chickens to cumulative dietary CP and lysine intakes. The response of broiler chicks to dietary CP and lysine was studied alone and in combination to better understand their interrelationships.

The results of the first study concerning protein level are qualitatively similar to what Frapps (1943) observed in the 1940's and Smith and Pesti (1998) observed in the 1990's. Dietary CP level has significant effects on carcass composition particularly, breast meat yield and abdominal fat pad percentage.

The results of the second study indicate that the lysine requirement is a direct proportion of the dietary CP level within a practical range. The practice of keeping amino acid requirements as a proportion of the dietary CP content appears to be adequate for practical feed formulation.

In examining the effect of dietary CP and lysine on genotype, the level of dietary CP appeared to be less important for broilers during the grower phase when compared to starter phase chicks. Cobb x Cobb chicks were more efficient when compared to the Ross 308 chicks and this may indicate a lower need for lysine and/or dietary CP. Arbor Acres broiler chicks were heavier for all dietary lysine and CP levels however, Ross 508 broiler chicks had higher breast yields. In addition, Arbor Acres broilers were more efficient at utilizing the low lysine diets indicating a need for lower levels of dietary lysine and/or CP. The levels of dietary lysine fed during the grower phase were higher than NRC (1994) recommendations however, performance continued to improve. In these studies, the responses of the four genotypes to increasing dietary lysine and CP were quantitatively different.

The response of broiler chicks to cumulative dietary CP and lysine intakes was determined to follow “the law of diminishing returns.” Maximum profit diets formulated using the quadratic program based on this relationship could significantly increase returns over the least-cost formulation models under some economic situations for the starter diet alone. The quadratic programming model workbook (WUPP’EM) gives producers a working tool to demonstrate the interdependencies of costs, technical response functions and the value of broiler meat. Since many nutrition students and nutrition practitioners already understand and use Microsoft® Excel, it is hoped that this workbook will serve as a foundation for the development of improved models.

CHAPTER 2

LITERATURE REVIEW

Crude Protein

Crude protein (CP) is determined by analyzing a feedstuff for nitrogen content and multiplying the value by 6.25. This value was derived as a factor to convert the nitrogen content of a pure protein such as albumin (15.5% nitrogen) to 100% protein. It was assumed that all proteins contain approximately 16% nitrogen however, this is not true. For example, corn protein contains approximately 15.65% nitrogen and wheat protein contains approximately 17.54% nitrogen. Therefore to convert their nitrogen content to 100% protein, the factors 6.39 and 5.70 are needed, respectively. Despite obvious differences in nitrogen contents of feedstuffs, the factor 6.25 has been adopted for the estimation of crude protein (Ewing, 1963). In addition, because pure protein contains approximately 16% nitrogen, the percentage of nitrogen in corn represents more than that incorporated in amino acids. The term “crude” protein implies that a protein contains nitrogen from more than just amino acids. There is also non-protein nitrogen and nitrogen representing the total nitrogen percentage. For this reason the CP percentage of a feedstuff reveals little about the quality of the protein. That is, the utilization of the protein in a feedstuff and the digestibility and availability of its constituent amino acids are indicators of quality, not total nitrogen content.

Dietary Crude Protein Quality

Factors affecting protein quality. The true quality of a protein depends on its constituents primarily the indispensable amino acids and the digestibility of the protein. The amino acid profile of a feedstuff can be rapidly determined with ion exchange chromatography and high performance liquid chromatography (HPLC). However, these profiles only reflect relative quantities of each amino acid in the feedstuff. Chromatography methods do not reflect the digestion (hydrolysis) and absorption (availability) of individual amino acids for utilization by an animal.

Most proteins lose some of their nutritional value due to reactions involved in processing (e.g., oil extraction) between inherent compounds and the amino acids lysine, methionine, cysteine, and tryptophan. Phenolic compounds are found in a variety of feedstuffs such as peanut, rapeseed, sunflower, and cottonseed meals. There are four major biochemical groups that phenolic compounds fall under. They are benzoic acids, cinnamic acids, flavonoids, and terpenoids. Terpenoids are the largest and most diverse of this group and are found in cottonseed as gossypol (~1%). A decline in protein quality has always been associated with the processing of cottonseed into a meal. Generally, it is a decline in lysine availability since lysine binds to gossypol derivatives. It is assumed that gossypol is oxidized to a quinone derivative and quinones are highly reactive with amino, sulfahydryl or substituent groups of amino acids. Quinone derivatives covalently bind to the epsilon group of lysine rendering it unavailable even after the effects of digestive processes (Finley and Hopkins, 1985) .

Protease inhibitors are compounds that bind to active sites of enzymes responsible for the breakdown of proteins in the small intestine. Trypsin inhibitor is an example of a protease inhibitor found in soybean meal. Animals fed raw, untreated soybeans show a decrease in growth, nitrogen digestibility and retention as well as pancreatic hypertrophy (Finley and Hopkins, 1985). Trypsin inhibitor is heat labile and can be denatured simply by heating soybean meal.

Phytic acid (hexophosphoinositol) is the major form of phosphorus in most grains such as wheat and corn (Groff et al., 1995). Its association with protein occurs naturally during maturation of seeds as well as during processing of protein isolates such as soy protein (Finley and Hopkins, 1985). This association is due to electrostatic attractions between negatively charged phosphate groups of phytic acid and positively charged amino groups of amino acid residues in protein when the pH is low. At the isoelectric point of the protein (no net electrical charge) the solubility of the protein is low and the phytate dissociates. As the pH rises above the isoelectric point of the protein the solubility of both phytate and protein increases allowing them to associate again. However, this time it is through a divalent cation bridge formed by either calcium, magnesium or zinc between the negatively charged carboxyl groups of the protein and phytate (protein-cation-phytate).

Oxidizing lipids can also associate with the amino acid residues of proteins. This process occurs mostly in feedstuffs that contain a moderate to large number of unsaturated fatty acids (corn, soy, and safflower oil, etc.). Methionine, lysine, cysteine and tryptophan are amino acids most sensitive to this process and can be oxidized to forms unavailable to an animal (Finley and Hopkins, 1985).

Biological Value. Biological Value (BV) is the ratio of nitrogen retained for growth or maintenance to the nitrogen absorbed. The BV of a protein can be determined in humans and animals and requires that measurements be taken on nitrogen intake, in addition to fecal, urinary, and endogenous nitrogen. The endogenous fecal and urinary nitrogen values are obtained with animals or subjects maintained on a nitrogen free diet. Nitrogen equilibrium is necessary because levels of protein fed below the level required for nitrogen equilibrium will give a higher BV (Groff et al., 1995).

Protein Efficiency Ratio. The Protein Efficiency Ratio (PER) measures the ratio of gain in body weight when fed a test protein to the amount of protein consumed and is a predictor of weight gain for young growing animals. For example, a PER of 2.5 for protein A means that an animal that consumes 1 gram of protein A will gain 2.5 grams in body weight (Groff et al., 1995).

Net Protein Utilization. Net Protein Utilization (NPU) measures the utilization of protein nitrogen by measuring nitrogen intake, in addition to fecal, urinary, and endogenous nitrogen as in the BV procedure. In animals whole carcass nitrogen can be analyzed to yield a more accurate measurement. An obvious disadvantage to this method is the preparation of whole carcasses for analysis (Groff et al., 1995).

Dietary Crude Protein and Broiler Performance

Crude Protein Recommendation. There is not a requirement for crude protein per se, rather a requirement for its constituent amino acids. NRC (1994) gives recommendations for dietary CP levels for the specific ages or growth periods of broiler chickens**.** These were dietary protein levels found to result in the best performance during each growth period. However, industry standards diverge from NRC (1994) recommendations particularly because lower CP diets are found to be more economical by least-cost linear feed formulation models. Unfortunately, low CP diets result in poorer feed conversion ratios (FCR) and more carcass fat.

Crude Protein and Body Composition. The dietary CP level of a feed has profound affects on feed intake, FCR, and body composition. Fraps (1943) was one of the earliest to observe changes in body composition due to changing the energy and CP levels of a diet. Later, Hill and Dansky (1950) using crossbred chicks, fed a diet high in productive energy with no improvements in growth as CP was increased from 20 to 30%. Reducing the productive energy and feeding protein levels below 20% resulted in normal growth compared to the same CP levels at the higher productive energy level. Thus, the significance of the relationship between dietary energy and CP levels became the topic of numerous studies.

Hill and Dansky (1954) found that carcass fat content of chickens is reduced when dietary energy levels are reduced in isonitrogenous diets. Donaldson et al. (1955) noted differences in carcass moisture and fat content (decrease in moisture and increase in fat) when widening the calorie to protein ratio. Donaldson et al. (1955) also noted that increasing dietary CP levels in isocaloric diets resulted in a reduction of feed consumption and a decrease in carcass fat. In addition, significant negative correlations between the calorie and CP ratios and carcass water or protein content and a positive correlation between the ratios and carcass fat were found.

Marion et al. (1978) found a similar relationship and observed carcass fat to be inversely related to moisture levels. In addition, carcass moisture levels were significantly lower when either low protein or fat supplemented diets were fed.

Dietary energy and CP levels have effects on body weight, feed intake, and FCR independently of dietary energy level (Pesti, 1986). Pesti (1986) found growth was dependent on both energy and protein and that this response follows the "law of diminishing returns."

Jackson (1982) fed a range of dietary CP concentration (16 to 36%) and found a significant increase in carcass protein and decrease in abdominal fat percentage as CP increased. Carcass protein increased in response to increasing CP and plateaued at 28% CP. The rate of increase in carcass protein, as dietary CP increased, followed a diminishing response. Summers (1965), Marion (1966), and Twinning (1978) found similar results.

More recently, Bartov and Plavnik (1998) tested all combinations of two dietary energy and CP levels and found breast meat yield in 47 and 53 d broiler chicks to be negatively correlated with dietary energy to protein ratios. That is, the low energy to protein ratio (higher CP diet) had significantly higher breast meat yield and carcass yield and lower abdominal fat pad percentages when compared to the recommended energy to protein ratio of NRC (1994).

Dietary Crude Protein and Lysine. Morris et al. (1999) stated that the requirement for broiler chicks increases nearly in direct proportion to the dietary CP in the 22 to 30% CP range. In addition, a response to increasing levels of the first limiting amino acid occurs past the level of CP necessary for maximum BWG. That is, while the maximum BWG between the 20 and 30% CP diets of Grau (1948) did not change, the requirement for lysine (as a % of the diet) increased. Morris et al. (1999) concluded that an amino acid imbalance at the higher CP levels decreases the efficiency of utilization of the first limiting amino acid causing an increase in the requirement. D'Mello (1988), when referring to the results of Boomgaardt and Baker (1973a) and Morris et al. (1987), explained that the decline in the first limiting amino acids' utilization for growth is a result of the disposal of excess amino acids present at the higher CP levels and not an imbalance. In addition, Baker (1978) suggested that a reduced utilization of lysine in soybean meal (SBM) was due to excess amino acids in SBM. However, the classic definition of an imbalance (Harper et al., 1970) states that the efficiency of utilization remains unchanged in the presence of excess amino acids. Morris et al. (1999) explained that the imbalance seen at the higher CP levels is different from classical imbalances because a decline in feed intake was not apparent although growth was depressed at these levels when one essential amino acid was limiting. It is reasonable to assume that an imbalance occurs at higher CP levels. The experiments conducted by Davis and Austic (1994) suggest an amino acid imbalance can result from the addition of one or more amino acids to a diet adequate in CP. In this regard, it is just as likely that the presence of excess amino acids decreases the utilization of the first limiting amino acid. D'Mello (1994) observed that excess amino acids were present in the diets of Morris et al. (1987) using the diet dilution method when compared to the diets of Boomgaardt and Baker (1973a) who used the graded supplementation method. D'Mello (1994) concluded that these excess amino acids reduced the utilization of the first limiting amino acid, in this case lysine. The reduction in utilization was partly due to the cost of metabolizing the excess amino acids causing the chicken to make less efficient use of lysine (D'Mello, 1994).

Lysine

Lysine Metabolism. Lysine is one of 12 indispensable amino acids required by the chicken and because it is not synthesized by the chick, it must be provided in the diet. Its primary function in the body is for protein synthesis. However, it is also important in the formation of cross-linked proteins such as collagen and it is a precursor of the fatty acid transporter carnitine (Linder, 1991).

Lysine degradation. The initial degradation of lysine proceeds in two separate pathways (Figure 2.1). Both pathways result in the formation of α-aminoadipic semialdehyde (Wang and Nesheim,1972). The pipecolic acid pathway involves the oxidative deamination of lysine resulting in the release of ammonia. The saccharopine pathway is the primary pathway that results in lysine being converted to sacchropine by the enzyme lysine α-ketoglutarate reductase. The intermediate product of lysine degradation is α-aminoadipic semialdehyde that is converted through a series of reactions to 2 Acetyl CoA molecules. Lysine is considered ketogenic because its degradation yields acetyl CoA that can be converted to the ketone body acetoacetate.

Lysine Absorption. In the intestinal brush border membrane, many energy dependent systems with different amino acid specificities exist. In an experiment conducted by Gous et al. (1977), evidence was provided that lysine transporters in the chick intestinal rings is both sodium-dependent and -independent. The carrier system in both the brush border and basolateral membranes for the dibasic amino lysine has been identified as y+ and is sodium-independent Groff et al. (1995).

Lysine Digestibility and Availability

The total dietary level of an amino acid gives no indication of whether or not that amino acid will be available for utilization by an animal (D'Mello, 1994). In many cases in the literature, the terms digestible and available have been used interchangeably. Digestible lysine is defined as the lysine available to the chick for absorption. Available or "bioavailable" lysine takes into account the proportion of the ingested amino acid that has been digested, absorbed and is available at sites of protein synthesis in an animal. Therefore, the digestible lysine content gives no indication of the bioavailability of lysine in a feedstuff (Fernandez and Parsons, 1995, 1996).

In general, amino acid digestibility and availability techniques were devised to measure the nutritive value of protein sources such as soybean meal, cottonseed meal and sesame seed meal, that are known to have been subjected to heat during oil extraction processes. The free epsilon groups of lysine react with compounds such as reducing sugars as part of the Maillard reaction, and gossypol, a toxic substance in cottonseed meal. Protein sources such as cottonseed meal and sesame seed meal are known to have low digestible lysine values due to Maillard reactions. Maillard reactions occur under conditions of high humidity and temperature such as those encountered during extraction processes. The free epsilon groups of lysine react with free carbonyl groups of reducing sugars (e.g., glucose and lactose) (D'Mello, 1994). The resulting lysyl-sugar compound has no bioavailability.

The availability of lysine in feedstuffs has been studied using both in vitro and in vivo methods. The most common in vitro methods include chemical assays. The most common in vivo methods include digestibility assays including slope ratio, and ileal digestibility assays.

Digestibility Assays. Sibbald (1979) described a biological procedure for determining the digestible lysine in a feedstuff as a modification of a true metabolizable energy assay. In these assays, birds are fasted, gavage dosed with a known amount of a feedstuff and total voided excreta is collected, frozen, freeze-dried and weighed. Endogenous losses of amino acids are measured by fasting a separate set of birds and collecting excreta. Feces samples are hydrolyzed and amino acids are analyzed. The endogenous fecal amino acid concentration is subtracted from the total fecal amino acid concentration to give the true fecal amino acid concentration. The total digested amino acid concentration is calculated by subtracting the true fecal amino acid concentration from the total amino acid intake and expressing this value as a percent of the total consumed.

Ileal Digestibility Assays. One disadvantage to using the fecal digestibility method described above involves the metabolism of unabsorbed amino acids by microorganisms in the hind gut of animals and ceca of the chicken. Because these amino acids are cleared from the feces they are assumed to have been absorbed by the individual. For this reason, ileal digestibility studies focus on collecting digesta at the point where amino acid absorption is complete, the terminal ileum. In pigs, many techniques have been devised, all with the goal of avoiding the movement of digesta beyond the ileum. The pigs are either slaughtered or anaesthetized and their intestinal contents are collected; or they are cannulated, or the ileum is surgically shunted to the rectum. In chickens, cannulation can be used for ileal digestiblity measures, however the ceca are the principle site of bacteria,

therefore, cecectomized birds are commonly used. Calculations are similar for ileal and digestible amino acid coefficients with the exception that an indigestible marker is commonly used with ileal digestibility assays.

True Versus Apparent Digestibility. True digestibility makes a correction for the amino acids derived from endogenous sources (secretions, mucus, sloughed cells, bacteria), thus without the knowledge of endogenous contributions the digestibility is called apparent. Endogenous sources are accounted for by feeding either a non-protein diet or fasting an animal then measuring the concentrations of amino acids in feces.

The advantage to using the apparent digestibility model is in the simplicity of its measurement in that no corrections are needed to be made. However, the dietary CP level has been shown to affect the digestibility percentage (Rademacher, 1999). The apparent digestibility of a feedstuffs increases as the dietary CP level increases. This is assumed to be associated with the decrease in endogenous losses as a percentage of the total amino acid concentration as dietary CP increases. The true digestibility percentages remain constant over a range of CP levels because endogenous losses are accounted for.

Slope-ratio Assays. An example of measuring lysine availability in SBM was given by Baker (1978) who describes the slope-ratio procedure in detail. Two response curves were determined, one to establish the L-lysine HCl standard curve by feeding a crystalline amino acid diet with synthetic supplemental L-lysine HCl (from 0 to 1.0%).

Synthetic lysine is considered to be 100% available. A second curve was established to describe the SBM response curve as the dietary level of SBM was increased (from 3.45 to 20.70%). L-Lysine was added to these diets from (0.10 to 0.60%) to provide increasing total dietary lysine levels of 0.20 to 0.70%.

The slope of the regression equation for the SBM response curve was related to the slope associated with the L-lysine HCl standard curve. The ratio of the SBM response curve divided by the L-lysine standard curve slope yields the mg of lysine in 1 gram of SBM. The availability of lysine of SBM was determined to be 80%.

In addition, Baker (1978) found that synthetic lysine is not utilized equally at all dietary levels. The lysine efficiency ratio (grams body weight gain per grams lysine intake) increased between 0 and 0.4% and decreased after 0.8% lysine. Similar observations were made with the SBM diets.

Chemical Assays. Carpenter (1960) described a method for assessing the chemical availability of lysine in process damaged feedstuffs. The 1-Fluoro-2, 4-Dinitrobenzene (FDNB) method is a colormetric assay that measures the absorbance of the epsilon dinitrophenyl-lysine derivative. The derivative is produced as the FDNB reagent react with free epsilon groups of lysine on intact proteins. The reaction with free epsilon groups gives an indication of the amount of lysine available for absorption. However, this procedure requires acid hydrolysis of the protein to free the derivatives for measurement. The hydrolysis is known to partially destroy the derivatives. Another similar chemical procedure procedure uses the 2,4,6-Trinitrobenzene Sulonic Acid (TNBS) reagent to produce an epsilon trinitrophenyl-lysine derivative (James and Ryley, 1986). Chemical procedures are considered advantageous because they are faster when compared to biological assays. However, these methods cannot detect free lysine or early Maillard products. In addition, the reagents binding is slightly non-specific resulting in erroneous measurements in the chemical availability (Nordheim and Coon, 1984).

There are other in vitro methods such as microbiological assays, dye-binding, ^{19}NMR, and immobilized enzymes (D'Mello, 1994). These methods are faster and less expensive (except ^{19}NMR) than biological assays. However, in vivo methods remain the reference standard.

Enzymatic assays include the use of proteolytic enzymes such as pancreatin, pepsin, and papain that are mixed with feedstuffs under conditions similar to those found in the gut and small intestine. They primarily measure the digestibility of the test material with the assumption that if the enzymes digest the test material in vitro the same will be true in the course of digestion by an animal. The digested materials are separated by chromatography methods after being subjected to incubation with the enzymes. One problem associated with this method is that the reactions are too slow and are seldom completed before analysis of constituent amino acids. In addition, care must be taken to include the amino acids contributed from the enzyme itself. However, there is an advantage to using this technique when measuring tryptophan over chemical means that tend to destroy it.

Microbiological assays involve three different technical procedures in which bacterial growth is measured. In all cases the amino acid profile of the test material must be known to make comparisons. In one procedure, enzymatic hydrolysis of the test material (as mentioned above) takes place with the hydrolysate included in the bacterial media. In another procedure, hydrolysis of the test material either under acid or alkaline conditions occurs prior to being included in media. In a third procedure, proteolytic microorganisms are utilized and bacteria growth is measured against graded supplements of the test material to the media. The principle behind the assay is that the availability of the amino acids to the bacteria will also be available to an animal.

Nordheim and Coon (1984) compared four methods for determining the lysine availability of a feedstuff. Two chemical assay methods, a chick bioassay and a digestible lysine chicken assay were compared. The two chemical assay methods were the FDNB and TNBS methods. The chick bioassay was a slope-ratio assay and the digestible lysine chicken assay was the procedure of Sibbald (1979). The correlation coefficients were 0.90, 0.93, and 0.97 for the chick bioassay versus the TNBS, FDNB and digestible lysine procedures, respectively. Norheim and Coon (1984) concluded that the digestible lysine procedure was the most practical method for determining the lysine availability in feedstuffs.

Lysine and the Ideal Amino Acid Profile

Responses to amino acids, and therefore amino acid requirement estimates can vary depending on the dietary protein source and quality, dietary energy level, genetic strain, sex, experimental conditions, and statistical evaluation. Recognizing the difficulty in estimating amino acid requirements under such circumstances, researchers developed the "Ideal Amino Acid Profile" (IAAP). The ideal amino acid profile and protein concept consists of controlling the concentration of the indispensable amino acids by fixing them as ratios to lysine (Baker and Han, 1994). The only amino acid requirement needed to be established is lysine. Then the ratio between lysine and other indispensable amino acids determines their appropriate feeding levels.

How Requirements are Determined

The NRC (1994) dietary CP recommendation is represented by the collective requirement of twelve indispensable amino acids (IDAA) and additional dispensable amino acids (DAA) needed to satisfy the requirement for the synthesis of proteins and non-protein molecules. Therefore, the recommended CP level is really a requirement for amino acids. An amino acid requirement is the minimum level of that amino acid needed for optimum production.

Growth Assays. Growth assays are one of the primary methods used to measure amino acid requirements for poultry and are the simplest in both design and measurement. Growth assays are also used to compare results of nontraditional methods of determining amino acid requirements such as the indicator amino acid technique. A typical assay measures the response of growing chickens to the addition of graded levels of an amino acid to a basal diet. The basal diet is deficient in the test amino acid and is usually altered by adding crystalline amino acids. Plotting the response versus dietary amino acid level reveals a response that increases or decreases as dietary levels of the test amino acid increase and then plateaus at levels reaching the requirement. A relationship is considered to follow the "law of diminishing returns" if the ascending portion of the response is non-linear. Recommendations for dietary levels of amino acids are made by measuring production criteria such as BWG, feed intake and FCR. The dietary requirement is the minimum level of the test amino acid that minimizes or maximizes these production criteria. Therefore, the requirement of an amino acid is dependent upon the criteria being measured. For example, the lysine requirement estimated to minimize abdominal fat, FCR and maximum breast meat yield and BWG rank in order from highest to lowest (Leclercq, 1998). Therefore, maximizing one production criteria lowers the potential of maximizing another. It is up to the nutritionist and production manager to decide which criteria is to be maximized.

Diet Selection. The choice of diet for establishing the requirement of an amino acid is usually made between a conventional diet containing natural sources of protein, a purified diet, and a semi-purified diet (Table 10.1 of NRC, 1994). Purified diets contain pure sources of carbohydrate, protein and/or amino acids such as corn starch, casein, and crystalline amino acids, respectively. A semi-purified diet contains at least one natural source of protein and crystalline amino acids. The advantage to using a purified diet is that relative amounts of certain amino acids can be controlled easily by either adding or omitting them from the amino acid mixture. The disadvantage is in the cost of the amino acids and the response of chicks fed these diets, as measured by growth and feed consumption, is usually depressed compared to conventional diets.

The choice of diet preparation for conventional diets is usually made between the diet dilution and graded supplementation methods. The graded supplementation method comprises the graded addition of a test amino acid to a basal diet deficient in that amino acid (D'Mello, 1994). In general, the test amino acid is in cyrstalline form. A separate basal diet must be formulated if different CP levels are desired. Amino acid ratios or proportions within the different CP levels are somewhat different, especially if different proportions of several ingredients are used. Gous and Morris (1985) published an extensive report comparing the diet dilution and graded supplementation methods and concluded that the diet dilution method was superior in that it maintains the balance of amino acids within narrow limits between dietary CP levels. The diet dilution method comprises the dilution of a high CP diet with a diet that is devoid or low in CP. Amino acid proportions within the different CP levels are identical. In general, the diet dilution method is best used when it is difficult to create a diet where the test amino acid is deficient and/or it is necessary to incorporate several protein sources in order to avoid the expense of incorporating synthetic amino acids. Gous and Morris (1985) used the diet dilution method to create diets with increasing levels of a test amino acid by using combinations of the low and high CP diets and allowing the CP level to increase at the same time. The disadvantage to using the diet dilution method in this respect is that it is difficult to determine whether the response is due to increasing dietary lysine or CP. However, in the study by Morris et al. (1987) the diet dilution method was used to create diets with increasing levels of dietary CP and to each diet graded levels of the test amino acid were added. In that case, the only difference between the diet dilution and the graded supplementation method was that the amino acid profiles between each diet in the study of Morris et al. (1987) were the same. D'Mello (1994) found the diet dilution and graded supplementation methods to be highly comparable.

Mathematical Methods. The most common mathematical models used to determine amino acid requirements are the ascending line and plateau (one-slope), ascending line and sloped plateau (two-slope), quadratic and ascending quadratic with plateau models (Table 2.2). Barbour et al. (1993) found along with protein source, statistical evaluation can influence the estimate of an amino acid requirement. That is, the quadratic procedure estimates were higher for all protein sources when compared to a two-slope procedure. Similarly, with the original analysis of Morris et al. (1987), performed using a quadratic model, the lysine requirement was estimated to be a constant proportion of the dietary CP level. In a re-analysis of the data obtained by Morris et al. (1987), Abebe and Morris (1990a) used the Reading model (similar to an ascending quadratic and plateau model) and concluded that the lysine requirement decreased in proportion to the dietary CP in two separate experiments (Figure 2).

Vazquez and Pesti (1997) used the ascending quadratic and plateau and ascending line and plateau models to determine the lysine requirement from various data sets in the literature. They determined the predicted lysine requirement to be higher for the ascending quadratic for both BWG and FCR when compared to the one-slope model. Hurwitz et al. (1998) used a one-slope model to establish the requirements and a t-test to determine differences between CP levels in three experiments. Hurwitz et al. (1998) found the requirements for diets containing 20 and 18% CP to be significantly different from a 23% CP diet when expressed as a % of the diet using a t-test. Other models include, but are not limited to exponential models. Mack et al. (1999) found the modified broken line model estimated a lower requirement when compared to an exponential model. These researchers concluded that the exponential model was a more accurate model to use considering the response to increasing a nutrient from deficient to adequate levels follows the "law of diminishing returns."

The Lysine Requirement

"It has been shown by Osborne and Mendel (1913) in their study of the nutritional value of various pure proteins, that only those proteins containing the lysine and tryptophan complexes are capable of maintaining the animal organism in a condition of nitrogenous equilibrium and that only those proteins containing lysine are able to promote the growth of young animals" (Turner and Spears, 1916). Lysine is often limiting in the diets of growing poultry since cereal grains are deficient in lysine. The requirement of the chick for lysine has been of great interest to many researchers since the early 1940's (Table A-1). There are at least three reasons this subject has been extensively studied. Synthetic lysine has been readily available for use in poultry feeds and can be used in diets that would otherwise be deficient in lysine, 2) supplementation of synthetic lysine has allowed for more economical feed formulation solutions, and 3) perhaps the most important reason this subject has been revisited over the years is due to the lack of consistency in the determination of the lysine requirement.

Buckner et al. (1916 and 1919) were the first to indicate the chick's need for lysine and Almquist and Mecchi (1942) were the first to determine a lysine requirement for the chick. Almquist and Mecchi (1942) determined the lysine requirement for a young chick to be 0.90% of a corn, edestin or casein diet. Grau et al. (1946) using a sesame seed meal (SSM) based diet determined the lysine requirement of chicks to be a little higher at 0.96% of the diet.

In contrast, Almquist (1947) also found the requirement to be 0.90% of the diet. Grau (1948) and Grau and Kamei (1950) later found a lower requirement of 0.87 and 0.85% of a 20% CP diet when SSM-based diets were fed to White Leghorn chicks (14 to 22 d), respectively. The differences in the lysine requirement as determined by Almquist and Mecchi (1942) and Almquist (1947) when compared to Grau et al. (1946) and Grau (1948) may have been the result of a lower lysine availability of the diet, lower growth rates or age of the chicks. Grau (1948) determined the available lysine in SSM must be close to the amount present. Grau (1948) also established that the requirement for lysine increased as a percentage of the diet as dietary CP increased. Milligan et al. (1951) fed a cottonseed meal (CSM) based diet a from 0 to 42 d and determined the lysine requirement to be 1.00% of a 21% CP diet. Bird (1953) found the lysine requirement of 56 d Rhode Island Reds to be 0.72% for a 16% CP, SSM-based diet for both BWG and FCR. The requirement established by Bird (1953) was probably lower due to a lower dietary CP level and older chick.

Edwards, Jr. et al. (1956) hypothesized that the work of Almquist and Mecchi (1942), Grau et al. (1946), Grau (1948), and Grau and Kamei (1950) in which the lysine requirements were below 1.00% of the diet, should be closer to the requirement established by Milligan et al. (1951). Edwards, Jr. et al. (1956) using wheat gluten and SSM-based diets found that chicks grew slower on the wheat gluten diet and subsequently required less lysine. The lysine requirement was concluded to be related to the growth rate and was found to be 0.90% and 1.10% for the wheat gluten and SSM-based diets, respectively. The higher requirement established by Edwards, Jr. et al.

(1956) compared to Grau (1948), Grau and Kamei (1950) and Milligan et al. (1951) could not be explained by differences in breed and diet because White Leghorn Males and SSM-based diets were used in all experiments.

Griminger and Scott (1959) tested the conclusions of Edwards, Jr. et al. (1956) that the lysine requirement was related to growth rate. The lysine requirement in their experiments was similar for genetically slow-growing and fast-growing chicks at 1.03% of the diet. However, the FCR requirement was 1.13% for the slow-growing chicks suggesting a smaller maintenance requirement. They concluded that growth rate per se is not related to the lysine requirement.

Schwartz et al. (1958) studied the effect of age on the lysine requirement with broiler-type males and determined the requirement to be 1.10% for chicks from 0 to 4 weeks of age. The requirement declined with age to 1.00, 0.90, and 0.80% of the diet from 4 to 6, 6 to 8, and 8 to 11 weeks of age, respectively. Schwartz et al. (1958) using productive energy (Cal/lb) as the measurement of energy, found the requirement increased as dietary energy increased. This observation was later studied and confirmed by Attia and Latshaw (1979) with metabolizable energy (kcal/kg).

Dean and Scott, 1965 were among the earliest to publish data on the use of crystalline amino acid diets to study the amino acid requirements of chicks. Klain et al. (1960) reported the first of such diets found to sustain adequate consumption and growth by chicks. Dean and Scott (1965) later modified this diet thereby reducing the composition of the amino acid mixture and determining the requirement for 14 amino acids. The lysine requirement was determined to be 1.12% of the diet for maximum response. Similarly, Boomgaardt and Baker (1970) determined the requirement for young crossbred chicks to be a constant proportion of the dietary CP level at 4.59% when fed crystalline amino acid based diets. Boomgaardt and Baker (1973ab) also found the lysine requirement to be a constant proportion of dietary CP in a SSM-based diet.

Zimmerman and Scott (1965) determined the lysine requirement based on growth, FCR, and plasma amino acids. These researchers found the point at which growth began to plateau corresponded to the point in which plasma lysine levels began to accumulate. The requirement for 7 to 14 d-old chicks was 0.83% of the diet and the plasma lysine concentration began to accumulate after 0.94% of the diet. They concluded that the plasma amino acid technique was suitable for determining amino acid requirements.

Bornstein (1970) determined the requirement for the finishing period of a broiler-type chicken to be 0.92% of the diet, which was similar to the requirement of Schwartz et al. (1958). However, Twinning et al. (1973) and Thomas et al. (1977) found the 7 to 9 week-old broiler chick to require 0.68 and 0.64% lysine. Boomgaardt and Baker (1973b) found with increasing age the requirement remained a constant proportion of the dietary CP as it decreased from 23 to 20%. The results of Chung et al. (1973) confirmed those of Boomgaardt and Baker (1973b), however estimated lysine requirement levels were lower due to the lower dietary CP levels tested. Chung (1973) found the lysine requirement to differ for two stages of growth. The requirements were 5.0 and 4.1% of CP (0.94 and 0.70% of the diet, respectively) for 7 to 21 and 35 to 42 d of age.

Velu et al. (1972) in a study examining body composition and nutrient utilization determined the lysine requirement to be 0.95% of the diet. Hewitt and Lewis (1972) used a similar amino acid mixture derived from Dean and Scott (1965) with added corn and SBM and found the lysine requirement to be 0.85%. Similarly, Woodham and Deans (1975) found the estimated lysine requirement to be 0.87% of the diet.

McNaughton et al. (1979) tested the effect of temperature on the lysine requirement and found the requirement was lower at the higher temperature for 4-week-old male broiler chicks. The lysine requirement was 1.10% at 15.6 C and 1.00% at 29.4 C for body weight. The lysine requirement was 1.00% at 15.6 C and 0.95% at 29.4 C for feed efficiency. Total plasma feed amino acids for the same chicks peaked at 1.05% dietary lysine for 15.6 C and 0.95% at 29.4 C.

Burton and Waldroup (1979) tested the antagonism between lysine and arginine in an experiment in that the treatments were arranged as a factorial. In all, twenty different diets containing various levels of arginine and lysine were fed to male and female broiler chicks. They estimated the lysine requirement to be 1.10% of the diet and found no interaction between dietary lysine and arginine at the levels tested in practical diets.

Morris et al. (1987) studied the effect of dietary CP level on the lysine requirement by using the diet dilution method to create diets with various combinations of dietary lysine and CP. The original analysis of Morris et al. (1987) determined the lysine requirement to be a constant proportion of the dietary CP level, however with a re-evaluation of the data, Abebe and Morris (1990) determined that the lysine requirement declined as a percentage of dietary CP as dietary CP increased. In a similar study, Surisdiarto et al. (1991) observed the effect of dietary CP on the lysine requirement in diets formulated to contain an ideal amino acid profile. The results of Surisdiarto et al. (1991) revealed a linear relationship between the dietary CP and lysine level and from the linear equations a requirement at 23% CP was determined to be similar between experiments and amino acid profiles. No interactions between dietary CP and lysine were tested by Morris et al. (1987), Abebe and Morris (1990) or Surisdiarto et al. (1991)

Han and Baker (1991) determined no differences in the lysine requirement between fast- and slow-growing broiler chickens. Similarly, Han and Baker (1993b) tested the effect of genotype, sex, heat stress and body weight on the lysine requirement of broiler chicks. Males required a higher level, heat increased the requirement for females and reduced the weight gain and feed intake, and the requirement of heavy versus light chicks of the same genotype was the same. They concluded no genotype effect on the lysine requirement.

Barbour et al. (1993) determined that the lysine requirement is effected by diet and statistical evaluation. The quadratic model tended to overestimate the requirement when compared to the two-slope method. The requirement determined by feeding adjusted (with supplemental amino acids) peanut meal was the highest followed by SSM and unadjusted peanut meal (unsupplemented).

Hurwitz et al. (1998) tested the effect of dietary CP level on the lysine requirement with diets formulated to be deficient in one or more amino acids. However, it is not clear whether the 20 and 18% CP diets were actually deficient in certain amino acids considering that the requirement for amino acids (as % of the diet) are linearly related to the dietary CP level (Grau, 1948). For example, the requirement for threonine in a 23% CP diet is 0.80% of the diet. Therefore, in an 18% CP diet the requirement is expected to decrease in proportion to the dietary CP level to approximately 0.63%. In the 18% CP diet of Hurwitz et al. (1998) the level of threonine was adequate at 0.65%. Therefore, the study of Hurwitz et al. (1998) was similar to those of Morris et al. (1987) and Surisdiarto et al. (1991) except that the dietary CP levels were fewer and a more modern broiler genotype was used. Careful examination of the Hurwitz et al. (1998) data reveals that the lysine requirement did indeed increase as a percentage of the diet as CP level increased; but it clearly decreased as a percentage of CP as CP level increased.

Mack et al. (1999) tested two different genotypes and found differences in the digestible lysine requirement as measured by FCR when estimated using a modified broken-line model. However, when estimated using an exponential model requirements of both lines were similar. The experiments were conducted at two different sites, one breed per site. Therefore, the differences observed in lysine requirement may have been site related.

As new genotypes are developed and the criteria of breeding companies changes, the lysine requirement should be determined by using the criteria of greatest importance such as breast meat yield. Labaden et al. (2001) were the first to determine the lysine requirement as measured by breast meat yield and found this requirement to be greater than that for maximum BWG (Table A-1). Kidd and Fancher (2001) found the lysine requirement as measured by BWG to be 1.07 to 1.22% for Ross x Ross 508 broiler chicks at 41d. Mack et al. (1999) found the digestible lysine requirement to be 1.15% of the diet. Many of the earlier studies used White Leghorn chicks that differ significantly in growth rate, feed consumption and body composition when compared to the modern broiler. Appendix A, Table 1 lists the lysine requirement determined by several investigators and includes in some cases requirements determined from separate experiments within an article. Table 2.2 summarizes the average lysine requirement estimated from the literature listed in Appendix A, Table 1. The requirement for lysine for either growth or BWG from the earliest to the latest determination in the literature (Table 2.2) has fallen between 0.59 and 1.33% of the diet with an average of 0.97%. Broiler-type chicks had an average of 1.12% for 14 to 22 d of age. This average for New Hampshire x Columbian chicks was lower at 1.00%. Broiler-type chicks at 41 and 42d had an average lysine requirement of 1.01% (0.78 to 1.22%).

The NRC (1994) recommendation for a 0 to 21 d broiler chick, estimated from the literature from 1942 to 1981, appears to be adequate. These observations confirm the results of Vazquez and Pesti (1997) who reviewed the world's literature on the lysine requirement of starting chicks from 0 to 21 d and determined the requirement to be 1.04 and 1.21% of the diet depending on the mathematical model used. The NRC (1994) recommendation for broiler chicks between 21 and 42 d appears adequate at 1.00%, however the NRC (1994) value for 42 d broiler chicks appears to be too low compared to the average from the literature (Table 2.2).

Lysine Maintenance Requirement. The requirement of lysine for young chicks is considered to include the requirement of lysine for maintenance and growth. The maintenance requirement is considered the amino acid level required for nitrogen equilibrium. Nitrogen equilibrium in mature chickens means that body weight remains

unchanged, however in growing poultry, nitrogen equilibrium occurs with a loss of weight
and body fat (D'Mello, 1994).

The chick's maintenance requirement for lysine were established by Edwards, III et al. (1999) by determining the level of lysine (mg/d) at which there was zero whole-body lysine or protein accretion (mg/d). The maintenance requirement for lysine at zero protein accretion was higher than that for zero lysine accretion (12 mg/d versus 30.3 mg/d, respectively) for New Hampshire x Columbian chicks. Edwards, III et al. (1999) also found the maintenance requirement to be similar between New Hampshire x Columbian and Avian x Avian male chicks at 10 to 20 d. Kim et al. (1997) found the maintenance lysine requirement for 8 to 22d Arbor Acres male chicks to be less than 0.275% or 0.332 mg/d per unit of metabolic body size ($W^{0.75}$).

The Lysine Requirement for Feed Conversion Ratio and Carcass Composition

Further effects of feeding dietary lysine levels above those determined to maximize body weight and BWG have been observed. However, this observation has proven to be just as inconsistent as the determined lysine requirement. Bird (1953) was one of the first to use feed efficiency as a measure of the chicks requirement for lysine and found the requirement to be equal to that of rate of growth. In contrast, Edwards, Jr. et al. (1956) and Griminger et al. (1959) were among the first to observe a higher lysine requirement for FCR when compared to BWG followed by Baker (1978) who found the requirement to be 0.80% for BWG and 0.90% for FCR. However, this observation continued to be inconsistent as McNaughton et al. (1978) found the requirement for FCR to be lower than maximum BWG when chicks were fed both a SSM and corn gluten meal (CGM) based diet and Thomas et al. (1977) observed the BWG requirement to be more than that for minimal FCR. In addition, Moran and Bilgili (1990) found no differences in body weight due to lysine supplementation from 0.85% to 1.05% in 28 to 42 d, however, the FCR decreased as the lysine level increased indicating a higher requirement for FCR. Han and Baker (1994) found the requirement for male and females to be higher for FCR when compared to BWG. Vazquez and Pesti (1997) using data from published experiments found the lysine requirement to be higher for FCR than BWG regardless of the mathematical model used. Hurwitz et al. (1998) found the lysine requirement as measured by FCR to be higher than BWG at several dietary CP levels. More recently, Labaden et al. (2001) found the lysine requirement for minimum FCR was lower than maximum BWG and breast muscle weight for 0 to 14 d, and 21 to 30d broilers.

Tissue Synthesis. The difference in the lysine requirement as determined by BWG and FCR have been assumed to be related to alterations in muscle and fat depots which also differ in energy (Moran and Bilgili, 1990). That is, as dietary lysine increases, protein deposition increases and fat deposition decreases resulting in an improved FCR (Grisoni, 1991). Sibbald and Wolynetz (1986) concluded that dietary lysine intake effects the composition of the carcass independent of energy intake. They observed that as dietary lysine increased, gain in energy as protein increased, and as fat decreased, at a fixed TME_n intake. Hickling et al. (1990) found linear and quadratic effects of increasing dietary lysine (1.20 to 1.42% of the diet) on breast meat yield were close to significant for lysine intake. Hickling et al. (1990) concluded that “an increasing muscle mass with no increase in growth suggests a decrease in fat content and an anticipated improvement in FCR." In the study by Han and Baker (1994), data on breast meat yield were not suitable for determining the lysine requirement because the response between the three highest lysine levels was variable.

Hurwitz et al. (1998) attempted to determine the lysine requirement by using total carcass fat (as a percentage of BW) but an appropriate model could not be fitted to the data. However, it was still determined that total carcass fat decreased as dietary lysine increased from 0.85 to 1.37% and was lower in the 23% CP diet when compared to 20% CP diet.

More recently, Tesseraud et al. (1999) found chicks fed lysine deficient diets (dietary lysine levels below NRC (1994) recommendations) had depressed gastrocnemius, sartorius, and pectoralis major muscle weights. In addition, a significant effect of genotype on pectoralis major and gastrocnemius muscles was observed. The differences in protein deposition by the genotype was observed but the underlying mechanisms responsible for the differences are not well understood.

Nutrient Interactions

Lysine and Arginine. An amino acid antagonism exists between lysine and arginine that is related to their structural similarities. An amino acid antagonism is described as the consumption of a diet containing one amino acid in excess antagonizing a second structurally similar amino acid. The result is a growth depression. Supplementation of the second amino acid to the diet counteracts this depression. In this situation, the reduced growth is caused in part by a depression in food intake (Jones et al., 1967). In addition, high levels of dietary lysine reduces the utilization of arginine and increases its requirement. The reduction in utilization is the result of reduced absorption of arginine at the intestinal levels, increase in excretion of arginine from the kidney (Nesheim, 1968), and an increase in kidney arginase activity at the metabolic level.

Wang et al. (1973) observed an increase in kidney arginase activity when dietary levels of lysine were increased. In addition, genetic differences between chicks selected for low arginine and chicks selected for high arginine requirements were noted. High arginine requirement chicks had a higher kidney arginase and a lower lysine α-ketoglutarate reductase activity when lysine was increased from 0.25 to 1.00% of the diet. Excess arginine did not increase lysine oxidation in the liver as measured by lysine α-ketoglutarate reductase activity. The high arginine requirement genotype had a lower α-ketoglutarate reductase activity. However, in the high arginine requirement chicks α-ketoglutarate reductase activity doubled from low to high lysine, while it only increased by 50% in the low arginine requirement chicks. The authors concluded that in addition to the higher arginase activity, the susceptibility to an arginine/lysine antagonism was greater for the high arginine requirement chicks. Nesheim (1968) showed that the high arginine requirement genotype responds similarly to the normal population of chicks suggesting a natural selection for susceptibility to the antagonism.

Jones et al. (1967) suggested that the effects of excess lysine on arginine metabolism occur before kidney arginase activity responds to excess lysine. Nesheim (1968) concluded, “the high arginine requirement genotype may have a higher requirement for arginine because of the reduced rate of metabolism of lysine.”

More recently, Chamruspollet et al. (2001) found a reduction in muscle creatine formation when chicks were fed excess levels of lysine. This is thought to be due to an increased kidney arginase activity that subsequently decreases the arginine available for muscle creatine synthesis. Chamruspollet et al. (2001) suggested that a reduction in muscle creatine formation was probably due to a reduction in transamidinase activity. Transamidinase uses arginine as a substrate in the biosynthesis of muscle creatine. A decrease in the transamidinase activity was observed by Jones et al. (1967) when chicks were fed excess dietary lysine. It is reasonable to assume that a reduction in transamidinase activity and creatine formation are related to the reduction in growth observed during an arginine/lysine antagonism.

Lysine and Threonine. Kidd et al. (1997) detected an interaction between dietary lysine and threonine for BWG and breast meat yield in 18 to 54d Ross x Ross male broiler chicks. That is, as dietary lysine was increased from 100 to 105% of NRC (1994) recommendations, BWG and breast meat yield changed. The BWG and breast meat yield of chicks fed increasing levels of dietary threonine in the 100% of NRC (1994) lysine fed chicks decreased as dietary threonine increased. However, when chicks were fed increasing dietary threonine levels at the 105% of NRC (1994) lysine diet, BWG and breast meat yield increased until the highest dietary threonine level (108%) in which both parameters appeared to decrease. The observation that threonine addition in the lower lysine diet decreased these parameters suggests an interaction detrimental in nature. No linear affects due to increasing threonine and lysine were observed. The biochemical nature of the interaction is not known, and the gross observations need confirmation.

Clearly, there are still many questions concerning appropriate lysine levels to feed to modern commercial broiler chickens. In earlier studies lysine levels were most often estimated from ingredient composition tables and actual lysine content and bioavailabilities of the diets were not known. Differences between estimated and actual lysine levels may account for much of the variation in requirements observed in Table 2.2. Controversy still exists over the relationship between dietary crude protein and lysine levels. And different chicken genotypes are known to respond differently to graded levels of lysine. Broilers continue to respond to selection pressure for growth rate, so that amino acid requirements for maintenance are a smaller proportion of the total with each succeeding generation.

FIGURE 2.1. The degradative pathways of lysine.

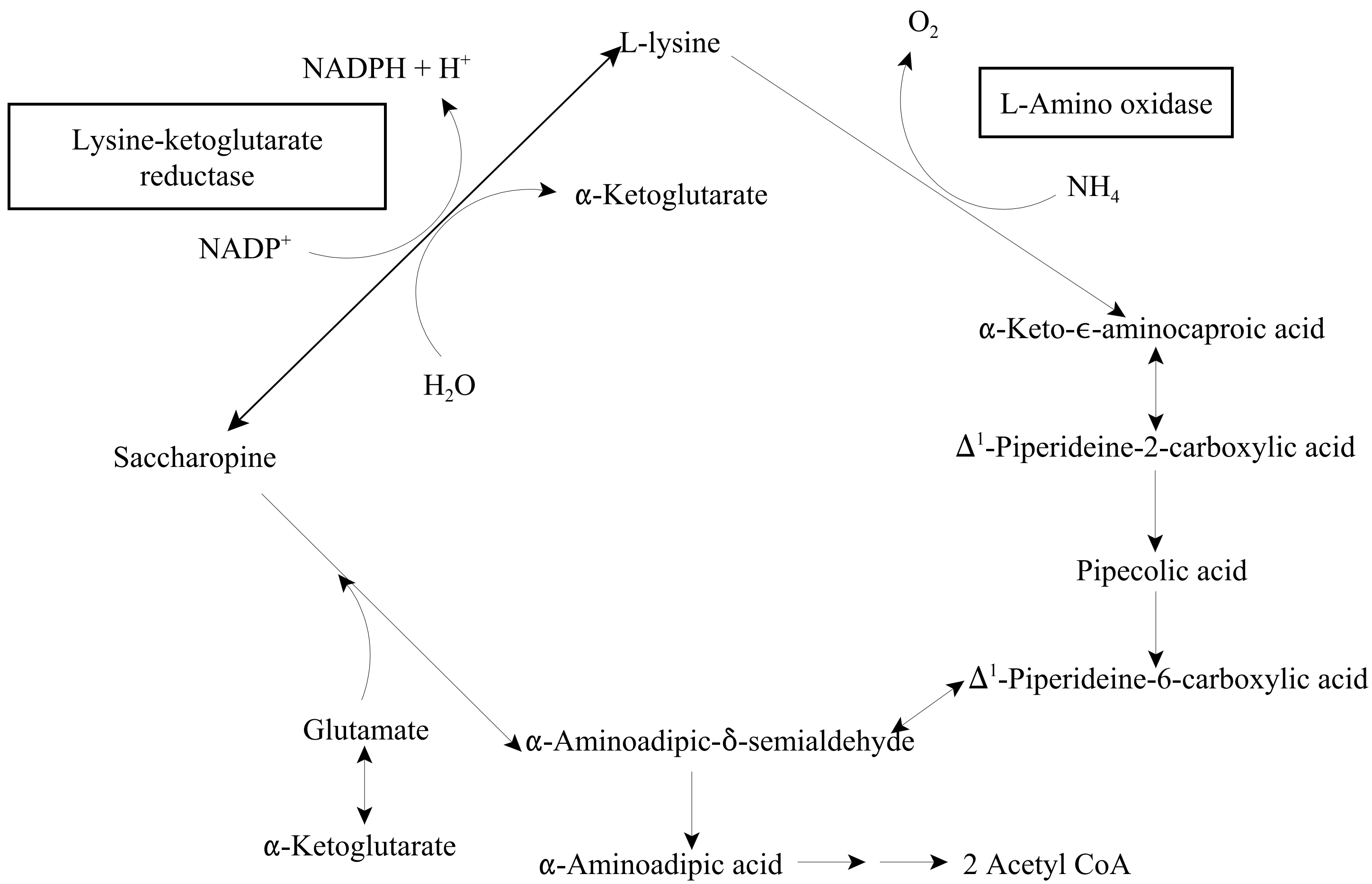

TABLE 2.1. Comparison of mathematical models used to determine amino acid requirements.

Model	Equation	Reference
Ascending line and plateau	Y = Max + RC x (Req - X) x I; where X = independent variable; REQ = requirement; Y = dependent variable; MAX = theoretical maximum; I = 0 (if X > REQ), and RC = rate constant	Sterling et al. (2002)
Ascending quadratic and plateau	Y = Max + RC x $(Req - X)^2$ x I, where X = independent variable; REQ = requirement; Y = dependent variable; MAX = theoretical maximum; I = 0 (if X > REQ), and RC = rate constant	Vazquez and Pesti (1987)
Ascending line and sloped plateau	Y = L + U x (Z1) + V x (Z2), where Z1=(X < R)*(R - X) and Z2=(X > R)*(X - R), where L is the ordinate and R the abscissa of the breakpoint in the curve, U is the slope of the line for X < R, and V is the slope of the line at X > R.	Robbins (1986)
Quadratic	$Y = a + bX + cX^2$, were a = intercept, a = coefficient for the linear slope, and b = coefficient for the quadratic slope.	Barbour et al., (1983)

TABLE 2.2. Average lysine requirement by genotype and age calculated from the literature between the years 1942 and 2003.

Genotype	Days of age	Lysine Requirement from literature	Range of Lysine Requirement	Range of CP fed	Days of age	Lysine Requirement NRC (1994)[1]
			(%)			(%)
Broiler	14 to 22	1.12	0.75 to 1.33	17 to 24	0 to 21	1.10
	28	1.05	0.95 to 1.13	18 to 21	21 to 42	1.00
	42	1.01	0.78 to 1.22	20 to 22	42 to 56	0.85
	56 to 77	0.74	0.67 to 0.90	18 to 21	----	----
New Hampshire x Columbian	14 to 22	0.96	0.70 to 1.12	18 to 28.7	----	----
	28	0.92	0.67 to 1.06	18.5 to 23	----	----
Layer	22	0.89	0.85 to 0.94	19 to 20	0 to 42	0.85
	28	1.00	0.90 to 1.10	20.5	0 to 42	0.85
	42	0.85	0.70 to 1.00	17 to 21	42 to 84	0.60
Overall		0.97	0.59 to 1.33	16 to 28.7	----	----

[1]NRC (1994) TABLE 2-6 for broilers and TABLE 2-1 for leghorn-type chickens.

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CHAPTER 3

RESPONSES OF BROILER CHICKENS TO COTTONSEED- AND SOYBEAN-MEAL BASED DIETS AT SEVERAL PROTEIN LEVELS[1]

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[1]Sterling, K. G., E. F. Costa, M. H. Henry, G. M. Pesti, and R. I. Bakalli, 2002. Poult. Sci. 81:217-226.
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ABSTRACT

Three experiments were conducted to evaluate the performance of broiler chicks fed diets with Cottonseed Meal (CSM) as the major protein source. Experiment 1 was a 3 x 2 factorial with three protein levels (17, 20, or 23%) by two protein sources, CSM or soybean meal (SBM). Diets were fed to male broilers in floor pens from 21 to 49 d of age. L-lysine was added to keep lysine level at 5.22% of protein. Protein source and level had significant ($P < 0.001$) effects on body weight gain (BWG) and feed conversion ratio (FCR), respectively (no source by level interactions). The average BWG were 1.80, 2.00, and 2.00 kg for birds fed CSM-based diets, compared to 1.93, 2.09, and 2.21 for SBM-based diets (17, 20, and 23% protein, respectively). The average FCR were 2.56, 2.31, and 2.25 for CSM-fed broilers and 2.39, 2.16, and 2.08 for SBM-fed broilers. Significant effects of protein source or level were found for percentage of chilled carcass, fillets, tenders, and fat pads. In Experiment 2, male broiler chicks (n = 336) were used to determine the lysine requirement of chicks fed a corn and CSM-based diet with 20% CSM and 6% SBM. The basal diet contained 3,200 kcal/kg of ME, 20% CP and 0.81% lysine. Graded levels of lysine (0.81 to 1.30% lysine) were fed to chicks from 10 to 20 d and BW and residual feed were measured at 20 d. The requirement, as determined by breakpoint analysis, was 1.023 ± 0.01% lysine ($R^2 = 0.84$) for BWG and 1.028 ± 0.02% lysine ($R^2 = 0.56$) for FCR. In Experiment 3, a 2 x 2 x 4 factorial arrangement of treatments involved feeding either CSM or SBM to male and female broiler chicks (n = 768) from 21 to 42 d at four dietary protein levels (17, 20, 23, and 26% CP). Lysine was kept at 5.5% of the dietary protein and consisted of the calculated minimum level,

established in Experiment 2, plus 7%. Protein level, but not source, had a significant effect on BWG and FCR ($P < 0.01$ and $P < 0.001$, respectively) for males. The average BWG were 1.53, 1.74, 1.78, and 1.81 kg for birds fed CSM, compared to 1.46, 1.72, 1.84, and 1.82 kg for those fed SBM (17, 20, 23, and 26% CP, respectively); average FCR were 2.36, 2.14, 2.05, and 1.97 for CSM compared to 2.35, 2.04, 1.87, and 1.80 for SBM. Protein source and level significantly ($P < 0.05$) affected feed intake. Significant effects of protein source and/or level were found for percentage carcass, fillet, tenders, leg quarters, and fat pads. Females had similar qualitative responses. This study showed that at slightly higher protein levels CSM could replace SBM in broiler grower diets to achieve similar performance.

INTRODUCTION

Soybean meal (SBM) is the most widely used protein source in the formulation nutritionists seek sources of protein that are more economical sources of protein to use in the formulation of poultry rations. Cottonseed meal (CSM) has long been considered a potential source of protein for poultry. CSM is high in protein, however, its utilization in poultry feed as a protein source has been limited due to the toxic substance, gossypol, low lysine level, and high fiber content. Gossypol, a naturally occurring metabolite of cottonseed is associated with depressed weight gains, increased feed intake, decreased feed efficiency and increased mortality in chickens (Lillie and Bird, 1950; Couch et al., 1955; Lipstein and Bornstein, 1964a; Smith, 1970). However, several feeding trials have also shown that chick performance is not significantly affected when the dietary level of free gossypol was lower than 200 mg/kg of feed (Heywang and Kemmerer, 1966; Smith and Clawson, 1970; Hermes et al., 1983). In addition, studies have shown that several factors influence the tolerance of chicks have to gossypol. These factors include gossypol source (free vs. total gossypol), age of birds, strain of chickens, dietary iron, and dietary lysine (Heywang and Bird, 1955; Lipstein and Bornstein, 1964; Clawson and Smith, 1966; Martin, 1990; Henry et al., 2001).

In recent years, cottonseed processors have changed the method of oil extraction, which has resulted in low gossypol CSM with 44% CP. The CSM produced from this process was evaluated in young chicks from day 7 to14 d. Chicks fed diets with 20% extruded CSM and adequate lysine supplementation performed as well as those fed corn- and SBM-based diets (Henry et al., 2001). Watkins et al. (1993) reported that rations formulated with 30% low gossypol CSM (41% CP) and fed to 21-d-old broilers had no adverse effect on BW. However, as the level of CSM was elevated from 0 to 30%, the feed consumption and feed/gain ratio increased.

Other than the study by Watkins et al. (1993), who fed broilers for 42 d, most of the evaluations of CSM in broilers were performed with young chicks, less than 21 d of age, when the nutritional requirements and sensitivity to toxins are at the maximum. Based on the results obtained in previous trials, we hypothesized that a 44% CP, low-gossypol CSM can partially replace SBM in the diet of broilers chicks beyond 21 d of age without detrimental effects on performance.

The objectives of this study were to determine the performance of chicks fed grower diets at various levels of protein with a full substitution of CSM with supplemental lysine or a partial substitution of CSM with an established lysine requirement.

MATERIALS AND METHODS

Cottonseed meal was obtained from a commercial oil processing plant, which used the expander/solvent (hexane) extraction method. The soapstock was added back to the cottonseed meal at 5% (wt:wt), and free gossypol level was analyzed to be 224 mg/kg of the meal. Free gossypol was determined by the method of the Association of Official Analytical Chemists (1989). Proximate analysis was performed on CSM according to the Association of Official Analytical Chemists (1990), except for CP, which was determined by the Dumus combustion technique (Etheridge et al., 1998). The CSM was analyzed for cyclopropene fatty acids by a gas liquid chromatography method (Raju and Reiser, 1966). The NRC (1994) value of 2400 kcal ME/kg for CSM and nutrient values in Table 3.1 were used for feed formulation.

Experiment 1

Peterson x Arbor Acres broiler chicks were obtained from a commercial hatchery,[2] vent sexed. Nine hundred, twelve (912) 1-d-old and randomly assigned to 1 of 24 pens (1.22 x 3.66 m) in an environmentally controlled house. A commercial broiler starter diet was fed from 0 to 21 d of age and was formulated according to NRC (1994) recommendations to contain 23% crude protein and 3,200 kcal/kg ME.

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[2]Harrison Poultry, Bethlehem, GA.

Experiment 2

Three hundred thirty-six (336) 1-d-old Ross x Ross male broiler chicks were obtained from a commercial hatchery[3] and were placed in battery brooders.[4]

A corn-and-SBM-based broiler starter diet was fed from 0 to 10 d of age and was formulated according to NRC (1994) recommendations with 23% crude protein and 3,200 kcal/kg ME. At 10 d of age, chicks were weighed, wing-banded, and allotted to treatments in a manner that ensured a similar average weight and similar weight range per replicate (eight chicks/rep with three reps/treatment). The batteries were divided into blocks with one treatment replicate occurring within each block (randomized complete block design). Treatments were randomly distributed across each block. Chicks were fed a common corn and CSM diet containing 20% CSM as the major protein source, 18.88% CP, and a basal lysine level of 0.86% (Table 3.3). Amino acids levels in the formulations met or exceeded the NRC (1994) recommendations for a 20% CP broiler diet. The protein and amino acid values for CSM in Table 3.1 were used in formulation of the diets. The experimental diets varied in lysine levels that ranged from 0.86% to 1.35% with increments of 0.07%, with and without 0.10% supplemental L-isoleucine (added at the expense of the diet). Isoleucine supplementation did not affect gain or FCR ($P \leq 0.56$), and significant lysine by isoleucine interactions ($P \geq 0.35$) were not found;

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[3]Seaboard Farms, Athens, GA.

[4]Petersime Incubator Company, Gettysburg, OH.

therefore, data were pooled for evaluating lysine requirements (n = 6 replicates per lysine level). Chicks were maintained on continuous lighting, and feed and water were provided ad libitum. Body weights and residual feed were measured at 20 d of age, and FCR calculated.

Experiment 3

One thousand eight hundred twenty-four (1,824) 1-d-old Peterson x Arbor Acres broiler chicks were obtained from a commercial hatchery,[4] vent sexed, and randomly assigned to 1 of 48 pens (1.22 x 3.66 m) by sex. A broiler starter diet of corn and SBM was fed from 0 to 21 d of age and was formulated according to NRC (1994) recommendations with 23% CP and 3,200 kcal/kg ME.

At 21 d of age, 32 chicks per pen were weighed and allotted in a manner to ensure similar weights by treatment, replication, and sex. Chicks were fed diets that contained protein levels of 17, 20, 23, and 26% with SBM or CSM as the major protein source (Table 3.4). The minimum amino acid levels (as % of dietary protein) were set for lysine, methionine, TSAA, threonine, glycine plus serine, leucine, valine, phenylalanine, phenylalanine plus tyrosine and tryptophan. The lysine to protein ratio, based on the results from Experiment 2, was set at 5.50% (7% more than the determined requirement). The experiment was designed as a factorial with protein level and protein source as the main effects with three replications per treatment for each sex. All diets were pelleted. Body weights and residual feed were measured at 42 d, and FCR was calculated. Lighting was continuous, and feed and water were offered ad libitum except during 12 h prior to processing when feed was withdrawn.

Processing

On Day 49 for Experiment 1 and Day 42 for Experiment 3, after the final weighing of all birds by pen, three randomly chosen chickens from each pen were wing-banded and moved to separate floor pens for an overnight withdrawal of feed (approximately 12 h); water was provided for ad libitum. The following morning, chickens were randomly crated and transported to the processing room where each was weighed, killed by exsanguination, scalded, defeathered, and eviscerated. Abdominal fat pads and livers were collected. Carcasses were weighed and chilled on ice in a walk-in freezer at 5 C overnight. The following day, carcasses were weighed, pectoralis major (breast fillets) and minor (tenders) muscles, wings, and leg quarters (drum and saddle) were excised (including skin), and all weights were recorded. Percentage carcass yield, abdominal fat pad, and liver were calculated based on live BW (before processing). Percentage breast, tenders, wings, and leg quarters yields were calculated based on chilled carcass weight.

Statistical Analysis

The experimental unit was the pen mean. All data for Experiments 1 and 3 were analyzed by two-way analysis of variance using the general linear procedure of SAS (SAS Institute, 1998). In Experiment 3, data for each sex were analyzed separately. A probability level of $P \leq 0.05$ was considered significant. In Experiment 2, a nonlinear procedure of SAS, was applied to determine the lysine requirement based on BW gain (BWG) and FCR. The interactive procedure makes repeated guesses for coefficients and minimizes residual error until the best-fit lines are achieved: One line with a slope of zero and the other with a marked slope. The two lines are fitted to the values using the following equation:

$$Y = MAX + RC \times (REQ - X) \times I$$

where X = independent variable; REQ = requirement; Y = dependent variable; MAX = theoretical maximum; I = 0 (if X > REQ), and RC = rate constant. R^2 values were determined as follows: $R^2 = 1$ - (residual sum of squares/corrected total sum of squares).

RESULTS AND DISCUSSION

Measured protein levels were slightly lower than expected in Experiments 2 and 3 (Tables 3.2 to 3.4). The trends in protein levels were consistent with expectations, and all statistical analyses for Experiments 1 and 3 were based on calculated protein levels. In Experiment 2, analyzed values were used.

In Experiment 1, responses to dietary protein level in CSM-based diets were qualitatively similar to SBM based diets (Tables 3.5 to 3.7). In general, BWG increased and FCR decreased as protein levels increased. Feed intake was not changed by protein source or CP level. Protein source and level had significant effects on chilled carcasses, fillet, tender, and fat pad weights, but not drums or saddles (Table 3.6). Relative part yields (% of live BW) were similar, except percentage saddles changed with protein source and level (Table 3.7). For neither absolute nor relative part weights were there any significant interactions; protein from both sources affected growth parameters in the same way. The significant effect of protein source for all these parameters demonstrated that when CSM was fed at the same protein level as SBM, the gross responses were different.

For instance, BWG for chicks fed 17% protein from SBM diets were similar to those fed 20 and 23% protein from CSM diets.

Experiment 2 established that there was adequate lysine in the diets fed in Experiment 1 (Figures 3.1 and 3.2). Lysine was formulated in Experiment 1 to be in the diets at 5.22% of the protein level. In Experiment 2, the lysine requirement was determined to be 1.02 ± 0.01% for BWG and 1.03 ± 0 .02% for FCR in a 20% protein diet (5.15% of protein). Nonetheless, minimum lysine levels were increased to 5.50% of the protein level in Experiment 3 to be certain that dietary lysine concentration was not influencing performance. Henry et al. (2001) found supplemental lysine or extrusion improved weight gain and feed efficiency by reducing gossypol toxicity. The requirement for lysine was found to be comparable to NRC (1994) recommendations. These results indicate that diets formulated with a low-gossypol CSM do not require significantly higher lysine levels than the NRC (1994) requirement.

Experiment 2 included an additional block of the experimental lysine treatments that differed only by the supplementation of 0.10% isoleucine to the 20% CP diet. The addition of supplemental isoleucine was considered because it is the fourth limiting amino acid in CSM-based diet, based on calculations from recommendations of the NRC(1994). The analyzed level of isoleucine in the isoleucine-supplemented diet (Table 3.3) was 0.66% and considered marginal by NRC (1994) recommendations. Responses between blocks were not significantly different, therefore the data were pooled. The isoleucine requirement is therefore less than or equal to the 0.66% present in the CSM basal diet.

In Experiment 3, increasing protein level increased growth rate, improved feed conversion, and decreased levels of abdominal fat (Tables 3.8 and 3.9). With animal by-product (ABP) meals in each diet being higher than in Experiment 1 (11 *vs* 5%), BW results were similar for males fed corn-CSM-ABP *vs* corn-SBM-ABP, but not for females. Females fed SBM diets were slightly heavier at the lower protein levels, however, at higher levels their weights were similar to the CSM-fed females. Feed conversion results were similar to Experiment 1, and FCR improved with increasing protein level. Feed intake was higher, however, for males fed the corn-CSM-ABP diets. In addition, a biphasic (increase followed by decrease) feed intake response was observed as dietary protein increased. This result was similar to those found by Smith and Pesti (1998) where feed intake of Peterson x Arbor Acres males decreased as the protein level increased from 16 to 24%. There was a significant protein source by protein level interaction for feed intake of females. Females fed CSM-based diets consumed more feed than those fed SBM at higher protein levels. As in this experiment, increased feed intake and depressed feed efficiency has been observed with broilers fed CBM-based diets (Watkins et al., 1993).

As in Experiment 1, in Experiment 3, protein source and protein level affected various carcass parts on an absolute and percentage of carcass weight basis (Tables 3.10 and 3.11). Male and female broilers fed CSM diets generally had smaller meat parts and larger abdominal fat pads than broilers fed SBM diets at the same protein level. Again, broilers fed higher protein levels with CSM had responses similar to broilers fed diets with lower protein level from SBM.

The results concerning protein level are qualitatively similar to what Frapps (1943) observed in the 1940's and Smith and Pesti (1998) observed in the 1990's. The observation that similar performance can be achieved by feeding CSM diets or SBM-based diets with higher protein levels brings up an interesting question: How would relative prices be calculated for CSM in terms of SBM, since performance is not equivalent? Slower growth means that broilers might be in the broiler house 1 or 2 d longer and, therefore, have perhaps 2 extra d of body maintenance.

Clearly, very good broiler performance can be achieved by feeding combinations of corn, CSM, and ABP meals, especially for males. Depending on other dietary components, CSM-fed broilers may not always perform as well as those fed diets based mainly on SBM.

A potential reason that the CSM fed broilers did not perform as well as SBM-fed broilers is that CSM may not be as digestible as SBM. Therefore, when feeding CSM, higher protein levels are required to supply the same levels of amino acids for absorption. A study by Fernandez et al. (1996) indicated that CSM-based diets (20% CSM) formulated on a digestible amino acid vs. a total amino acid basis were superior. However, at 30 and 40% CSM, performance was reduced, regardless of the dietary formulation used. Results of Experiment 2 indicated that supplementation of lysine or isoleucine beyond the NRC (1994) requirement was not necessary. Therefore, the digestibility of amino acids other than those supplemented may have been involved in reducing performance. In addition to digestibility problems, there may be toxic factors present in the CSM. Free gossypol levels were determined to be below levels expected to be toxic (Hermes et al., 1983; Smith and Clawson, 1970; Heyward and Kemmerer, 1966) and feed refusal was not a problem. In addition, the CSM sample fed here was free of cycloproprene fatty acids. Therefore, gossypol and cyclic fatty acids did not appear to be a problem. There were casual observations that pellet quality was reduced in the higher CSM (higher added fat) diets, which may account for some of the reduced performance and should be quantified in future experiments.

In summary, CSM-fed broilers performed very well but not quite to the standard of SBM-fed broilers. Birds fed the CSM diets were similar in BW to those fed the SBM diets at the same protein level and age. However, the CSM-fed broilers had smaller meat yields and more abdominal fat. Therefore, models to compare the feeding value of CSM *vs*. SBM need to consider that CSM-fed broilers would need extra time to reach comparable meat yields.

TABLE 3.1. Analyzed composition of cottonseed meal[1]

Item	Cottonseed Meal
	(%)
Dry matter	90.50
Crude protein	44.00
Arginine	5.10
Histidine	1.27
Lysine	1.95
Tryptophan	0.43
Phenylalanine	2.40
Tyrosine	1.28
Methionine	0.75
Cystine	0.79
Threonine	1.46
Leucine	2.75
Isoleucine	1.48
Valine	2.02
Glycine	1.82
Serine	1.80
Proline	1.65
Glutamate	8.87
Aspartate	4.12
Free gossypol	0.0244

[1]Amino acids were analyzed by the University of Missouri-Columbia, Experiment Station Chemical Laboratories, Columbia, MO.

TABLE 3.2. Composition of the diets used in Experiment 1

	Protein in Diets					
	Cottonseed Meal (CSM)			Soybean Meal (SBM)		
	17%	20%	23%	17%	20%	23%
Ingredients[1]	---------------------------		(%)	----------------------------		
CSM - 44% CP[2]	16.80	25.64	34.48	----	----	----
SBM - 48% CP	----	----	----	15.12	23.18	31.16
Corn, Grain	69.93	58.35	46.78	74.15	64.81	55.48
Poultry BP Meal	5.00	5.00	5.00	5.00	5.00	5.00
Poultry Fat	4.80	7.49	10.18	2.47	3.92	5.38
Defluorinated phosphate	1.13	1.31	1.24	1.41	1.36	1.30
Limestone	0.70	0.73	0.76	0.63	0.63	0.62
Common Salt	0.40	0.40	0.40	0.40	0.40	0.40
L-Lysine HCl	0.38	0.42	0.47	0.15	0.07	----
Vitamin Premix[3]	0.25	0.25	0.25	0.25	0.25	0.25
DL-Methionine	0.09	0.13	0.16	0.10	0.14	0.19
Mineral Premix[4]	0.08	0.08	0.08	0.08	0.08	0.08
Aviax[5]	0.05	0.05	0.05	0.05	0.05	0.05
Bacitracin BMD-50[6]	0.05	0.05	0.05	0.05	0.05	0.05
Copper Sulfate	0.05	0.05	0.05	0.05	0.05	0.05
L-Threonine	0.04	0.05	0.05	----	----	----
Composition by Calculation[1]						
ME (Kcal/g)	3.2	3.2	3.2	3.2	3.2	3.2
Crude protein (%)	17.0	20.0	23.0	17.0	20.0	23.0
Ether extract (%)	8.38	10.77	13.16	6.09	7.27	8.45
Calcium (%)	0.90	0.90	0.90	0.90	0.90	0.90
Available phosphate (%)	0.45	0.45	0.45	0.45	0.45	0.45
Iron mg/g	0.42	0.37	0.33	0.43	0.40	0.36
Isoleucine (%)	0.53	0.62	0.70	0.63	0.78	0.92
Lysine (%)	0.89	1.04	1.20	0.89	1.04	1.20
Methionine (%)	0.37	0.43	0.50	0.38	0.46	0.54
Met + Cys (%)	0.72	0.86	1.00	0.67	0.78	0.90
Threonine (%)	0.59	0.70	0.80	0.60	0.72	0.84
Tryptophan (%)	0.16	0.20	0.24	0.18	0.23	0.29

[1]Based on NRC (1994) feed composition tables, except where noted.

[2]See TABLE 3.1. for nutrient composition.

TABLE 3.2. Continued.

[3]Vitamin premix provides the following per kilogram of diet: vitamin A, 5,500 IU from all trans-retinyl acetate; cholecalciferol, 1,100 IU; vitamin E, 11 IU from all-rac-α-tocopherol acetate; riboflavin, 4.4 mg; Ca pantothenate, 12 mg; nicotinic acid, 44 mg; choline Cl, 220 mg; vitamin B_{12}, 6.6 μg; vitamin B6, 2.2 mg; menadione, 1.1 mg (as MSBC); folic acid, 0.55 mg; di-biotin, 0.11 mg; thiamine, 1.1 mg (as thiamine mononitrate); ethoxyquin, 125 mg.

[4]Trace mineral premix provide the following in milligrams per kilogram of diet: Mn, 60; Zn, 50; Fe, 30; Cu, 5; I, 1.5.

[5]Semduramicin, Phibro Animal Health, Exton, PA.

[6]Alpharma, Fort Lee, NJ.

TABLE 3.3. Composition of diets used in Experiment 2

Protein source	Diet Cottonseed meal basal (%)
Ingredients[1]	
Ground yellow corn	60.34
CSM-44% CP[2]	20.00
SBM-48% CP	6.00
Poultry by-product meal	5.00
Poultry fat (stabilized)	5.79
Defluorinated phosphate	1.31
Common salt	0.30
Vitamin premix[3]	0.25
L-Lysine HCl	
Limestone	0.72
L-Threonine	0.06
Mineral premix[4]	0.08
Bacitracin BMD-50[5]	0.05
Copper sulfate	0.05
DL-methionine	0.06
Composition by calculation[1]	
ME, kcal/kg	3,200
Isoleucine	0.68
Composition by analysis[6]	
Crude Protein, %	18.88
Ether Extract, %	10.3
L-Lysine, %	0.86
L-Threonine, %	0.73
L-Isoleucine	0.70

[1]Based on NRC (1994) feed composition tables, except where noted.

[2]See TABLE 3.1. for nutrient composition.

[3]Vitamin premix provides the following per kilogram of diet: vitamin A, 5,500 IU from all trans-retinyl acetate; cholecalciferol, 1,100 IU; vitamin E, 11 IU from all-rac-α-tocopherol acetate; rioboflavin, 4.4 mg; Ca pantothenate, 12 mg; nicotinic acid, 44 mg; choline Cl, 220mg; vitamin B_{12}, 6.6 µg; vitamin B_6, 2.2 mg; menadione, 1.1 mg (as MSBC); folic acid, 0.55 mg; d-biotin, 0.11 mg; thiamine, 1.1 mg (as thiamine mononitrate); ethoxyquin, 125 mg.

TABLE 3.3. Continued.

[4]Trace mineral premix provide the following in milligrams per kilogram of diet: Mn, 60; Zn, 50; Fe, 30; Cu, 5; I, 1.5.

[5]Alpharma, Fort Lee, NJ.

[6]Amino acids were analyzed by Degussa-Hüls Corporation, Allendale, NJ.

TABLE 3.4. Composition of diets used in Experiment 3

	Diets							
	Cottonseed Meal				Soybean Meal			
	17%	20%	23%	26%	17%	20%	23%	26%
Ingredients[1]								
Ground yellow corn	69.69	64.92	53.72	42.52	71.30	68.49	59.26	50.04
CSM-44% CP[2]	7.98	17.45	26.35	35.24	----	----	----	----
SBM-48% CP	----	----	----	----	7.30	15.77	23.60	31.44
Wheat middlings	5.45	----	----	----	5.45	----	----	----
Poultry by-product meal	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Menhaden meal	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Poultry fat (stabilized)	3.78	4.46	6.72	8.98	3.10	2.91	4.33	5.76
Meat and bone meal	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Defluorinated phosphate	0.82	0.77	0.70	0.63	0.84	0.81	0.75	0.70
Common salt	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Vitamin premix[3]	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
L-Lysine HCl	0.23	0.29	0.35	0.40	----	----	----	----
Limestone	0.19	0.21	0.24	0.27	0.15	0.13	0.13	0.12
L-Threonine	0.08	0.09	0.10	0.11	0.05	0.04	0.03	0.03
Mineral premix[4]	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
Aviax[5]	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Bacitracin BMD-60[6]	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05

TABLE 3.4. Continued

	Diets							
	Cottonseed Meal				Soybean Meal			
	17%	20%	23%	26%	17%	20%	23%	26%
Copper sulfate	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
DL-Methionine	0.01	0.03	0.05	0.07	0.04	0.07	0.10	0.13
Calculated composition[6]								
ME, kcal/kg	3,200	3,200	3,200	3,200	3,200	3,200	3,200	3,200
L-Lysine	0.94	1.10	1.26	1.43	0.85	1.06	1.26	1.47
L-Threonine	0.63	0.74	0.85	0.96	0.63	0.74	0.85	0.96
Analyzed composition[7]								
Crude protein	16.6	19.7	21.3	24.9	16.2	18.5	22.1	24.9
L-Lysine	0.69	1.05	1.22	1.42	0.75	0.89	1.15	1.39
L-Threonine	0.62	0.80	0.92	1.01	0.60	0.71	0.81	0.90

[1]Based on NRC (1994) feed composition feed tables, except where noted.

[2]See TABLE 3.1. for nutrient composition.

[3]Vitamin premix provides the following per kilogram of diet: vitamin A, 5,500 IU from all trans-retinyl acetate; cholecalciferol, 1,100 IU; vitamin E, 11 IU from all-rac-α-tocopherol acetate; riboflavin, 4.4 mg; Ca pantothenate, 12 mg; nicotinic acid, 4 mg; choline Cl, 220 mg; vitamin B_{12}, 6.6 µg, vitamin B_6, 2.2 mg; menadione, 1.1 mg (as MSBC); folic acid, 0.55 mg; d-biotin, 0.11 mg; thiamine, 1.1 mg (as thiamine mononitrate); ethoxyquin, 125 mg.

TABLE 3.4. Continued.

[4]Trace mineral premix provide the following in milligrams per kilogram of diet: Mn, 60; Zn, 50; Fe, 30; Cu, 5; I, 1.5.

[5]Semduramicin, Phibro Animal Health, Exton, PA.

[6]Alpharma, Fort Lee, NJ 07024.

[7]Amino acids were analyzed by DeGussa Hüls Corporation, Allendale, NJ.

TABLE 3.5. The influence of protein source and level on body weight, feed intake and feed conversion ratio of male broiler chicks (Experiment 1)[1]

		BWG	Feed Intake	FCR
Protein Source	CP	Days 21-49	Days 21- 49	Days 21- 49
	(%)	----------------- (kg)	---------------	(g/g)
Cottonseed Meal	17	1.80 ± 0.02	4.61 ± 0.07	2.56 ± 0.06
	20	2.00 ± 0.07	4.61 ± 0.13	2.31 ± 0.03
	23	2.00 ± 0.04	4.50 ± 0.06	2.25 ± 0.04
Soybean Meal	17	1.93 ± 0.02	4.62 ± 0.06	2.39 ± 0.02
	20	2.09 ± 0.01	4.54 ± 0.03	2.16 ± 0.02
	23	2.21 ± 0.03	4.61 ± 0.09	2.08 ± 0.03
ANOVA	df	----------------------	Probabilities	--------------------
Protein source (A)	1	0.0001	0.7752	0.0001
CP level (B)	2	0.0001	0.7570	0.0001
A x B	2	0.3004	0.5785	0.8851

[1]Means and standard errors of four pens per treatment.

TABLE 3.6. The influence of protein source and level on carcass parameters of male broiler chicks at 49 d of age (Experiment 1)[1]

Protein Source	CP (%)	Weight (g) Live BW	Chilled Carcass	Fillets	Tenders	Drums	Saddle	Fat Pad
Cottonseed Meal	17	2,806 ± 18	2,086 ± 20	393.7 ± 4.5	83.8 ± 1.23	307.7 ± 7.69	702 ± 9.18	88.3 ± 2.46
	20	2,960 ± 71	2,152 ± 39	446.6 ± 10.9	90.9 ± 1.61	306.7 ± 4.55	697 ± 13.91	82.1 ± 3.98
	23	3,027 ± 44	2,270 ± 46	470.2 ± 10.6	95.1 ± 2.30	316.3 ± 9.18	742 ± 21.68	79.5 ± 6.77
Soybean Meal	17	2,901 ± 28	2,258 ± 19	492.2 ± 8.5	97.8 ± 2.02	313.4 ± 13.90	717 ± 7.87	73.9 ± 3.19
	20	3,105 ± 18	2,341 ± 42	498.6 ± 9.5	106.9 ± 4.44	329.0 ± 3.73	726 ± 13.91	60.6 ± 7.18
	23	3,252 ± 36	2,356 ± 45	531.7 ± 16.1	117.0 ± 4.10	324.8 ± 9.64	715 ± 15.62	55.5 ± 3.10
ANOVA	df				Probabilities			
Protein source (A)	1	0.0002	0.0001	0.0001	0.0001	0.1085	0.6433	0.0001
CP Level (B)	2	0.0001	0.0051	0.0001	0.0002	0.5135	0.3736	0.0310
A x B	2	0.2946	0.3523	0.0959	0.3764	0.6081	0.1633	0.5912

[1]Means and standard errors of four pens (three birds randomly chosen per pen) per treatment.

TABLE 3.7. The influence of protein source and level on carcass parameters as a percent chilled carcass weight of male broiler chicks at 49 d of age (Experiment 1)[1]

Protein Source	CP	Carcass Yield	Fillets	Tenders	Drums	Saddle	Fat Pad
	(%)	(% of live BW)	------------------------(% Chilled carcass weight)			-----------------	(% of live BW)
Cottonseed Meal	17	72.47 ± 1.49	13.68 ± 0.31	2.91 ± 0.04	10.68 ± 0.23	24.39 ± 0.45	3.07 ± 0.16
	20	71.37 ± 1.53	14.81 ± 0.28	3.01 ± 0.01	10.17 ± 0.17	23.13 ± 0.21	2.73 ± 0.14
	23	72.88 ± 0.52	15.10 ± 0.22	3.05 ± 0.08	10.16 ± 0.28	23.82 ± 0.33	2.56 ± 0.21
Soybean Meal	17	74.15 ± 1.14	16.15 ± 0.27	3.21 ± 0.12	10.27 ± 0.27	23.54 ± 0.29	2.43 ± 0.13
	20	75.01 ± 0.68	15.98 ± 0.17	3.43 ± 0.18	10.55 ± 0.23	23.16 ± 0.36	1.93 ± 0.19
	23	73.44 ± 0.93	16.58 ± 0.51	3.64 ± 0.12	10.12 ± 0.24	22.28 ± 0.25	1.73 ± 0.09
ANOVA	df	--- Probabilities ---					
Protein source (A)	1	0.0209	0.0001	0.0001	0.8876	0.0011	0.0001
CP Level (B)	2	0.9876	0.0290	0.0464	0.3849	0.0243	0.0041
A x B	2	0.2832	0.1197	0.4132	0.2827	0.0585	0.8322

[1]Means and standard errors of four pens (three birds randomly chosen per pen) per treatment.

TABLE 3.8. The influence of protein source and level on the BWG, feed intake, and feed conversion ratio (FCR) of male and female broiler chicks at 42 d of age (Experiment 3)

		Males			Females		
Protein Source	CP	BWG[1]	Feed Intake[1]	FCR[1]	BWG[1]	Feed Intake[1]	FCR[1]
	(%)	(kg)	(kg)	(g:g)	(kg)	(kg)	(g:g)
Cottonseed Meal	17	1.53 ± 0.03	3.61 ± 0.05	2.36 ± 0.04	1.27 ± 0.01	3.09 ± 0.02	2.44 ± 0.03
	20	1.74 ± 0.02	3.73 ± 0.05	2.14 ± 0.03	1.42 ± 0.01	3.17 ± 0.01	2.24 ± 0.02
	23	1.78 ± 0.03	3.65 ± 0.03	2.05 ± 0.02	1.47 ± 0.01	3.15 ± 0.04	2.14 ± 0.02
	26	1.81 ± 0.02	3.58 ± 0.03	1.97 ± 0.02	1.52 ± 0.03	3.13 ± 0.06	2.06 ± 0.04
Soybean Meal	17	1.46 ± 0.03	3.44 ± 0.07	2.35 ± 0.06	1.34 ± 0.04	3.13 ± 0.08	2.34 ± 0.02
	20	1.72 ± 0.05	3.50 ± 0.08	2.04 ± 0.02	1.52 ± 0.02	3.18 ± 0.05	2.09 ± 0.05
	23	1.84 ± 0.02	3.45 ± 0.03	1.87 ± 0.01	1.53 ± 0.03	3.10 ± 0.04	2.02 ± 0.03
	26	1.82 ± 0.02	3.27 ± 0.01	1.52 ± 0.02	1.52 ± 0.02	2.98 ± 0.05	1.96 ± 0.01
ANOVA	df	--- Probabilities ---					
Protein Source (A)	1	0.9319	0.0001	0.0519	0.0763	0.2373	0.0160
CP Level Linear (B)	1	0.0018	0.0178	0.0001	0.0019	0.0736	0.0001
CP Level Quadratic	1	0.8055	0.0431	0.2866	0.6108	0.1966	0.3087
A x B	1	0.6067	0.1208	0.9063	0.0330	0.0140	0.1817

[1]Means ± standard errors of three pens per treatment.

TABLE 3.9. Influence of protein source and level on liver and fat pad weights for male and female broiler chicks at 42 d of age (Experiment 3)

		Male					Female				
Protein Source	CP	Live BW[1]	Liver[1]	Abdominal fat pad[1]	Liver[1]	Abdominal fat pad[1]	Live BW[1]	Liver[1]	Abdominal fat pad[1]	Liver[1]	Abdominal fat pad[1]
	(%)	(kg)	(g)		(% of BW)		(kg)	(g)		(% of BW)	
Soybean Meal	17	2.28 ± 0.22	42.0 ± 1.22	84.4 ± 1.64	1.84 ± 0.05	3.71 ± 0.12	1.98 ± 0.57	39.0 ± 2.65	73.4 ± 2.77	1.96 ± 0.07	3.70 ± 0.11
	20	2.45 ± 0.48	40.3 ± 1.04	62.0 ± 6.06	1.65 ± 0.01	2.54 ± 0.25	2.16 ± 0.19	36.5 ± 1.23	66.3 ± 4.41	1.69 ± 0.07	3.04 ± 0.20
	23	2.61 ± 0.68	40.3 ± 3.03	50.6 ± 6.76	1.54 ± 0.07	1.92 ± 0.21	2.13 ± 0.32	36.9 ± 2.20	57.1 ± 3.41	1.75 ± 0.11	2.67 ± 0.13
	26	2.47 ± 0.50	40.7 ± 0.71	47.2 ± 0.32	1.65 ± 0.02	1.92 ± 0.02	2.15 ± 0.46	36.5 ± 1.43	57.4 ± 1.57	1.69 ± 0.03	2.67 ± 0.13
Cottonseed Meal	17	2.36 ± 0.24	38.1 ± 2.24	72.5 ± 2.05	1.62 ± 0.07	3.07 ± 0.02	2.00 ± 0.50	34.2 ± 0.55	89.2 ± 6.56	1.71 ± 0.05	4.42 ± 0.24
	20	2.59 ± 0.59	42.5 ± 2.34	79.0 ± 2.05	1.65 ± 0.07	3.06 ± 0.18	2.08 ± 0.26	36.2 ± 1.63	82.5 ± 1.53	1.74 ± 0.06	3.97 ± 0.07
	23	2.64 ± 0.64	42.3 ± 1.53	71.8 ± 4.40	1.60 ± 0.07	2.73 ± 0.21	2.08 ± 0.70	33.2 ± 3.35	67.8 ± 3.14	1.59 ± 0.16	3.25 ± 0.23
	26	2.55 ± 1.11	40.9 ± 1.30	67.6 ± 1.89	1.61 ± 0.03	2.65 ± 0.16	2.14 ± 0.06	34.4 ± 1.67	69.9 ± 4.73	1.61 ± 0.08	3.26 ± 0.22
ANOVA	df	-- Probabilities --									
Protein Source (A)	1	0.1657	0.9135	0.0119	0.3336	0.1158	0.4387	0.0633	0.0003	0.1148	0.0005
CP Level Linear (B)	3	0.0561	0.4773	0.0157	0.4294	0.0134	0.0977	0.7118	0.0006	0.2559	0.0005
CP Level Quadratic	1	0.2269	0.1550	0.0431	0.6655	0.1686	0.2041	0.5163	0.8780	0.2189	0.7729
A x B	3	0.6393	0.4260	0.1518	0.6215	0.3046	0.3249	0.9944	0.3043	0.6786	0.1802

[1]Means and standard errors of three pens per treatment.

TABLE 3.10. Influence of protein source and level on carcass parameters of male and female broiler chicks at 42 d of age (Experiment 3)

		Males				
Protein Source	CP	Chilled carcass[1]	Breast fillets[1]	Breast tenders[1]	Leg quarters[1]	Wings[1]
	(%)	(kg)	---------- (g) ----------			
Soybean meal	17	1.57 ± 0.21	331.0 ± 2.23	71.0 ± 1.65	730.0 ± 7.47	187.7 ± 5.38
	20	1.75 ± 0.49	381.3 ± 13.12	83.0 ± 1.88	796.4 ± 27.18	204.0 ± 0.73
	23	1.86 ± 0.54	424.4 ± 14.99	97.0 ± 4.68	838.5 ± 29.95	216.4 ± 7.25
	26	1.74 ± 0.40	370.3 ± 12.10	87.0 ± 3.64	807.1 ± 24.67	205.3 ± 3.82
Cottonseed meal	17	1.61 ± 0.12	322.5 ± 4.92	68.2 ± 1.41	778.0 ± 4.68	189.0 ± 1.11
	20	1.80 ± 0.43	373.3 ± 11.23	80.1 ± 1.15	856.0 ± 18.53	205.0 ± 6.97
	23	1.84 ± 0.47	396.4 ± 17.57	83.0 ± 2.94	861.5 ± 29.73	210.1 ± 1.37
	26	1.77 ± 0.65	373.0 ±5.35	81.5 ± 1.71	835.2 ± 39.08	208.7 ± 9.24
ANOVA	df	---------- Probabilities ----------				
Protein source (A)	1	0.0118	0.0279	0.0014	0.0004	0.3808
CP Level Linear (B)	1	0.7809	0.1671	0.0083	0.5051	0.7054
CP Level Quadratic	1	0.7875	0.1850	0.8603	0.4655	0.3911
A x B	1	0.2505	0.2409	0.7299	0.1063	0.9863

[1]Means ± standard errors of three pens per treatment.

TABLE 3.10. Continued.

Protein Source	CP	Chilled carcass[1]	Breast fillets[1]	Breast tenders[1]	Leg quarters[1]	Wings[1]
		Females				
	(%)	(kg)	---------------- (g) ----------------			
Soybean meal	17	1.36 ± 0.29	285.2 ± 3.76	64.2 ± 2.81	617.0 ± 5.37	163.2 ± 3.44
	20	1.49 ± 0.14	342.8 ± 6.30	75.2 ± 1.70	667.2 ± 9.44	179.4 ± 3.35
	23	1.50 ± 0.20	337.0 ± 8.21	80.1 ± 2.05	653.7 ± 13.65	175.5 ± 3.81
	26	1.53 ± 0.39	356.3 ±18.36	85.0 ± 1.03	664.3 ± 22.52	186.4 ± 5.95
Cottonseed meal	17	1.36 ± 0.24	273.4 ± 5.38	63.2 ± 2.21	621.9 ± 19.26	169.4 ± 1.75
	20	1.43 ± 0.32	304.9 ± 9.22	69.7 ± 3.13	656.4 ± 28.45	176.1 ± 3.57
	23	1.46 ± 0.49	300.5 ± 27.34	74.8 ± 5.12	629.4 ± 42.07	167.7 ± 8.35
	26	1.49 ± 0.09	316.0 ± 3.69	73.3 ± 2.34	683.6 ± 2.44	177.1 ± 2.33
ANOVA	df	---------------- Probabilities ----------------				
Protein source (A)	1	0.1299	0.0033	0.1699	0.0074	0.3021
CP Level Linear (B)	1	0.0057	0.2000	0.0151	0.0884	0.3840
CP Level Quadratic	1	0.7580	0.2828	0.9755	0.6584	0.4302
A x B	1	0.6638	0.9894	0.3680	0.4713	0.2035

[1]Means ± standard errors of three pens (three birds randomly chosen) per treatment.

TABLE 3.11. The influence of protein source and level on carcass yield parameters of male and female broiler chicks at 42 d of age, (Experiment 3)[1]

		Males					Females				
Protein Source	CP	Carcass yield[1]	Fillet[1]	Tender[1]	Leg quarters[1]	Wing[1]	Carcass yield[1]	Breast Fillet[1]	Breast tender[1]	Leg[1]	Wing[1]
	(%)	(%)	(% of live weight)				(%)	(% of live weight)			
Soybean meal	17	69.1 ± 0.33	21.0 ± 0.23	4.5 ± 0.06	46.4 ± 0.20	11.9 ± 0.32	68.6 ± 0.70	21.0 ± 0.22	4.7 ± 0.14	45.4 ± 0.58	12.0 ± 0.24
	20	71.6 ± 0.92	21.7 ± 0.49	4.7 ± 0.05	45.4 ± 0.57	11.6 ± 0.28	69.1 ± 1.09	23.0 ± 0.37	5.0 ± 0.07	44.7 ± 0.32	12.0 ± 0.17
	23	71.3 ± 0.44	22.7 ± 0.25	5.2 ± 0.11	45.1 ± 0.37	11.6 ± 0.35	70.7 ± 0.29	22.4 ± 0.50	5.3 ± 0.19	43.4 ± 0.50	11.7 ± 0.23
	26	70.2 ± 0.18	21.2 ± 0.20	5.0 ± 0.19	46.5 ± 0.51	11.8 ± 0.15	71.0 ± 0.72	23.2 ± 0.61	5.5 ± 0.08	43.4 ± 0.72	12.3 ± 0.68
Cottonseed meal	17	68.6 ± 0.34	19.9 ± 0.15	4.2 ± 0.10	48.1 ± 0.63	11.7 ± 0.01	67.8 ± 0.90	20.4 ± 0.63	4.7 ± 0.22	46.5 ± 0.81	12.7 ± 0.68
	20	69.4 ± 0.33	20.7 ± 0.27	4.4 ± 0.15	47.7 ± 0.24	11.4 ± 0.19	68.9 ± 0.80	21.2 ± 0.53	4.9 ± 0.20	45.7 ± 1.27	12.3 ± 0.06
	23	69.6 ± 0.11	21.5 ± 0.75	4.5 ± 0.17	46.8 ± 0.64	11.4 ± 0.26	69.9 ± 0.34	21.4 ± 0.30	5.3 ± 0.12	45.1 ± 0.71	12.0 ± 0.36
	26	69.5 ± 0.76	21.1 ± 0.76	4.6 ± 0.14	47.1 ± 0.48	11.8 ± 0.27	69.5 ± 0.33	21.2 ± 0.14	4.9 ± 0.13	45.9 ± 0.47	11.9 ± 0.20
ANOVA	df	Probabilities									
Protein source (A)	1	0.0118	0.0279	0.0014	0.0004	0.3808	0.1277	0.0008	0.0944	0.0078	0.4239
CP Level Linear (B)	1	0.7809	0.1671	0.0083	0.5051	0.7054	0.0048	0.2794	0.0137	0.1303	0.3741
CP Level Quadratic	1	0.7875	0.1850	0.8603	0.4655	0.3911	0.7615	0.3680	0.9759	0.7037	0.4346
A x B	1	0.2505	0.2409	0.7299	0.1063	0.9863	0.7982	0.3752	0.1451	0.7266	0.6033

[1]Means ± standard errors of three pens (three birds randomly chosen) per treatment.

FIGURE 3.1. Fitted broken-line plot of weight gain as a function of dietary lysine level. Weight gain data points (SEM) are replications of 8 chicks during a 10 d feeding trial. The breakpoint occurred at 1.023% of the diet based on analyzed values of lysine.

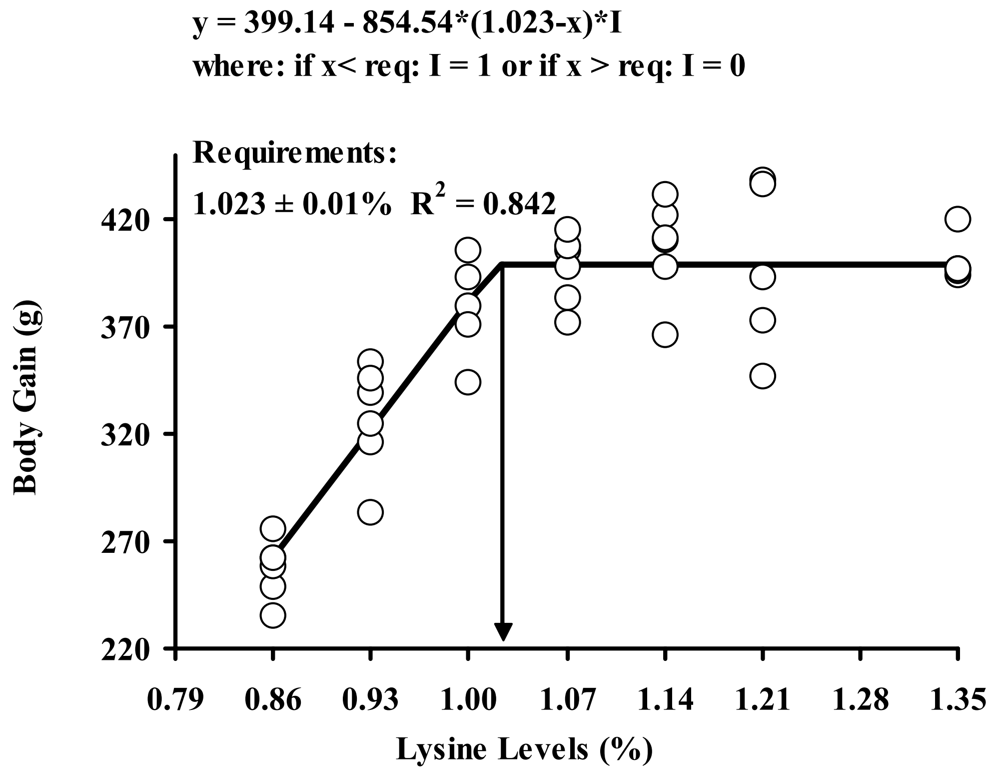
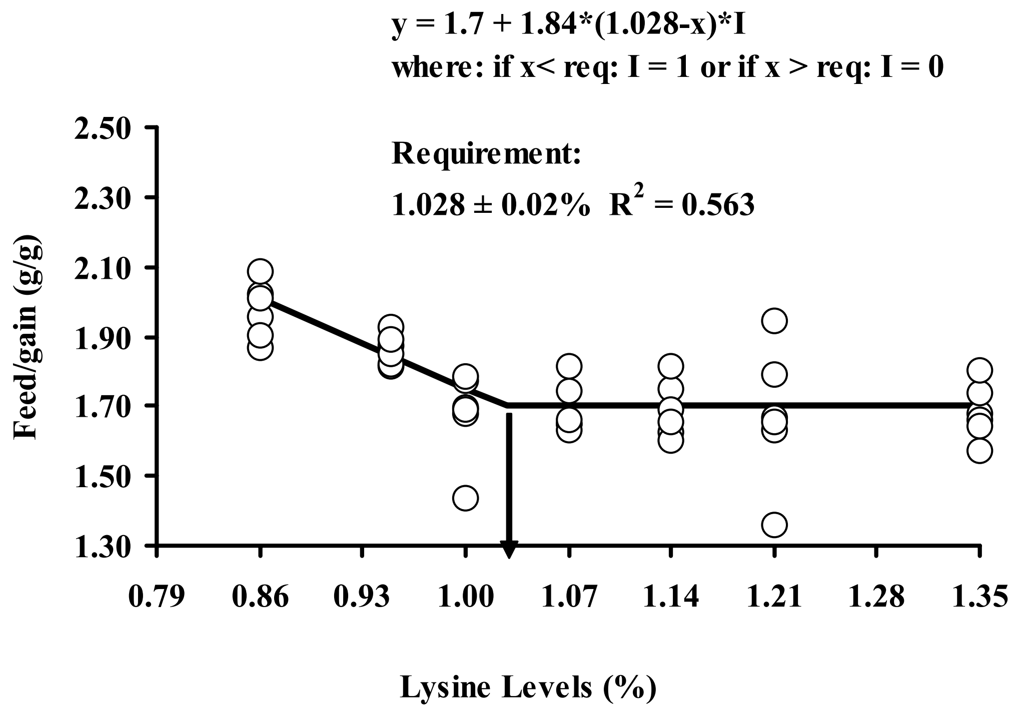


FIGURE 3.2. Fitted broken-line plot of feed to gain as a function of dietary lysine level. All FCR data points (SEM) are 6 replicates of 8 chicks during a 10 d feeding trial. The breakpoint occurred at 1.028% of the diet based on analyzed values of lysine.



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CHAPTER 4

PERFORMANCE OF BROILER CHICKS FED VARIOUS LEVELS OF DIETARY LYSINE AND CRUDE PROTEIN[1]

[1]Sterling, K. G., G. M. Pesti, and R. I. Bakalli. To be published in Poultry Science, 2003.

ABSTRACT

The response of broiler chicks to graded levels of lysine at two levels of crude protein (CP) were measured in diets mixed by two experimental methods. Experiment 1 had a 2 x 3 factorial arrangement of treatments with three dietary CP levels (17, 20, and 23%) and two levels of lysine (35 and 48g lysine/kg CP). Diluting a 26% CP based on corn and corn gluten meal allowed for the same amino acid profiles for each diet. Protein and/or lysine level had significant ($P < 0.001$) effects on body weight gain (BWG), feed intake, and feed conversion ratio (FCR), (no interactions). The average BWG were 161.5, 192.1, and 217.0 g for chicks fed 35 g lysine/kg CP, compared to 205.6, 253.5, and 297.7 g for chicks fed 48 g lysine/kg CP (17, 20, and 23% CP, respectively). The average FCR were 2.53, 2.20, and 1.93 for chicks fed the lower lysine level diets compared to chicks fed the higher lysine level diets with 2.17, 1.83, and 1.63 (17, 20, and 23% CP, respectively). In Experiment 2, the lysine requirement of chicks (9 to18 d of age) was determined at two levels of CP in diets mixed by the diet dilution method. The requirements for lysine at 17% CP were determined (on analyzed nutrient values) by breakpoint analysis to be 4.45 ± 0.18% lysine (% of CP) for BWG ($R^2 = 0.83$) and 4.33 ± 0.16% lysine (% of CP) for FCR (R^2=0.81). Similarly, the requirements at 23% CP were 4.34 ± 0.16% lysine (% of CP) for BWG ($R^2 = 0.84$) and 4.35 ± 0.13% lysine (% of CP) for FCR ($R^2 = 0.89$). In Experiment 3, the lysine requirement of chicks (10 to18 d of age) was determined at two levels of CP in diets mixed separately. The requirements for lysine at 18.5% CP were determined by breakpoint analysis to be 5.17 ± 0.25% lysine (% of CP) for BWG ($R^2 = 0.80$) and 4.26 ± 0.15% lysine (% of CP) for FCR ($R^2 = 0.85$).

Similarly, the requirements at 23% CP were 4.59 ± 0.17% lysine (% of CP) for BWG (R^2 = 0.83) and 4.71 ± 0.16% lysine (% of CP) for FCR (R^2 = 0.88). Results of a t-test show that the requirements were not significantly different between the two CP levels for BWG in Experiments 2 and 3 ($P < 0.05$).

INTRODUCTION

In the early 1950's Almquist (1952) concluded that the level of an indispensable amino acid required for optimum chick performance was a positive linear function of the dietary crude protein (CP) level. This relationship was based on the results of Almquist (1949) and Almquist and Merritt (1950) for methionine and arginine, respectively. Further, Almquist's (1952) plot of the data from Grau (1948) and Grau and Kamei (1950) revealed another aspect of the relationship between lysine and methionine and CP levels. Almquist noted that the lysine and methionine requirement and dietary CP level were not similar and that as the dietary CP level increased the requirements decreased as a proportion of CP (Figure 4.1). This assumption was later challenged by Boomgaardt and Baker (1970, 1973), Boomgaardt and Baker (1971) and Nelson et al. (1960) who reported that lysine, tryptophan, and methionine were required as constant proportions of CP, respectively (Figure 4.2). However, more recent studies have found the lysine (Abebe and Morris, 1990a; Surisdiarto and Farrell, 1991; Hurwitz et al., 1998), methionine (Mendonca and Jensen, 1989; Morris et al., 1992), and arginine (Hurwitz et al., 1998) requirements as a percentage of CP, decrease as the level of CP increased, thus confirming Almquist's earlier conclusion (Figure 4.2).

The examples above are only a few examples of the differences found in the literature. When comparing results from various research reports it is clear that the requirements for the amino acids mentioned above always increase as a percent of the diet (% of diet) as CP increases. However, the increases are not always quantitative even among studies testing the same amino acid. This is true for lysine, arginine, methionine, and tryptophan (Figures 4.1 and 4.2).

Responses to amino acids, and therefore amino acid requirement estimates, can vary depending on the dietary protein source and quality, dietary energy level, genetic strain, sex, experimental conditions, and statistical evaluation. Certainly, the comparison of experiments similar in their hypotheses is clouded by numerous differences in experimental design. It is difficult to attribute differences in the materials and methods these researchers employed to create such equivocal results (Figures 4.1 and 4.2).

The clearest division that could be made among the various papers reviewed in Figures 1 and 2, was between those experiments with different CP levels achieved by the diet dilution method, and those mixed using the graded supplementation method. The diet dilution method comprises the dilution of a high CP diet with one that is devoid or low in CP. Amino acid proportions within the different CP levels are identical. Graded levels of the test amino acid are then added to each mixture. The graded supplementation method comprises the graded addition of a test amino acid in a crystalline form to a basal diet deficient in that amino acid (D'Mello, 1988). A separate basal diet must be formulated for each CP level to obtain diets varying in dietary CP. Amino acid proportions within the different CP levels are somewhat different. There are exceptions to this division however, it holds true for the majority of the papers reviewed. Figure 4.1 illustrates the results of experiments where amino acids were found to be required as a constant proportion of the dietary CP content. In these studies, the diets were mixed using a diet dilution method, generally with one major protein source, or a crystalline amino acid mixture. Figure 4.2 illustrates the results of experiments where amino acids requirements were found to be a negative linear function of the dietary CP content. In these studies, the diets contained different proportions of various protein and carbohydrate sources across the dietary CP levels.

If amino acid requirements are constant at different dietary CP levels (Figure 4.1), then feed formulators can simply set a minimum amino acid requirement to protein ratio. However, if amino acid requirements (% of CP) decrease with increasing CP levels (Figures 4.2), then formulators will need to make much more complex adjustments. Further, if the slopes of the regression lines are different for different amino acids (Figures 4.1 and 4.2), then there will be a different ideal mixture of amino acids at each CP level.

The purpose of the studies described here was to test the hypothesis that the relationship between dietary CP level and the lysine requirement of broilers is constant. The first experiment was conducted to observe the magnitude of responses to dietary CP and lysine and to test for a CP by lysine interaction. Two feed formulation techniques were used: a diet dilution method (Experiment 2) and the graded supplementation method (Experiment 3) in an attempt to replicate the patterns observed in the literature.

MATERIAL AND METHODS

In all Experiments Cobb x Cobb broiler chicks were used. Straight-run chicks were used in Experiment 1 and males only in Experiments 2 and 3. All chicks were raised in battery brooders and fed a commercial broiler starter diet (formulated according to NRC (1994) recommendations to contain 23% CP and 3,200 kcal/kg ME) prior to being placed on the test diets. On the first day of each experiment, chicks were weighed, neck-banded and allotted to their respective treatments in a manner that ensured a similar average body weight and weight range per replication. Chicks were fed a semi-purified diet representing one of the combinations of dietary CP and lysine (Table 4.1) from 9 to 18 d for Experiments 1 and 2, and 10 to 18 d for Experiment 3. In Experiments 1 and 2, two diets were formulated, a 0% CP basal diet based on cornstarch, cellulose, and poultry fat and a 26% CP summit diet based on corn, CGM, cellulose and poultry fat as the major ingredients (Table 4.1). The basal and summit diets were combined to create the 17, 20, and 23% CP diets deficient in lysine in Experiment 1 and 17 and 23% CP in Experiment 2. In Experiment 3, chicks were fed one of two diets formulated to contain either 18.5 or 23% CP with CGM and cellulose (Table 4.1). L-Lysine-HCl was added to the diets at the expense of the diets. In Experiment 1, a commercial broiler starter diet (formulated according to NRC (1994) recommendations to contain 23% CP and 3,200 kcal/kg ME) was fed as a control. On d 18 chicks and residual feed was weighed and FCR was calculated.

Experimental Design

Experiment 1 had a completely randomized design with a 2 x 3 factorial arrangement of treatments (6 treatments with 3 replications per treatment and 6 chicks per replication). The main effects were dietary levels of lysine (3.5 and 4.8g lysine/100g CP) and dietary CP level (17, 20 and 23% CP).

In Experiments 2 and 3, the experimental design was a randomized complete block with a 2 x 8 fractional factorial arrangement of treatments with 16 treatments, 3 replications per treatment and 6 chicks per replication. The main effects were dietary CP level (17 or 18.5 and 23 %CP) and dietary lysine levels (0.5, 0.6, 0.7, 0.8, 0.9, 1.0, 1.1, and 1.2 for the 17 and 18.5%CP diets and 0.7, 0.8, 0.9, 1.0, 1.1, 1.2, 1.3, and 1.4 for the 23% CP, respectively).

Statistical Analysis

The experimental unit was the pen mean. All data were analyzed for significant differences at a probability level of $P < 0.05$ by two-way ANOVA using the General Linear Models Procedure of SAS (SAS, 1998). In Experiments 2 and 3 a nonlinear procedure of SAS was applied to determine the lysine requirement based on BWG and FCR. The iterative procedure makes repeated estimates for coefficients and minimizes residual error until the best-fit lines are achieved: one line with a slope of zero and the other with a marked slope. The two lines are fitted to the values using the following equation:

$$Y = MAX + RC \times (REQ - X) \times I$$

Where X = independent variable, REQ = requirement, Y = dependent variable, MAX = theoretical maximum, I = 1 (if X < REQ) or I = 0 (if X > REQ), and RC = rate constant. R2 values were determined as follows: R2 = 1 - (residual sum of squares/corrected total sum of squares). A t-test ($\alpha < 0.05$) was performed to determine if differences existed for the requirements established between CP levels for each experiment. The following equation was used to determine the absolute value of t (| t |):

| t | = (Req 1 - Req 2) / sqrt of ($(\text{Stderr } 1)^2 + (\text{Stderr } 2)^2$); where Req = requirement and Stderr = standard error of the requirement. If | t | > t, then reject the null hypothesis where $t_{\alpha < 0.05,\ df = 21} = 2.08$ (df = n - r where n = number of experimental units and r = number of replications).

RESULTS

In Experiment 1, responses to dietary protein level were significant ($P < 0.001$) for BWG and FCR (Table 4.2). BWG and FCR improved as CP increased in the diets. Feed consumption was not affected by CP level however increasing lysine in the diets significantly ($P < 0.001$) increased feed consumption and improved FCR. The performance of chicks fed the control diet based on Corn and Soybean Meal was superior when compared to chicks fed the experimental diets. In Experiments 2 and 3, the lysine requirement was determined at calculated and analyzed nutrient values and as a % of the diet or as a % of CP (Tables 4.3 and 4.4). In Experiment 2, lysine requirements for both BWG and FCR increased as a percentage of the diet, but were constant as a percentage of dietary CP (Tables 4.3 and 4.4, Figures 4.3 and 4.4). The t-test results based on calculated and analyzed nutrient values were similar for both BWG and FCR (Tables 4.3 and 4.4). In Experiment 3, lysine requirements for BWG and FCR increased as a percentage of the diet (Tables 4.3 and 4.4, Figures 4.5 and 4.6). The analyzed lysine requirement for BWG appeared to decrease as the percentage of dietary CP increased ($P > 0.05$) but the lysine requirement for FCR appeared to increase as the percentage of dietary CP increased ($P > 0.05$). In addition, the analyses of the lysine requirement for BWG increased the absolute value of t closer to the level of significance when based on analyzed nutrient values. However, the t value for the FCR requirement was reduced when determined based on analyzed nutrient values.

DISCUSSION

The analyzed nutrient values of the diets were slightly higher than expected values from NRC (1994) ingredient composition tables. Similarly, the lysine requirements established with analyzed nutrient values were higher for both BWG and FCR. Increasing dietary CP had no effect on the lysine requirement of broilers expressed as a percentage of the dietary CP, therefore the hypothesis that lysine requirements are a constant proportion of dietary CP must be accepted based on the present experiments. The requirements observed in Experiments 2 and 3 are in close agreement with the studies of Boomgaardt and Baker (1970, 1973). Boomgaardt and Baker (1970) determined the requirement of lysine to be 4.59% of dietary CP using crystalline amino acid diets (8.7 to 20.3% CP) with a slow-growing strain of chicks. Similarly, Boomgaardt and Baker (1973) used a semi-purified diet containing sesame seed meal

(SSM) and gelatin, and found the requirement to be 4.70 % of dietary CP for 14, 18.5, and 23% CP.

In a review of the experiments conducted by Abebe and Morris (1990a,b) and Morris et al. (1992), Morris et al. (1999) concluded that amino acid requirements (% of CP) for maximum growth probably decrease with increasing dietary CP. However, it is clear from the depiction in Figure 4.2 of the equations established by Surisdiarto and Farrell (1991) and Abebe and Morris (1992) that although a slope exists, the differences in the lysine requirements within a practical range (17 to 23% CP) are small. In both Experiments 2 and 3 the tendency for the requirements to nominally decrease as CP increased existed. This was especially noticeable in Experiment 3 where the differences in the lysine requirement (percentage of dietary CP) observed between the two CP levels were larger compared to Experiment 2. However even the largest difference in requirement in Experiment 3, (5.17 ± 0.24 versus 4.59 ± 0.17 for BWG) was still relatively small. Morris et al. (1999) stated that the dietary CP levels selected by Hurwitz et al. (1998) were not sufficient for examining the relationship between an amino acid requirement and dietary CP level. However, the range studied by Hurwitz et al. (1998), Boomgaardt and Baker (1973) and the present study serve a more practical purpose by closely resembling CP levels used in commercial broiler production. Although the use of a broader range of CP may allow for the detection of differences in the extremes, no differences may still exist in the practical range of dietary CP levels. The true relationship between dietary CP levels and amino acid requirements (% of the diet) is more likely to resemble a sigmoid curve with the plateau representing a practical range of

CP and the slopes representing the two extremes, sub-optimal and super-optimal CP levels.

The tendency for the lysine requirements as a percentage of dietary CP to decline is not related to the use of the graded supplementation method per se. However, the graded supplementation method could still be a factor if it results in large changes in the amino acid profiles of the diets between CP levels. In Experiment 3, the amino acid profile of the diets remained similar at different CP levels because Corn protein was substituted for CGM protein. Similarly, Boomgaardt and Baker (1973) replaced cornstarch with SSM and gelatin with the same ratio of SSM to gelatin resulting in a similar amino acid profiles between CP levels. In Experiment 3 of Hurwitz et al. (1998), the amino acid profiles changed at different CP levels more than in our Experiment 3 and the study of Boomgaardt and Baker (1973). For example, Hurwitz et al. (1998) formulated an 18% CP diet with more sorghum, less wheat and cottonseed meal and no CGM when compared to the 23% CP diet used in the same experiment. In Figure 4.2, the requirements established by Hurwitz et al. (1998) have been converted to a percentage of dietary CP. The requirements are 5.26 and 4.78% of CP for the 18 and 23% CP diets, respectively. Although conclusions regarding the relationship between dietary CP and the lysine requirement expressed as a percentage of dietary CP were not provided by Hurwitz et al. (1998) the differences in requirement are greater than those observed in the present study.

Gous and Morris (1985) published an extensive report comparing the diet dilution and graded supplementation methods and concluded that the diet dilution was superior in that it maintains the balance of amino acids within narrow limits between dietary CP levels. However, D'Mello (1988) stated that use of the diet dilution method often results in amino acids in excess of the required level, some up to 1.4 times the requirement. Surisdiarto and Farrell (1991) tested the response of chickens to dietary lysine and CP containing excess or an ideal balance of essential amino acids relative to lysine. Obvious differences exist between the two Experiments of Surisdiarto and Farrell (1991) in Figure 4.2. In their Experiment 2, the amino acids were balanced relative to lysine and revealed less of a response compared to Experiment 1 conducted with excess amino acids relative to lysine. Although variations in response have been observed when using the diet dilution technique (as seen with the study of Surisdiarto and Farrell, 1991), it is not solely responsible for the differences seen in the literature. The reduced response in Experiment 2 of Surisdiarto and Farrell (1991) may be due to the lack of response in growth rate and FCR to lysine at any given dietary CP level.

D'Mello (1988) found the diet dilution and graded supplementation methods to be highly comparable. There were no obvious differences between dietary methods noted in the present study. Therefore, the differences in the literature may be more attributable to the amino acid composition of the different ingredients incorporated into the diets regardless of the method used. For example, each ingredient or a combination of ingredients will yield differences in digestibility and availability of amino acids. In the case of establishing a lysine requirement, special consideration must be given to protein sources known to have problems with lysine availability such as SSM and cottonseed meal. For example, Mamputu et al. (1998) found SSM inclusions greater than 15% of the dietary CP to be detrimental to chick performance. In Experiment 1, chicks fed the control diet based on corn and soybean meal performed better than chicks fed the corn, CGM, cellulose based diets. This was probably due to the incorporation of cellulose in the experimental diets. Barbour et al. (1993) when determining the lysine requirement using adjusted peanut meal (with supplemental amino acids), peanut meal (without supplemental amino acids), and SSM and found the lysine requirement to be lower for SSM regardless of statistical evaluation.

The method of statistical evaluation can influence the relationship between an amino acid and dietary CP levels. The most common statistical models used to determine amino acid requirements are the broken-line (one-slope), two-slope, quadratic, and ascending quadratic with plateau models. Barbour et al. (1993) found along with protein source, statistical evaluation influences the estimate of an amino acid requirement. That is, the quadratic procedure estimates were higher for all protein sources when compared to a two-slope procedure. Similarly, with the original analysis of Morris et al. (1987) performed using a quadratic model, the lysine requirement was suggested to be a constant proportion of the dietary CP level. In a re-analysis of the data obtained by Morris et al. (1987), Abebe and Morris (1990a) used the Reading model (similar to an ascending quadratic with plateau model) and concluded that the lysine requirement appeared to decrease in proportion to the dietary CP in two separate experiments (Figure 4.2). Hurwitz et al. (1998) used a Split-Plot method similar to the breakpoint analysis used in the present study. The requirements established by Hurwitz et al. (1998) were similar to the requirements established in the present study determined at 18.5 and 23% CP and subjected to a simple t-test. In accord with the present study, Hurwitz et al. (1998) found significant differences in the lysine requirements expressed as a % of the diet between an 18 and 23% CP diet.

The practice of keeping amino acid requirements as a proportion of the dietary CP content constant appears to be adequate for practical feed formulation. Dietary CP level may be adjusted to find the most economical level of CP and amino acids to feed. The underlying assumption of this approach is that a balanced 16% CP diet will result in more carcass fat than a balanced 24% CP diet (Smith and Pesti, 1998). The most economical CP and amino acid levels to feed may not necessarily be the levels that contain the "required" amino acid levels for maximum growth or minimum carcass fat, but the diets providing the largest difference between costs and returns (Costa et al., 2002).

TABLE 4.1. Composition of diets used in Experiments 1, 2 and 3

	Diets						
	Experiment 1			Experiment 2		Experiment 3	
Percentage CP	17	20	23	17	23	18.5	23
	(%)						
Ingredients[1]							
Corn, grain	27.53	32.37	37.26	27.26	36.89	54.03	46.63
Corn, starch	25.43	16.98	8.45	25.36	8.42	----	----
CGM-60% CP	21.51	25.29	29.11	21.75	29.43	20.39	28.04
Cellulose[2]	13.00	13.00	13.00	13.86	13.29	13.00	13.00
Poultry fat (stabilized)	6.31	6.31	6.31	6.40	6.40	7.40	6.80
Di-calcium phosphate	2.30	2.24	2.17	2.30	2.17	2.18	2.14
Limestone	2.19	1.94	1.68	1.32	1.39	1.38	1.40
L-Lysine HCl	0.40	0.48	0.55	0.28	0.38	0.21	0.40
L-Arginine HCl	0.37	0.44	0.50	0.37	0.49	0.38	0.49
Common salt	0.48	0.48	0.47	0.48	0.47	0.47	0.47
Choline Cl-70%	0.16	0.15	0.15	0.14	0.13	0.11	0.12
L-Tryptophan	0.08	0.09	0.11	0.08	0.11	0.08	0.10
L-Threonine	0.06	0.07	0.08	0.05	0.08	0.06	0.07
Vitamin premix[3]	0.08	0.08	0.08	0.25	0.25	0.25	0.25
Mineral premix[4]	0.08	0.08	0.08	0.08	0.08	0.08	0.08
Calculated composition[1]							
ME (kcal/g)	3.2	3.2	3.2	3.2	3.2	3.2	3.2
Crude protein (%)	17.0	20.0	23.0	17.0	23.0	18.5	23.0
Ether Extract (%)	7.9	8.2	8.5	8.0	8.5	9.9	9.3
Lysine (%)	0.59	0.69	0.79	0.50	0.68	0.50	0.70
Threonine (%)	0.59	0.69	0.80	0.59	0.80	0.64	0.80
Methionine + Cystine (%)	0.71	0.84	0.96	0.72	0.97	0.77	0.97
Analyzed compostition[5]							
Crude protein (%)	17.6	19.4	23.5	17.5	23.3	17.7	21.9
Ether Extract (%)	8.2	7.8	8.0	8.0	8.3	10.0	9.3
Lysine (%)	0.60	0.71	0.78	0.53	0.74	0.51	0.67
Threonine (%)	0.62	0.72	0.83	0.62	0.84	0.62	0.80
Methionine + Cystine (%)	0.79	0.97	1.04	0.79	1.06	0.76	0.94

[1]Based on NRC (1994) feed composition tables.

[2]Solka Floc®, International Fiber Corporation, North Tonawanda, NY.

[3]Vitamin premix provides the following per kilogram of diet: vitamin A, 5,500 IU from all trans-retinyl acetate; cholecalciferol, 1,100 IU; vitamin E, 11 IU from all-rac-α-tocopherol acetate; riboflavin, 4.4 mg;

TABLE 4.1. Continued.

Ca pantothenate, 12 mg; nicotinic acid, 44 mg; choline Cl, 220 mg; vitamin B_{12}, 6.6 μg; vitamin B6, 2.2 mg; menadione, 1.1 mg (as MSBC); folic acid, 0.55 mg; di-biotin, 0.11 mg; thiamine, 1.1 mg (as thiamine mononitrate); ethoxyquin, 125 mg.

[4]Trace mineral premix provides the following in milligrams per kilogram of diet: Mn, 60; Zn, 50; Fe, 30; Cu, 5; I, 1.5.

[5]Degussa-Hüls Corporation, Allendale, NJ.

TABLE 4. 2. Relationship between dietary CP and lysine on body weight, feed intake and feed conversion ratio of male broiler chicks (9 to 18 d of age), Experiment 1[1]

Lysine	CP	BWG	Feed Intake	FCR
(g/100g CP)	(%)	--------- (g) --------		g/g
3.5	17	161.5 ± 0.98	409.3 ± 6.33	2.53 ± 0.03
	20	192.1 ± 10.07	422.3 ± 16.14	2.20 ± 0.06
	23	217.0 ± 2.23	413.6 ± 7.04	1.93 ± 0.03
4.8	17	205.6 ± 7.88	447.7 ± 2.43	2.17 ± 0.09
	20	253.5 ± 11.18	458.8 ± 13.38	1.83 ± 0.07
	23	267.7 ± 3.44	441.7 ± 3.78	1.63 ± 0.03
Control		421.8 ± 3.36	577.1 ± 8.21	1.40 ± 0.00
ANOVA	df	------------------------ Probabilities ------------------------		
Protein level (A)	2	0.0001	0.3391	0.0001
Lysine Ratio (B)	1	0.0001	0.0009	0.0001
A x B	2	0.4933	0.8204	0.7939

[1]Means and standard errors of three pens (6 birds each) per treatment.

TABLE 4.3. Requirement estimates from Experiments 2 and 3, BWG

		Calculated Nutrient Values		Analyzed Nutrient Values[2]	
	CP Level	Requirement	t-test[1]	Requirement	t-test[1]
Experiment 2 - Diet Dilution					
Lysine (% of diet)	17	0.75 ± 0.03	4.56	0.78 ± 0.03	4.77
	23	0.97 ± 0.04		1.01 ± 0.04	
Lysine (% of CP)	17	4.41 ± 0.18	0.74	4.45 ± 0.18	0.46
	23	4.23 ± 0.16		4.34 ± 0.16	
Experiment 3 - Graded Supplementation					
Lysine (% of diet)	18.5	0.90 ± 0.05	2.26	0.92 ± 0.05	1.58
	23	1.04 ± 0.04		1.01 ± 0.04	
Lysine (% of CP)	18.5	4.89 ± 0.24	1.31	5.17 ± 0.25	1.89
	23	4.51 ± 0.16		4.59 ± 0.17	

[1]Requirements considered significantly different if $| t | > t_{(\alpha=0.05,\ df = 21)} = 2.08$.

[2]Based on analyzed dietary CP and lysine values.

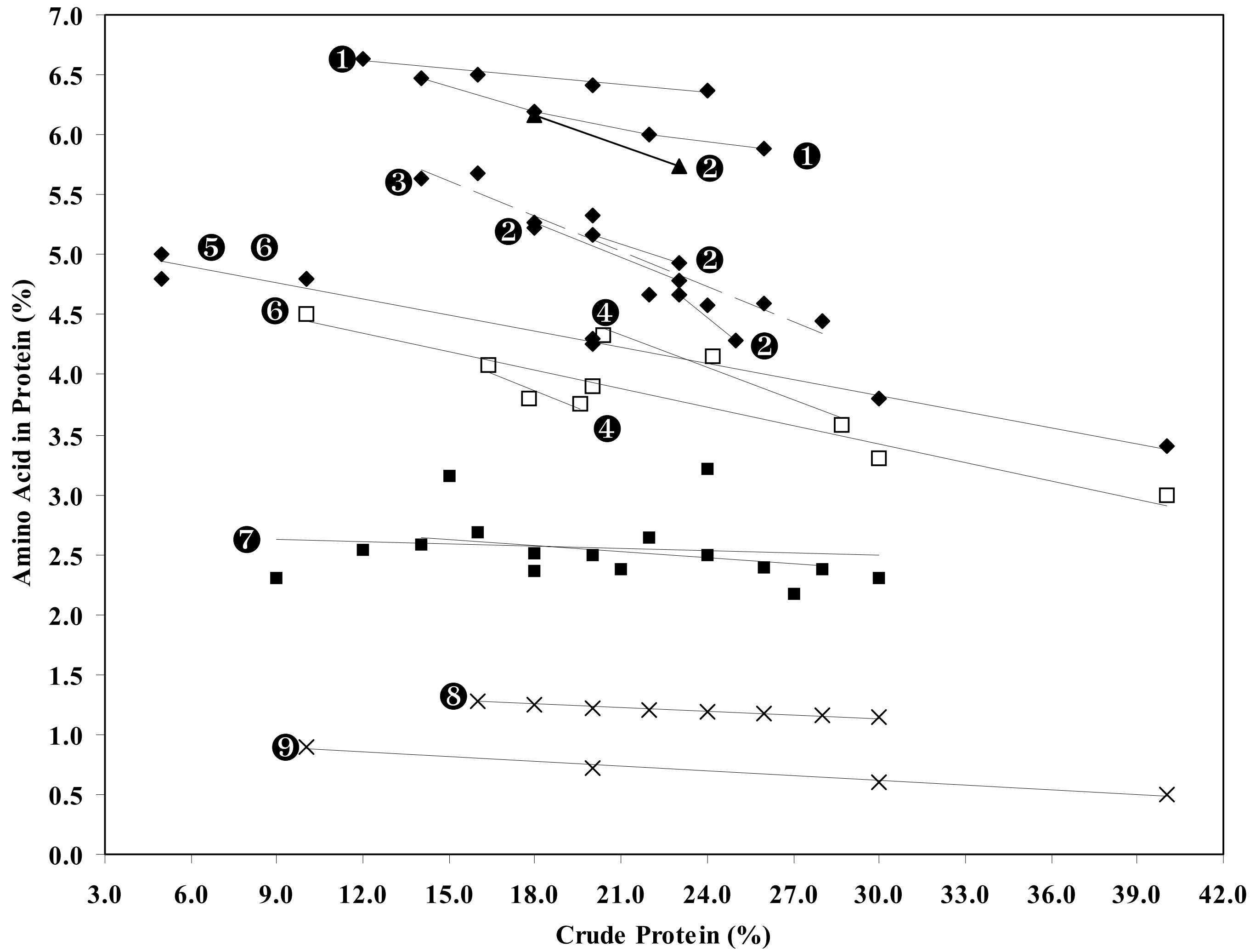
TABLE 4.4. Requirement estimates from Experiments 2 and 3, FCR

		Calculated Nutrient Values		Analyzed Nutrient Values[2]	
	CP Level	Requirement	t-test[1]	Requirement	t-test[1]
Experiment 2 - Diet Dilution					
Lysine (% of diet)	17	0.73 ± 0.03	6.05	0.76 ± 0.03	6.30
	23	0.98 ± 0.03		1.02 ± 0.03	
Lysine (% of CP)	17	4.28 ± 0.16	0.19	4.33 ± 0.16	0.13
	23	4.24 ± 0.13		4.35 ± 0.13	
Experiment 3 - Graded Supplementation					
Lysine (% of diet)	18.5	0.74 ± 0.03	7.16	0.75 ± 0.03	6.25
	23	1.06 ± 0.04		1.03 ± 0.04	
Lysine (% of CP)	18.5	4.02 ± 0.15	2.81	4.75 ± 0.15	2.01
	23	4.62 ± 0.15		4.71 ± 0.16	

[1]Requirements considered significantly different if $| t | > t_{(\alpha=0.05,\ df = 21)} = 2.08$.

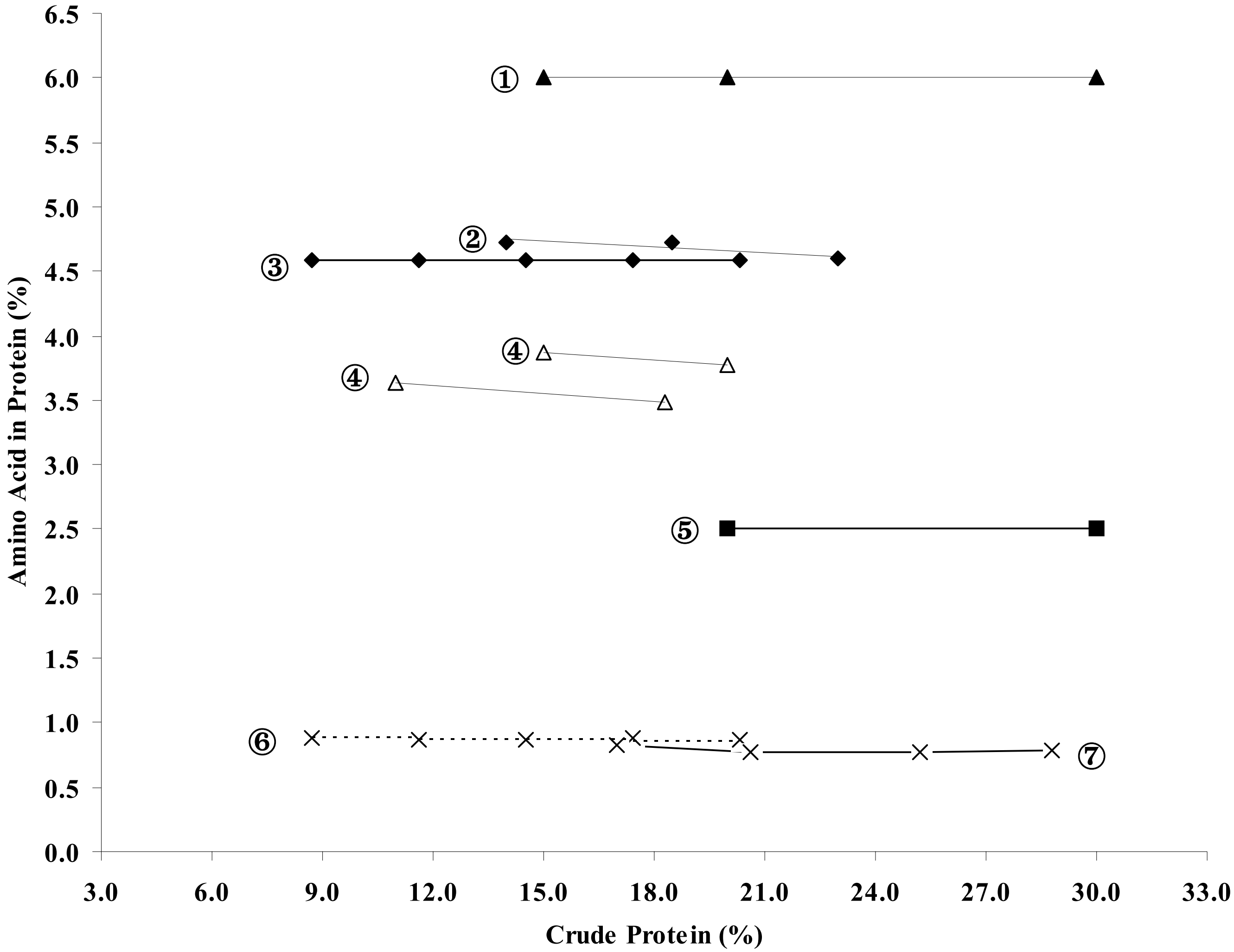
[2]Based on analyzed dietary CP and lysine values.

FIGURE 4.1. Linear plot of optimal amino acid levels (% of CP) as a function of dietary CP for experiments where the requirements decrease as dietary CP increases. ♦ Lysine; ☐ TSAA; ▲ Arginine; x Tryptophan; ■ Methionine. Surisdiarto et al. (1991), Exp. 1 and 2; ❷ Hurwitz et al. (1998). Exp. 1, 2, 3 and 4; ❸ Abebe and Morris (1990a), Exp. 1 and 2; ❹ Mendonca and Jensen (1989), Exp. 1 and 2; ❺ Grau (1948); ❻ Grau and Kamei (1950); ❼ Morris et al. (1992), Exp. 1 and 2; ❽ Abebe and Morris (1990b); ❾ Griminger et al. (1956).



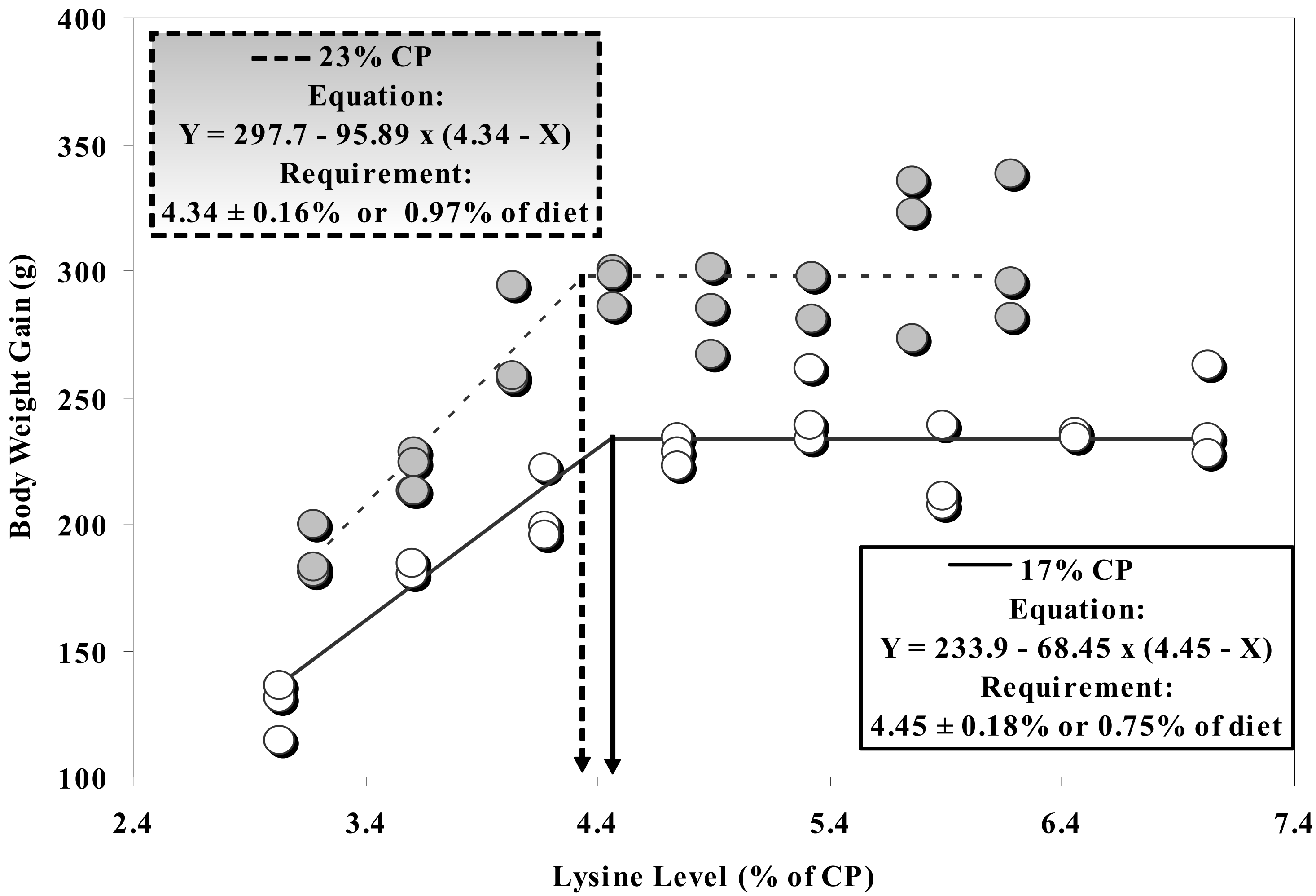
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Amino Acid in Protein (%)
3.0
6.0
9.0
12.0
15.0
18.0
21.0
24.0
27.0
30.0
33.0
36.0
39.0
42.0
Crude Protein (%)
1
1
2
3
2
2
5
6
6
4
2
4
7
8
9

FIGURE 4.2. Linear plot of optimal amino acid levels (% of CP) as a function of dietary CP for experiments where the requirements are a constant proportion of CP as dietary CP increases. ♦ Lysine; ☐ TSAA; ▲ Arginine; x Tryptophan; ■ Methionine. Almquist and Merritt (1950); ②Boomgaardt and Baker (1973); ③ Boomgaardt and Baker (1970); ④ Robbins (1987), Exp. 1 and 2; ⑤ Almquist (1949); ⑥ Boomgaardt and Baker (1971); ⑦ Rogers and Pesti (1990).



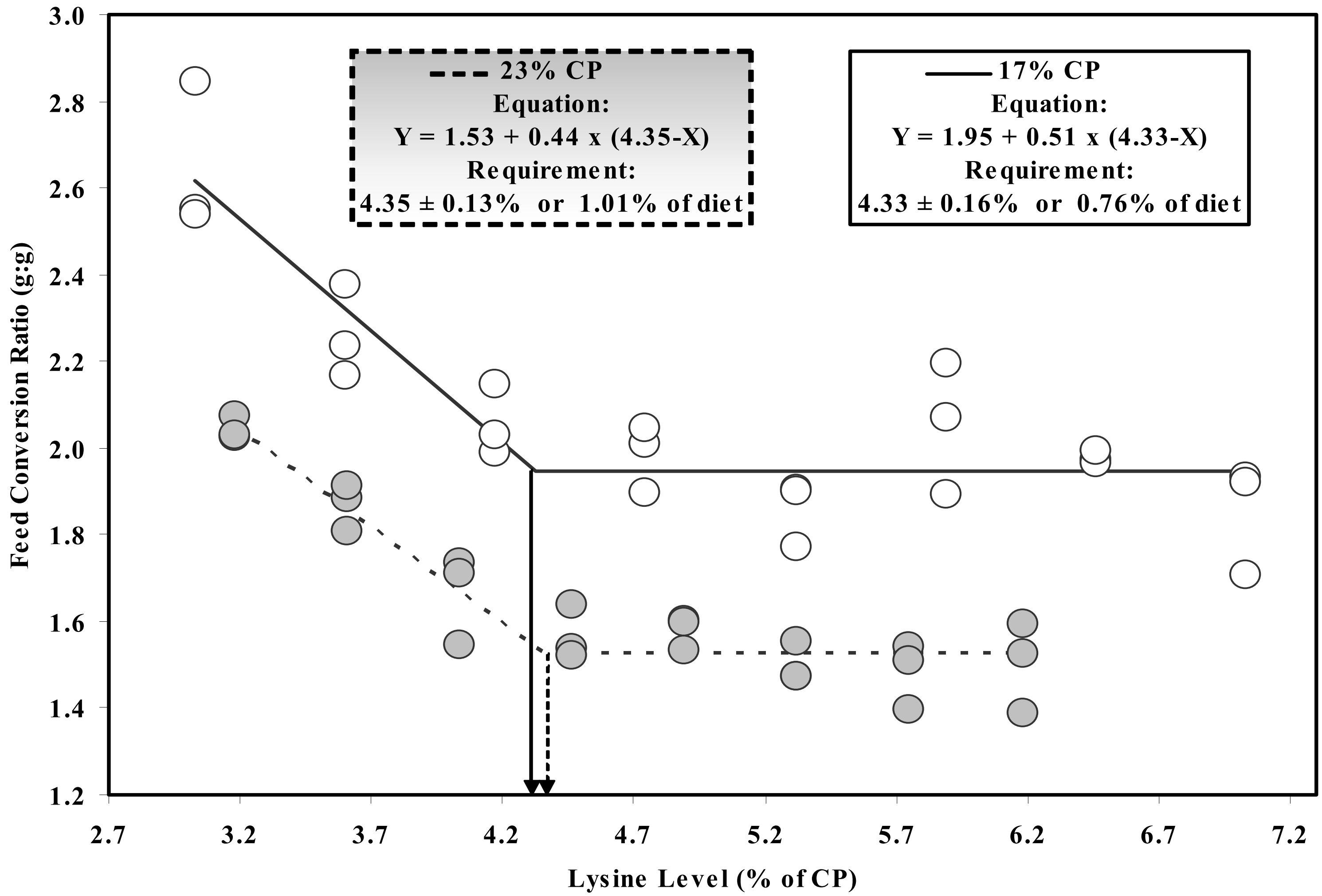
Amino Acid in Protein (%)
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
①
②
③
④
④
⑤
⑥
⑦
3.0
6.0
9.0
12.0
15.0
18.0
21.0
24.0
27.0
30.0
33.0
Crude Protein (%)

FIGURE 4.3. Fitted broken-line plot of weight gain as a function of dietary lysine level (% of CP), Experiment 2. Weight gain data points are replications of six chicks during a 9 d feeding trial. The breakpoint occurred at 4.45 ± 0.18% and 4.34 ± 0.16% of the dietary CP for 17 and 23% CP, respectively, based on calculated values of lysine. R^2 = 0.83 and 0.84 for 17 and 23% CP, respectively. Results of a *t*-test reveal that the requirements were not significantly different between 17 and 23% CP (P < 0.05).



23% CP
Equation:
Y = 297.7 - 95.89 x (4.34 - X)
Requirement:
4.34 ± 0.16% or 0.97% of diet
17% CP
Equation:
Y = 233.9 - 68.45 x (4.45 - X)
Requirement:
4.45 ± 0.18% or 0.75% of diet
Body Weight Gain (g)
Lysine Level (% of CP)
400
350
300
250
200
150
100
2.4
3.4
4.4
5.4
6.4
7.4

FIGURE 4.4. Fitted broken-line plot of feed to gain as a function of dietary lysine level (% of CP), Experiment 2. Feed to gain data points are replications of six chicks during an 9 d feeding trial. The breakpoint occurred at 4.33 ± 0.16% and 4.35 ± 0.13% of the dietary CP for 17 and 23% CP, respectively, based on calculated values of lysine. R^2 = 0.81 and 0.89 for 17 and 23% CP, respectively. Results of a *t*-test reveal that the requirements were not significantly different between 17 and 23% CP ($P < 0.05$).



23% CP
Equation:
Y = 1.53 + 0.44 x (4.35-X)
Requirement:
4.35 ± 0.13% or 1.01% of diet
17% CP
Equation:
Y = 1.95 + 0.51 x (4.33-X)
Requirement:
4.33 ± 0.16% or 0.76% of diet
Feed Conversion Ratio (g:g)
Lysine Level (% of CP)
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
2.7
3.2
3.7
4.2
4.7
5.2
5.7
6.2
6.7
7.2

FIGURE 4.5. Fitted broken-line plot of weight gain as a function of dietary lysine level (% of CP), Experiment 3. Weight gain data points are replications of six chicks during an 8 d feeding trial. The breakpoint occurred at 5.17 ± 0.25% and 4.59 ± 0.17% of the dietary CP for 17 and 23% CP, respectively, based on calculated values of lysine. $R^2 = 0.80$ and 0.83 for 17 and 23% CP, respectively. Results of a *t*-test reveal that the requirements were not significantly different between 17 and 23% CP ($P < 0.05$).

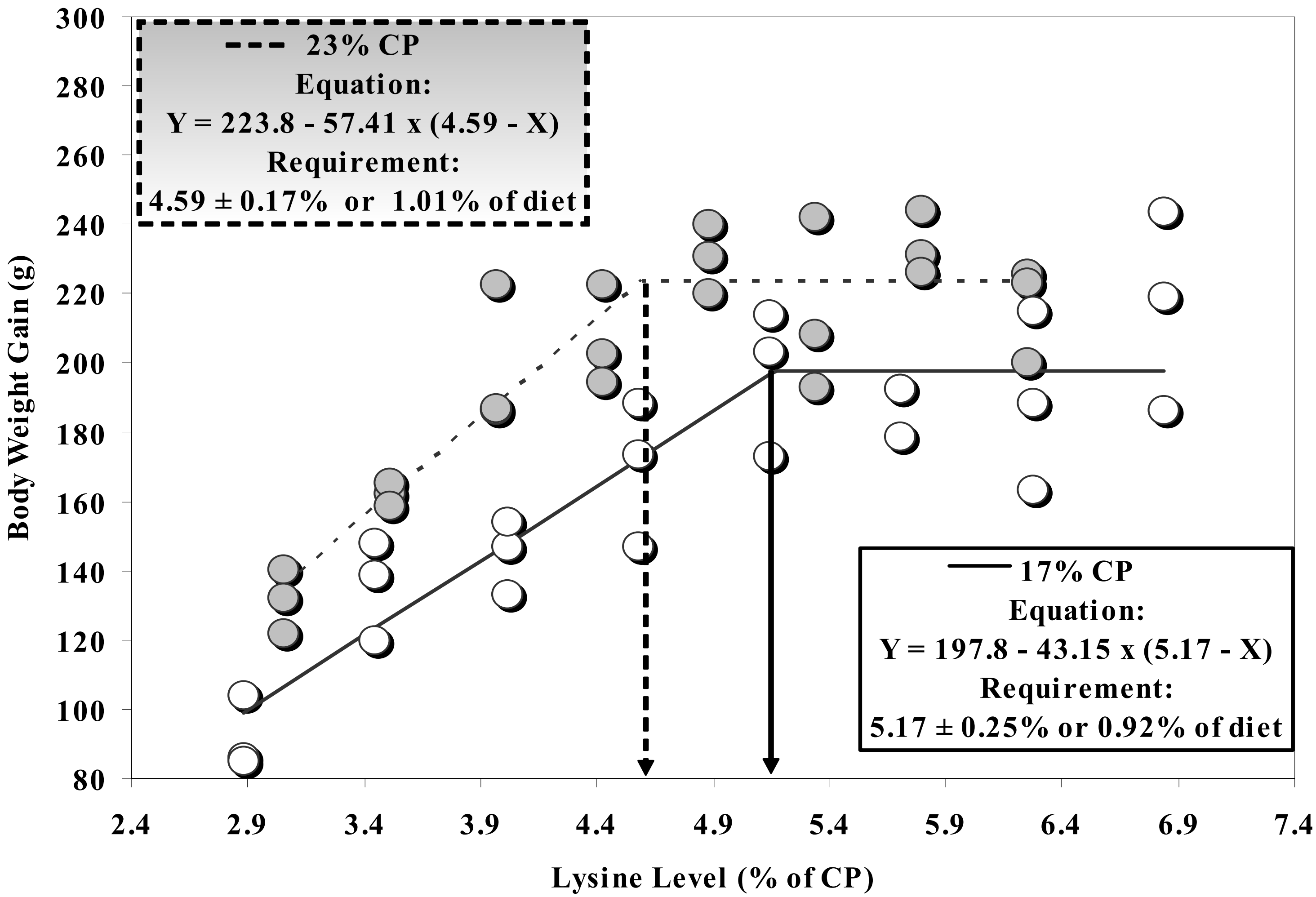
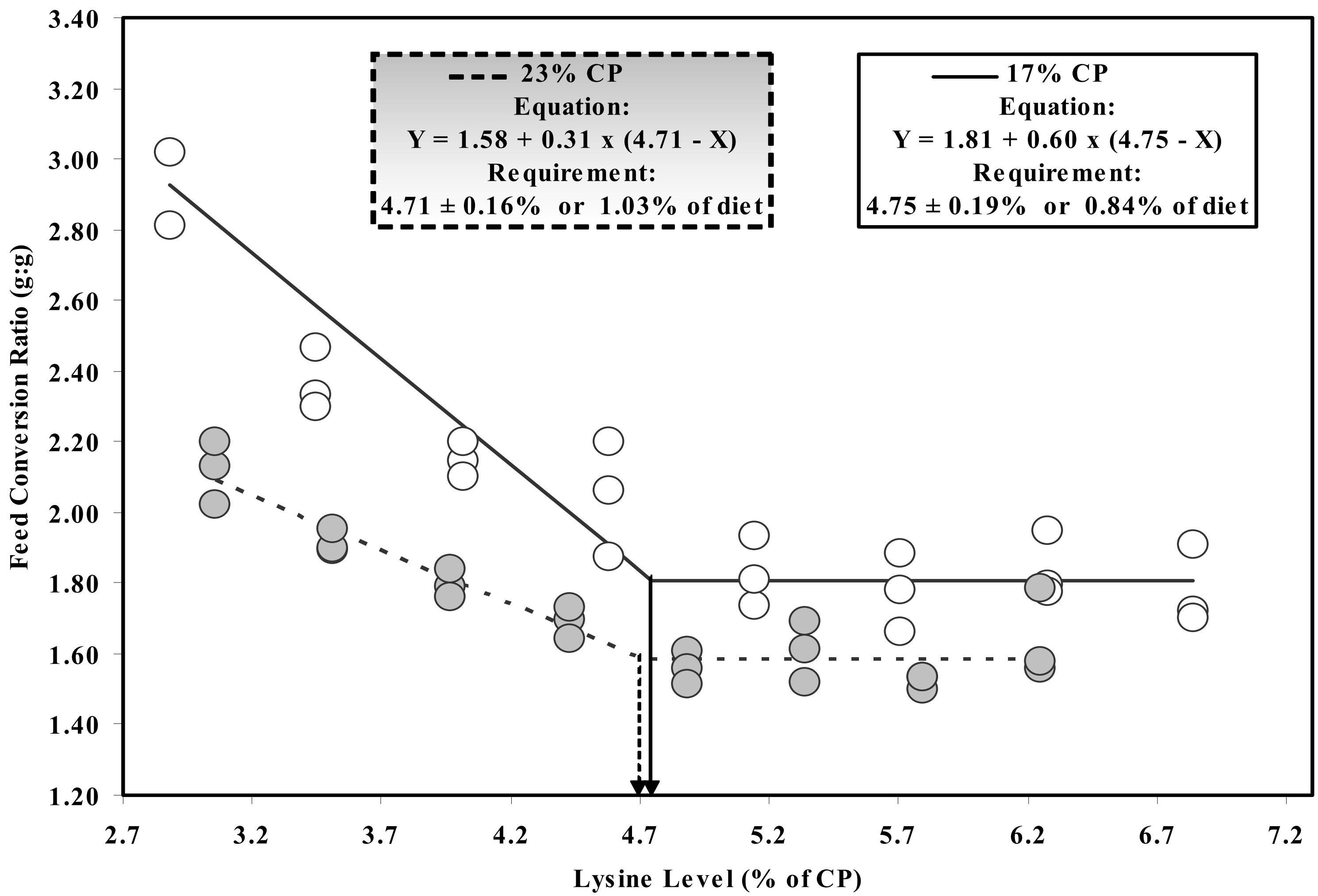

23% CP
Equation:
Y = 223.8 - 57.41 x (4.59 - X)
Requirement:
4.59 ± 0.17% or 1.01% of diet
17% CP
Equation:
Y = 197.8 - 43.15 x (5.17 - X)
Requirement:
5.17 ± 0.25% or 0.92% of diet
Body Weight Gain (g)
Lysine Level (% of CP)
300
280
260
240
220
200
180
160
140
120
100
80
2.4
2.9
3.4
3.9
4.4
4.9
5.4
5.9
6.4
6.9
7.4

FIGURE 4.6**.** Fitted broken-line plot of feed to gain as a function of dietary lysine level (% of CP), Experiment 3. Feed to gain data points are replications of six chicks during an 8 d feeding trial. The breakpoint occurred at 4.26 ± 0.15% and 4.71 ± 0.16% of the dietary CP for 17 and 23% CP, respectively, based on calculated values of lysine. $R^2 = 0.85$ and 0.88 for 17 and 23% CP, respectively. Results of a *t*-test reveal that the requirements were not significantly different between 17 and 23% CP ($P < 0.05$).



23% CP
Equation:
Y = 1.58 + 0.31 x (4.71 - X)
Requirement:
4.71 ± 0.16% or 1.03% of diet
17% CP
Equation:
Y = 1.81 + 0.60 x (4.75 - X)
Requirement:
4.75 ± 0.19% or 0.84% of diet
Feed Conversion Ratio (g:g)
3.40
3.20
3.00
2.80
2.60
2.40
2.20
2.00
1.80
1.60
1.40
1.20
2.7
3.2
3.7
4.2
4.7
5.2
5.7
6.2
6.7
7.2
Lysine Level (% of CP)

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CHAPTER 5

PERFORMANCE OF DIFFERENT BROILER GENOTYPES FED DIETS WITH VARYING LEVELS OF DIETARY CRUDE PROTEIN AND LYSINE[2]

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[1]Sterling, K. G., G. M. Pesti, and R. I. Bakalli. To be published in Poultry Science, 2003.

ABSTRACT

Two experiments were conducted to determine if a three-way interaction between genotype, dietary lysine and CP is an important influence on dietary responses. The genotypes were Ross 308 and Cobb x Cobb in Experiment 1 and Ross 508 and Arbor Acres in Experiment 2. The experimental designs were completely randomized with an incomplete 2 x 2 x 3 factorial arrangement of treatments. On d 7 of Experiment 1, four replicate pens of six chicks each were fed one combination of dietary lysine and CP (17% CP with 0.6, 0.7 and 0.8% lysine and 23% CP with 0.7, 0.8 and 0.9% lysine) until d 21. On d 17 of Experiment 2, four replicate pens of thirty-four chicks each were fed one combination of dietary lysine and CP (17% CP with 0.7, 0.8 and 0.9% lysine and 23% CP with 0.8, 0.9 and 1.0% lysine) until d 42. On d 43 of Experiment 2, three birds per pen were processed. Regression analysis showed differences ($P < 0.05$) due to genotype for BWG, feed intake and FCR in Experiment 1, and BWG, carcass yield, breast fillet and tender yields and abdominal fat pat percentage in Experiment 2. Increasing dietary CP decreased abdominal fat pad percentage in both Experiments however increasing dietary lysine only decreased this parameter in the starter-phase chicks. In both experiments Ross broilers had a larger response to supplemental lysine when 17% CP was fed, but a smaller response to supplemental lysine when 23% CP was fed for both BWG and FCR (three-way interaction). Three-way interactions between dietary CP and lysine levels and genotype were observed for BWG ($P < 0.01$), feed intake ($P < 0.01$) and FCR ($P < 0.02$) in Experiment 1 and for feed intake ($P < 0.06$) and FCR ($P < 0.03$) in Experiment 2. The three-way interactions demonstrate that quantitative differences exist

between genotypes in response to increasing dietary levels of CP and lysine.

INTRODUCTION

Researchers have realized the diverse production potentials offered by gender, genotype and genotype crosses and how nutrition, particularly nutrient levels, can influence those potentials. Genetic differences in growth rate, feed intake, and feed efficiency have been reported between genotypes (Washburn et al., 1975; Malone et al., 1979; Holsheimer and Veerkamp, 1992; MacLeod et al., 1998; Smith and Pesti, 1998; Smith et al., 1998). In addition, genetic differences have been observed for breast meat yield, abdominal fat pad percentage and other parts yields (Holsheimer and Veerkamp, 1992; Acar et al., 1991; Smith and Pesti, 1998; Smith et al., 1998). Genetic differences influence the response of chicks to varying dietary levels of CP (Smith et al., 1998) and subsequently the requirements of amino acids (Han and Baker, 1991, 1993; Pesti et al., 1994).

Leclercq (1998) stated that the required level of lysine is highest for minimizing abdominal fat pad percentage followed by minimizing feed conversion ratio (FCR), and maximizing breast meat yield and BWG. Therefore, the lysine requirement may change as the selection criteria of geneticists are focused on the different response criteria. In the last decade, the focus of breeding companies has been to select for improved FCR and higher meat yields. Determining nutrient requirements and different profit maximizing feeding programs for each genotype seems impossible and may result in redundancy. A simpler approach would be to first determine if differences in response exist between genotypes without determining a requirement. For example, Tesseraud et al. (1999)

measured the response of two experimental chick lines, a quality line selected to have higher breast meat yield and a control line, to four dietary lysine levels. Tesseraud et al. (1999) concluded that the dietary requirement of the quality line chicks could be lower because they were less sensitive to deficient levels of dietary lysine when compared to the control line.

Relationships between dietary lysine and genotype are known, as are relationships between dietary CP and genotype. Bilgili et al. (1992) found significant genotype cross by dietary lysine level interactions for BWG from 42 to 53 d of age. Holsheimer and Veerkamp (1992) and Praharaj et al. (2002) found a similar interaction for broiler chicks at 42 and 48 d for BWG and at 14 and 28 d for body weight, respectively. Acar et al. (1991) found significant genotype by lysine interactions for abdominal fat, breast fillets yield and tenders yield. Similarly, Smith and Pesti (1998) found significant genotype cross by protein level interactions for body and carcass weight. It has been well established that two-way interactions exist between genotype and dietary CP and lysine level. However, dietary CP level has been found to affect the lysine requirement (as a percentage of the diet) of chicks (Morris et al., 1987; Hurwitz et al., 1998; Sterling et al., 2002). The purpose of this study was to test the hypothesis that a three-way interaction in commercial broiler genotypes to increasing dietary lysine at two dietary crude protein levels could be important in determining dietary responses. In the first experiment, two high yield genotypes were compared during the starter phase (7 to 21 d). In the second experiment a high yield genotype was compared to a classic genotype during the grower phase (17 to 42 d).

MATERIALS AND METHODS

General Procedures

All chicks were fed a crumbled, broiler starter diet formulated according to NRC (1994) recommendations to contain 23% CP and 3,200 kcal/kg ME prior to being placed on the test diets. All chicks were vent-sexed, vaccinated in ovo with Marek's vaccine (HVT-1), and obtained at 0 d of age. On the first day of each test period, chicks were weighed and allotted to their respective treatments in a manner that ensured a similar weight and weight range between replicates by genotype. Chicks were progeny from parental stock similar in age and maintained under the same management conditions (feeding, vaccination programs, etc.) within each Experiment. The placement of chicks to treatments by genotype was random with equal representation of each treatment and genotype in each housing facility. In Experiment 1 chicks were neck-banded with color coded bands according to genotype and in Experiment 2 the head of each chick was marked with a permanent marker according to genotype for the correction of a cross-over between pens. In Experiment 1 neckbands remained throughout the trial and in Experiment 2 the mark disappeared by d 17 so that a visual identification between genotypes was no longer apparent and the genotypes could only be identified by their location.

The experimental design for both experiments was a completely randomized design with an incomplete factorial arrangement of treatments. The factorial included two genotypes, two dietary crude protein levels and three dietary levels of lysine per CP level.

Experiment 1

Ross 308 and Cobb x Cobb (n = 144 per genotype) male broiler chicks were reared in battery brooders and fed a commercial starter diet from 0 to 7 d of age. Average pen weight (means ± standard error) at d 7 was 844.2 ± 3.8 and 892.6 ± 10.3 g. for the Ross 308 and Cobb x Cobb chicks, respectively. On d 7, chicks were weighed, neck-banded and allotted to their respective treatments in a manner that ensured a similar weight and weight range between replicates (6 chicks per pen and 3 replications per treatment). Chicks were then placed on a mash diet (Table 5.1) representing one combination of dietary lysine and crude protein (17% CP with 0.6, 0.7, and 0.8% lysine and 23% CP with 0.8, 0.9, and 1.0% lysine). On d 21 chicks and residual feed were weighed and FCR calculated. In addition, 3 chicks per pen were weighed, sacrificed by asphyxiation with CO_2 and abdominal fat pads and livers were excised and weights recorded.

Experiment 2

Ross (Ross "high yield" 508 females x Ross "high yield" males) and Arbor Acres (Arbor Acres "classic" males x Arbor Acres "classic" females) male broiler chicks (n = 840 per genotype) were raised in floor pens (35 birds per pen) and fed the starter diet from 0 to 17 d of age. Average pen weight (means ± standard error) at d 7 was 20.4 ± 0.13 and 20.8 ± 0.11kg. for the Ross 508 and Arbor Acres chicks, respectively. On d 17, chicks were fed a pelleted diet (Table 5.1) representing one of the dietary levels of lysine and crude protein (17% CP with 0.7, 0.8, and 0.9% lysine and 23% CP with 0.8, 0.9, and 1.0% lysine). On d 42 chicks and residual feed were weighed and FCR calculated. On d

42, three randomly chosen chickens from each pen were wing banded and moved to separate floor pens for an overnight fast (approximately 12 hours); water was provided for ad libitum consumption. The following morning, chickens were randomly crated and transported to the processing room where each was weighed, killed by exsanguination, scalded, defeathered, and eviscerated. Abdominal fat pads and livers were collected from the birds after they were partially eviscerated by a mechanical eviscerator. Carcasses were weighed and chilled on ice in a walk-in freezer at 5 C overnight. The following day, pectoralis major (breast fillets) and minor (tenders) muscles (without skin), wings, and leg quarters (drum and saddle) were excised, and weights recorded. Percentage carcass yield, abdominal fat pad and liver were calculated based on live body weight. Percentage breast, tenders, wings, and leg quarters yields were calculated based on chilled carcass weight.

Statistical Methods

The experimental unit was the pen mean. Regression analyses were employed with models that included all linear and quadratic terms as well as any possible interactions. All analyses were conducted using the General Linear Models procedure of SAS (SAS Institute, 1998).

RESULTS AND DISCUSSION

All statistical analyses were based on calculated nutrient values. The analyzed nutrient values of dietary lysine and CP were in close agreement with calculated values (Table 5.1) computed from the nutrient composition tables in NRC (1994). Significant differences ($P < 0.05$) were observed due to genotype for most of the parameters measured (Table 5.2 and 5.4). Therefore, separate ANOVA analyses were performed (Table 5.3, 5.5, 5.6, 5.7, and 5.8) for each genotype.

Performance

In Experiment 1, the response of chicks to increasing dietary levels of CP and lysine revealed trends consistent with expectations. Regression analyses showed there was a significant difference due to genotype for BWG, feed intake and FCR (Table 5.2). Bilgili et al. (1992) and Tesseraud et al. (1999) found similar results between genotypes with 21 d broiler chicks. Acar et al. (1991) found differences between Ross x Ross and Peterson x Arbor Acres chicks at 21 d for body weight however initial chick weights were also significantly different. Increasing dietary CP and lysine levels significantly improved BWG and FCR for both genotypes (Table 5.3). Similar to Tesseraud et al. (1999) the responses in BWG and FCR to increasing dietary lysine were not quantitative. In the 17% CP diets, the differences between the genotypes decreased as dietary lysine increased. However, in the 23% CP diets, the differences between the genotypes increased as dietary lysine increased (Figure 5.1). There was a significant interaction between dietary CP and lysine for BWG and feed intake for the Ross 308 chicks. These chicks fed the 17 and 23% CP diet with 0.8% lysine had a similar BWG. However, feed intake and FCR of the chicks fed the 17% CP diet with 0.8% lysine was higher. Feed intake was significantly higher at the 17% CP level for both genotypes thus confirming the results of Smith and Pesti (1998), Smith et al. (1998) and Sterling et al. (2002). The Cobb x Cobb chicks had higher BWG and lower FCR at the lowest lysine levels (0.6 and 0.7%) when compared to the Ross 308 chicks. This may indicate that the Cobb x Cobb may require less lysine. Tesseraud et al. (1999) found higher BWG and lower FCR in a quality line of chick which are comparable here to the Cobb x Cobb chicks. Tesseraud et al. (1999) noted the quality line to be more efficient at utilizing lysine for protein deposition (Pectoralis *major*) and BWG at equal lysine intakes.

Overall, Cobb x Cobb broiler chicks gained more and consumed more feed and had a better FCR when compared to Ross 308 broiler chicks. These results are similar to the observations of Holsheimer and Veerkamp (1992) who found Ross broiler chicks to gain less and have a lower FCR when compared to Arbor Acres broiler chicks. Again, Ross 308 broiler chicks may require more lysine and may be more efficient at levels closer to their requirement. No significant interactions between dietary lysine and genotype were detected for BWG and feed intake (Table 5.2). Praharaj et al. (2002) found significant interactions between dietary lysine and genotype for BWG and feed intake but not FCR for broiler chicks from 0 to 14 d. Significant interactions for FCR were observed for all two-way combinations, except CP by lysine, of parameters indicating that FCR is very sensitive to changes in dietary CP and lysine levels and that the response is different for each genotype (Table 5.2). A significant three-way interaction between dietary CP, lysine levels and genotype for BWG, feed intake and FCR was observed. The three-way interaction indicates that the two genotypes responded differently to increasing dietary levels of CP and lysine (Figures 5.1 and 5.2). Cobb x Cobb broilers performed better than Ross 308 at the lowest lysine level when 17% CP was fed, but with the highest lysine level when 23% CP was fed.

In Experiment 2, BWG was not significantly influenced by dietary CP level for the Ross 508 or Arbor Acres broiler chicks (Table 5.4). As in Experiment 1, feed intake was significantly affected by dietary CP level in that the chicks fed 17% CP consumed more feed when compared to chicks fed 23% CP (Table 5.5). Increasing dietary lysine significantly increased BWG and improved FCR for the Ross 508 broiler chicks and increased BWG and feed intake and improved FCR for the Arbor Acres broiler chicks. In contrast, Praharaj et al. (2002) found no significant effect of dietary lysine level on 42 d body weight of broiler chicks. However, Praharaj et al. (2002) tested 4 different genotypes and it is possible that the variation between the genotypes studied was small and/or the dietary lysine levels fed were adequate for 42 d-old broilers. The latter is probably a more accurate assumption because significant genotype by lysine interactions were observed at 14 and 28 d for the same dietary lysine levels.

Overall, Arbor Acres chicks gained more and consumed more feed and had a better FCR when compared to the Ross 508 chicks (Table 5.5). The better FCR observed with the Arbor Acres chicks either indicates their ability to better utilize lysine deficient diets or indicates a lower lysine requirement under similar conditions. FCR has been shown to decrease as dietary lysine increases up to the minimum level required for optimum performance (Sterling et al., 2002). In Experiment 2, FCR decreased as dietary lysine increased and there is no evidence that the minimum required dietary lysine level had been reached. Therefore the NRC recommendation of 1.0% for broiler chicks between 3 and 6 weeks of age may be too low. This is probably not true for all genotypes. For example, Acar et al. (1991) found no additional response to supplemental lysine above 0.75% for body weight and FCR in 42 to 56 d-old Ross x Ross and Peterson x Arbor Acres broiler chicks. In contrast, Bilgili et al. (1992) tested two (0.85 and 0.95%) dietary lysine levels and unlike the studies of Acar et al. (1991) and Praharaj et al. (2002) these levels of lysine gave a response in 53 d-old broilers.

The results of Experiments 1 and 2 explain apparent differences observed by Praharaj (2002) and Bilgili et al. (1992). Although Bilgili et al. (1992) observed differences in the responses of different genotypes to dietary lysine level, Praharaj et al. (2002) could detect none. Results of Experiments 1 and 2 make it clear that protein level will affect the responses of different genotypes to dietary lysine differently. It would be wrong to infer from Table 5.2 that Experiment 1 confirms the conclusion of Praharaj et al. (2002) that there is no lysine by genotype interaction for BWG because the significant probability is 0.7094. The significant three-way interaction (CP x Lysine x genotype P = 0.0058) substantiates that the lysine x genotype interaction is indeed real.

Dietary CP and Carcass Parameters

In Experiment 2, the response of chicks to increasing dietary levels of CP and lysine revealed trends consistent with expectations. Regression analyses showed there was a significant difference due to genotype for BWG, feed intake, carcass weight and yield, abdominal fat pad weight and percentage, breast fillet yield and breast tender yield (Table 5.4). No differences were noted for carcass weight and the various parts weights due to dietary CP level (Table 5.6). Similar to some genotypes but not others used by Smith et al. (1998) and Sterling et al. (2002), dietary CP level had no significant effects on carcass yield.

In contrast to Smith and Pesti (1998) and Sterling et al. (2002) no significant effect of dietary CP on breast yield was observed. When Smith and Pesti (1998) and Sterling et al. (2002) changed CP levels amino acid minimum restrictions were kept constant as a % of dietary CP. Therefore, both dietary CP and lysine levels were increased simultaneously. The results of Experiments 1 and 2 suggest that the carcass yield responses they observed were probably due to increasing lysine level and not dietary CP level per se (although other amino acids may have been involved). Carcass fat changes were probably due to protein per se, but small changes in abdominal fat (waste) are not necessarily measurable as obligatory changes in carcass yield. In agreement with Sterling et al. (2002) dietary CP did not influence leg quarter weights or yields. However, in the present study different genotypes were used and chicks were fed diets deficient in dietary lysine.

Dietary CP level significantly affected abdominal fat pad and abdominal fat pad percentage for both genotypes of broiler chicks (Table 5.4 and 5.8). Abdominal fat pad weights and percentage were higher for chicks fed the lower CP diets. These findings are consistent with those of Smith and Pesti (1998), Smith et al. (1998) and Sterling et al. (2002). Overall, Arbor Acres broilers had higher abdominal fat pad weights when compared to the Ross 508 broilers, however abdominal fat pad percentages (% of live body weight) were similar and were not reflected in a lowered carcass yield for the Arbor Acres broilers.

Dietary Lysine and Carcass Parameters

Dietary lysine level significantly affected most of the carcass parameters by increasing the weight of each as dietary lysine levels increased in the diets (Tables 5.5 and 5.6 to 5.8) with exception to leg quarter weights and yields that decreased as dietary lysine increased for both genotypes. Dietary lysine level did not significantly affect liver or abdominal fat pad percentage (Table 5.9). In contrast, Acar et al. (1991) found no differences in chilled carcass percentage, carcass without abdominal fat percentage, wings, drumsticks, thigh meat, and cage percentages due to increasing dietary lysine in broiler chicks from 42 to 56 d. Acar et al. (1991) stated that the lack of response in live performance to dietary lysine was not apparent at the levels above 0.75% of the diet, a level lower than NRC (1994) recommendations. Bilgili et al. (1992) found differences due to genotype and dietary lysine level for total breast weight, thigh yield and carcass yield at 53 d.

SUMMARY

Dietary CP appeared to be less important for broilers during the grower phase when compared to starter phase chicks. Cobb x Cobb chicks were more efficient at converting food to BWG when compared to the Ross 308 chicks and may indicate a lower need for lysine and/or dietary CP. Arbor Acres broiler chicks were heavier for all dietary lysine and CP levels however, Ross 508 broiler chicks had higher breast yields. In addition, Arbor Acres broilers were more efficient indicating a need for lower levels of dietary lysine and/or CP. The levels of dietary lysine fed during the grower phase were higher than NRC (1994) however, performance continued to improve. In these studies, the responses of the four genotypes to increasing dietary lysine and CP were quantitatively different.

TABLE 5.1. Composition of Experimental Diets

	Experiment 1		Experiment 2	
	Crude Protein Level (%)			
	17	23	17	23
Ingredients	(%)			
Ground yellow corn	75.81	62.56	72.73	62.30
Soybean meal 48% (dehulled)	10.55	16.51	15.63	16.52
Corn Gluten Meal	8.06	14.87	4.81	14.90
Poultry fat (stabilized)	1.21	1.75	2.45	1.84
Dicalcium Phosphate	2.05	1.98	2.04	1.98
Common salt	0.46	0.46	0.46	0.46
Vitamin Premix[1]	0.25	0.25	0.25	0.25
Limestone	1.36	1.37	1.34	1.37
Mineral Premix[2]	0.08	0.08	0.08	0.08
Coccidiostat[3]	. . . .	. . . .	0.08	0.08
Bacitracin BMD-60[4]	. . . .	. . . .	0.05	0.05
Choline Cl-70%	0.05	0.03	0.03	0.03
L-Lysine HCl	. . . .	. . . .	. . . .	. . . .
L-Threonine	. . . .	. . . .	. . . .	. . . .
L-Arginine HCl	0.10	0.13	0.01	0.13
L-Tryptophan	. . . .	. . . .	. . . .	0.01
DL-Methionine	0.02	0.02	0.05	0.02
Calculated composition[5]				
ME, kcal/g	3.2	3.2	3.2	3.2
Lysine	0.60	0.80	0.70	0.80
TSAA	0.67	0.90	0.67	0.90
Threonine	0.59	0.80	0.60	0.80
Analyzed composition[6]				
Crude Protein	17.1	23.2	16.9	22.4
Lysine	0.61	0.79	0.70	0.79
TSAA	0.75	0.97	0.64	0.87
Threonine	0.64	0.77	0.60	0.78

[1]Vitamin premix provides the following per kilogram of diet: vitamin A, 5,500 IU from all trans-retinyl acetate; cholecalciferol, 1,100 IU; vitamin E, 11 IU from all-rac-α-tocopherol acetate; riboflavin, 4.4 mg; Ca pantothenate, 12 mg; nicotinic acid, 44 mg; choline Cl, 220 mg; vitamin B_{12}, 6.6 g; vitamin B_6, 2.2 mg; menadione, 1.1 mg (as MSBC); folic acid, 0.55 mg; d-biotin, 0.11 mg; thiamine, 1.1 mg (as thiamine mononitrate); ethoxyquin, 125 mg.

[2]Trace mineral premix provides the following in milligrams per kilogram of diet: Mn, 60; Zn, 50; Fe, 30; Cu, 5; I, 1.5.

[3]Aviax, Phibro Animal Health, Fairfield, NJ.

TABLE 5.1. Continued.

[4]Alpharma, Fort Lee, NJ.

[5]Based on NRC (1994) feed composition tables.

[6]Degussa-Huls Corporation, Allendale, NJ.

TABLE 5.2. Analysis of variance summary of the effect of protein level, lysine level, and genotype on chick performance, Experiment 1

Regression	df	BWG	Feed Intake	FCR	Abdominal fat pad weight	Abdominal fat pad percentage
		---------------- Significant probabilities -----------------				
CP	1	***0.0001***	***0.0153***	***0.0001***	***0.0281***	***0.0001***
Lysine	1	***0.0001***	***0.0001***	***0.0001***	0.1623	***0.0357***
Lysine x Lysine	1	0.5012	0.4345	***0.0001***	0.4124	0.3569
Genotype	1	***0.0001***	***0.0031***	***0.0001***	***0.0261***	0.6376
CP x Lysine	1	0.9262	0.6207	0.8464	0.5793	0.2163
CP x Genotype	1	0.6687	0.3451	***0.0006***	0.7286	0.5623
Lysine x Genotype	1	0.7094	0.8446	***0.0043***	0.4731	0.6377
CP x Lysine x Genotype	1	***0.0058***	***0.0099***	***0.0154***	0.7899	0.1384
Error	47					
Coefficient of determination		0.8851	0.6362	0.9543	0.2683	0.5706

TABLE 5.3. The influence of protein and lysine level on the BWG, feed intake, and feed conversion ratio (FCR) of Ross 308 and Cobb x Cobb male broiler chicks 7 to 21 d, Experiment 1[1]

CP Level	Lysine Level	Ross 308 BWG	Ross 308 Feed Intake	Ross 308 FCR	Cobb x Cobb BWG	Cobb x Cobb Feed Intake	Cobb x Cobb FCR
---------- (%) ----------		(kg)		(g:g)	(kg)		(g:g)
17%	0.6	140.7 ± 7.0	350.1 ± 18.2	2.49 ± 0.04	177.2 ± 9.7	387.1 ± 18.0	2.19 ± 0.02
	0.7	184.4 ± 8.2	381.6 ± 10.4	2.07 ± 0.04	219.4 ± 8.3	420.5 ± 9.9	1.92 ± 0.03
	0.8	242.9 ± 10.1	454.7 ± 18.1	1.87 ± 0.01	238.0 ± 5.3	433.1 ± 5.5	1.82 ± 0.02
23%	0.7	214.8 ± 7.8	397.1 ± 19.0	1.85 ± 0.03	223.1 ± 14.6	394.3 ± 16.3	1.77 ± 0.05
	0.8	240.7 ± 8.1	400.2 ± 12.3	1.67 ± 0.03	272.0 ± 4.6	456.7 ± 8.8	1.68 ± 0.03
	0.9	272.3 ± 3.9	428.2 ± 8.2	1.57 ± 0.02	312.6 ± 14.0	476.1 ± 15.8	1.52 ± 0.03
ANOVA	df	-- Probabilities --					
CP	1	0.0863	0.2086	0.0001	0.0811	0.9211	0.0002
Lysine	3	0.0001	0.0017	0.0001	0.0001	0.0014	0.0001
CP x Lysine	1	0.0493	0.0311	0.7443	0.1537	0.0745	0.967
Error	23						

[1]Means ± standard errors of four pens (six birds each at 7 d) per treatment.

TABLE 5.4. Analysis of variance summary of the effect of protein level, lysine level, and genotype on chick performance, Experiment 2

Regression	df	BWG	Feed Intake	FCR	Carcass weight	Carcass yield	Abdominal fat pad weight	Abdominal fat pad percentage	Breast fillet yield	Breast tender yield
		Signficant probabilites								
CP	1	0.1566	***0.0002***	***0.0032***	0.5623	0.5310	***0.0001***	***0.0001***	0.6464	***0.0271***
Lysine	1	***0.0001***	***0.0001***	***0.0001***	***0.0001***	***0.0001***	***0.0151***	0.6602	***0.0001***	***0.0001***
Lysine x Lysine	1	0.8554	0.5720	0.6139	0.5155	0.2535	0.5859	0.1156	0.4529	0.5998
Genotype	1	***0.0009***	***0.0321***	0.0534	***0.0011***	***0.0005***	***0.0002***	***0.0072***	***0.0001***	***0.0001***
CP x Lysine	1	0.1702	***0.0177***	0.8517	***0.0183***	0.3428	0.8392	0.4096	0.6091	0.5249
CP x Genotype	1	0.4854	0.8230	0.9255	0.9938	0.2278	0.1481	0.2034	0.0960	0.4269
Lysine x Genotype	1	0.9050	0.0899	0.1144	0.4230	0.4842	0.6476	0.4614	0.8554	0.3167
CP x Lysine x Genotype	1	0.1686	0.0579	***0.0247***	0.4617	0.5507	0.1502	0.1275	0.2707	0.8907
Error	47									
Coefficient of determination		0.6876	0.5872	0.5188	0.4291	0.3188	0.3036	0.3499	0.6013	0.4742

TABLE 5.5. The influence of protein and lysine level on the BWG, feed intake, and feed conversion ratio (FCR) of Ross 508 and Arbor Acres male broiler chicks 17 to 42 d, Experiment 2[1]

		Ross 508			Arbor Acres		
CP Level	Lysine Level	BWG	Feed Intake	FCR	BWG	Feed Intake	FCR
---------- (%) ----------		(kg)		(g:g)	(kg)		(g:g)
Starter		0.557 ± 0.004	0.734	1.32 ± 0.01	0.570 ± 0.003	0.756 ± 0.004	1.32 ± 0.01
17%	0.7	1.27 ± 0.11	3.52 ± 0.10	2.85 ± 0.30	1.52 ± 0.02	3.32 ± 0.01	2.18 ± 0.03
	0.8	1.58 ± 0.12	3.60 ± 0.09	2.33 ± 0.23	1.70 ± 0.09	3.89 ± 0.08	2.32 ± 0.16
	0.9	1.83 ± 0.01	3.52 ± 0.03	1.93 ± 0.02	1.90 ± 0.10	3.91 ± 0.12	2.08 ± 0.13
23%	0.8	1.35 ± 0.13	3.02 ± 0.26	2.25 ± 0.03	1.44 ± 0.09	3.19 ± 0.13	2.24 ± 0.17
	0.9	1.64 ± 0.11	3.43 ± 0.07	2.12 ± 0.14	1.94 ± 0.04	3.50 ± 0.08	1.80 ± 0.01
	1	1.81 ± 0.05	3.45 ± 0.05	1.92 ± 0.07	2.06 ± 0.09	3.59 ± 0.13	1.76 ± 0.13
ANOVA	df	-- Probabilities --					
CP	1	0.6512	0.0243	0.0641	0.098	0.0039	0.0181
Lysine	3	0.0007	0.2836	0.0078	0.0001	0.0007	0.0316
Lysine x CP	1	0.8265	0.0663	0.4324	0.0634	0.1688	0.4328
Error	23						

[1]Means ± standard errors of four pens (34 birds each at 17 d) per treatment.

TABLE 5. 6. Influence of protein and lysine level on carcass parameters of Ross 508 and Arbor Acres male broiler chicks 17 to 42 d, Experiment 2[1]

CP Level	Lysine Level	Ross 508 Live weight	Ross 508 Breast fillets	Ross 508 Breast tenders	Ross 508 Leg quarters	Ross 508 Wings	Arbor Acres Live weight	Arbor Acres Breast fillets	Arbor Acres Breast tenders	Arbor Acres Leg quarters	Arbor Acres Wings
	(%)	(kg)	(g)								
17%	0.7	2.06 ± 0.09	233.3 ± 12.2	62.7 ± 1.8	490.5 ± 24.9	175.1 ± 7.3	2.17 ± 0.10	203.7 ± 18.6	53.4 ± 3.8	532.6 ± 20.3	187.2 ± 5.6
	0.8	2.25 ± 0.11	284.5 ± 20.7	73.2 ± 5.1	531.4 ± 24.2	191.4 ± 11.4	2.61 ± 0.07	291.9 ± 12.2	78.1 ± 5.3	613.0 ± 13.3	221.4 ± 5.9
	0.9	2.46 ± 0.04	350.5 ± 8.1	88.8 ± 2.4	569.3 ± 10.9	208.5 ± 6.5	2.60 ± 0.10	298.3 ± 12.5	79.9 ± 3.1	590.7 ± 17.3	226.2 ± 7.0
23%	0.8	1.97 ± 0.13	222.5 ± 21.8	60.2 ± 4.9	460.9 ± 34.6	167.8 ± 8.8	2.27 ± 0.10	214.7 ± 10.7	59.3 ± 2.9	550.0 ± 20.1	199.2 ± 6.1
	0.9	2.42 ± 0.08	290.0 ± 6.9	79.9 ± 3.5	572.7 ± 26.0	208.6 ± 5.1	2.54 ± 0.07	283.6 ± 11.9	76.5 ± 2.3	607.3 ± 19.4	221.0 ± 4.4
	1	2.51 ± 0.11	346.0 ± 25.2	94.1 ± 3.7	580.3 ± 26.2	212.5 ± 9.7	2.64 ± 0.05	319.5 ± 11.0	90.2 ± 4.4	618.9 ± 15.6	234.0 ± 2.8
ANOVA	df	Probabilites									
CP (A)	1	0.5914	0.8202	0.3155	0.7213	0.5094	0.7192	0.4665	0.1361	0.3744	0.1646
Lysine (B)	3	0.0011	0.0001	0.0001	0.0074	0.0015	0.0001	0.0001	0.0001	0.0127	0.0001
A*B	1	0.2226	0.9681	0.5991	0.1645	0.1738	0.1204	0.0283	0.0567	0.0385	0.1382
Error	23										

[1]Means ± standard errors of four replicates per treatment (3 birds each pen).

TABLE 5.7. The influence of protein and lysine level on carcass yield parameters of Ross 508 male broiler chicks 17 to 42 d, Experiment 2[1]

CP Level	Lysine Level	Carcass weight	Carcass yield	Breast Fillets	Breast tenders	Leg quarters	Wings
		Ross 508					
	(%)	(kg)	(% of LWT)	(% of carcass weight)			
17%	0.7	1.47 ± 0.07	71.5 ± 0.33	15.8 ± 0.29	4.3 ± 0.08	33.4 ± 0.45	11.9 ± 0.10
	0.8	1.65 ± 0.09	73.1 ± 0.53	17.2 ± 0.36	4.4 ± 0.10	32.4 ± 0.38	11.6 ± 0.26
	0.9	1.82 ± 0.03	74.1 ± 0.38	19.2 ± 0.27	4.9 ± 0.09	31.3 ± 0.21	11.5 ± 0.32
23%	0.8	1.40 ± 0.11	71.0 ± 0.67	15.8 ± 0.30	4.3 ± 0.06	33.0 ± 0.50	12.0 ± 0.29
	0.9	1.74 ± 0.06	71.6 ± 0.52	16.7 ± 0.43	4.6 ± 0.09	33.0 ± 0.50	12.0 ± 0.14
	1	1.86 ± 0.08	74.3 ± 0.55	18.4 ± 0.60	5.0 ± 0.12	31.4 ± 1.32	11.4 ± 0.31
ANOVA	df	Probabilites					
CP (A)	1	0.7613	0.1722	0.1472	0.175	0.8251	0.4051
Lysine (B)	3	0.0001	0.0001	0.0001	0.0001	0.0732	0.1719
A*B	1	0.3168	0.6737	0.1811	0.4699	0.3989	0.7472
Error	23						

[1]Means ± standard errors of four replicates per treatment (three chicks each pen).

TABLE 5.8. The influence of protein and lysine level on carcass yield parameters of Arbor Acres male broiler chicks 17 to 42 d, Experiment 2[1]

		Arbor Acres					
CP Level	Lysine Level	Carcass weight	Carcass yield	Breast Fillets	Breast tenders	Leg quarters	Wings
	(%)	(kg)	(% of LWT)	(% of carcass weight)			
17%	0.7	1.52 ± 0.07	70.2 ± 0.72	13.3 ± 0.71	3.5 ± 0.11	35.1 ± 0.79	12.4 ± 0.33
	0.8	1.88 ± 0.05	72.1 ± 0.27	15.5 ± 0.44	4.1 ± 0.21	32.7 ± 0.33	11.8 ± 0.13
	0.9	1.87 ± 0.07	71.8 ± 0.70	16.0 ± 0.21	4.3 ± 0.03	31.7 ± 0.71	12.1 ± 0.44
23%	0.8	1.59 ± 0.07	69.9 ± 0.52	13.5 ± 0.17	3.7 ± 0.12	34.6 ± 0.28	12.6 ± 0.22
	0.9	1.81 ± 0.05	71.6 ± 0.28	15.6 ± 0.35	4.2 ± 0.12	33.5 ± 0.17	12.2 ± 0.08
	1	1.93 ± 0.04	73.1 ± 0.46	16.5 ± 0.27	4.7 ± 0.15	32.2 ± 0.66	12.1 ± 0.12
ANOVA	df	Probabilities					
CP (A)	1	0.6872	0.6676	0.4099	0.0539	0.4865	0.3295
Lysine (B)	3	0.0001	0.002	0.0001	0.0001	0.0001	0.5035
A*B	1	0.062	0.0824	0.0529	0.185	0.9112	0.171
Error	23						

[1]Means ± standard errors of four replicates per treatment (three chicks each pen).

TABLE 5.9. The influence of protein and lysine level on abdominal fat pad and liver weights of Ross 508 and Arbor Acres male broiler chicks 17 to 42 d, Experiment 2[1]

		Ross 508					Arbor Acres				
CP Level	Lysine Level	Live weight	Liver weight	Abdominal fat pad	Liver	Abdominal fat pad	Live weight	Liver weight	Abdominal fat pad	Liver	Abdominal fat pad
	(%)	(kg)	(g)		(% of live weight)		(kg)	(g)		(% of live weight)	
17%	0.7	2.06 ± 0.09	33.6 ± 2.0	55.9 ± 3.6	1.6 ± 0.04	2.7 ± 0.14	2.17 ± 0.10	35.1 ± 1.8	64.1 ± 8.4	1.6 ± 0.07	2.9 ± 0.29
	0.8	2.25 ± 0.11	37.0 ± 1.8	55.1 ± 3.2	1.6 ± 0.01	2.4 ± 0.05	2.61 ± 0.07	42.5 ± 1.5	71.7 ± 6.9	1.6 ± 0.05	2.7 ± 0.19
	0.9	2.46 ± 0.04	39.6 ± 1.1	56.6 ± 2.6	1.6 ± 0.04	2.3 ± 0.07	2.60 ± 0.10	43.5 ± 2.9	78.4 ± 2.2	1.7 ± 0.10	3.0 ± 0.04
23%	0.8	1.97 ± 0.13	32.8 ± 3.4	37.4 ± 5.5	1.7 ± 0.06	1.9 ± 0.17	2.27 ± 0.10	37.1 ± 1.7	47.9 ± 5.7	1.6 ± 0.05	2.1 ± 0.19
	0.9	2.42 ± 0.08	41.7 ± 3.5	41.7 ± 2.5	1.7 ± 0.12	1.7 ± 0.14	2.54 ± 0.07	40.9 ± 2.2	48.9 ± 3.6	1.6 ± 0.05	1.9 ± 0.11
	1	2.51 ± 0.11	39.5 ± 1.2	51.0 ± 5.8	1.6 ± 0.06	2.0 ± 0.19	2.64 ± 0.05	44.1 ± 1.3	54.5 ± 11.6	1.7 ± 0.06	2.0 ± 0.41
ANOVA	df	---------- Probabilites ----------									
CP (A)	1	0.5914	0.5137	0.0015	0.6163	0.0001	0.7192	0.8310	0.0020	0.9454	0.0003
Lysine (B)	3	0.0011	0.0544	0.1621	0.6034	0.0960	0.0006	0.0068	0.5181	0.8902	0.9921
A*B	1	0.2226	0.2031	0.7307	0.4840	0.8686	0.1204	0.5050	0.6902	0.6981	0.3592
Error	23										

[1]Means ± standard errors of four replicates per treatment (three chicks each pen).

FIGURE 5.1. Three-way interaction between the effects of dietary CP and lysine levels and broiler genotype on 7 to 21 d body weight gain (BWG), Experiment 1. ○ Cobb x Cobb 17% CP; ● Cobb x Cobb 23% CP; □ Ross 308 17% CP; ■ Ross 308 23% CP.

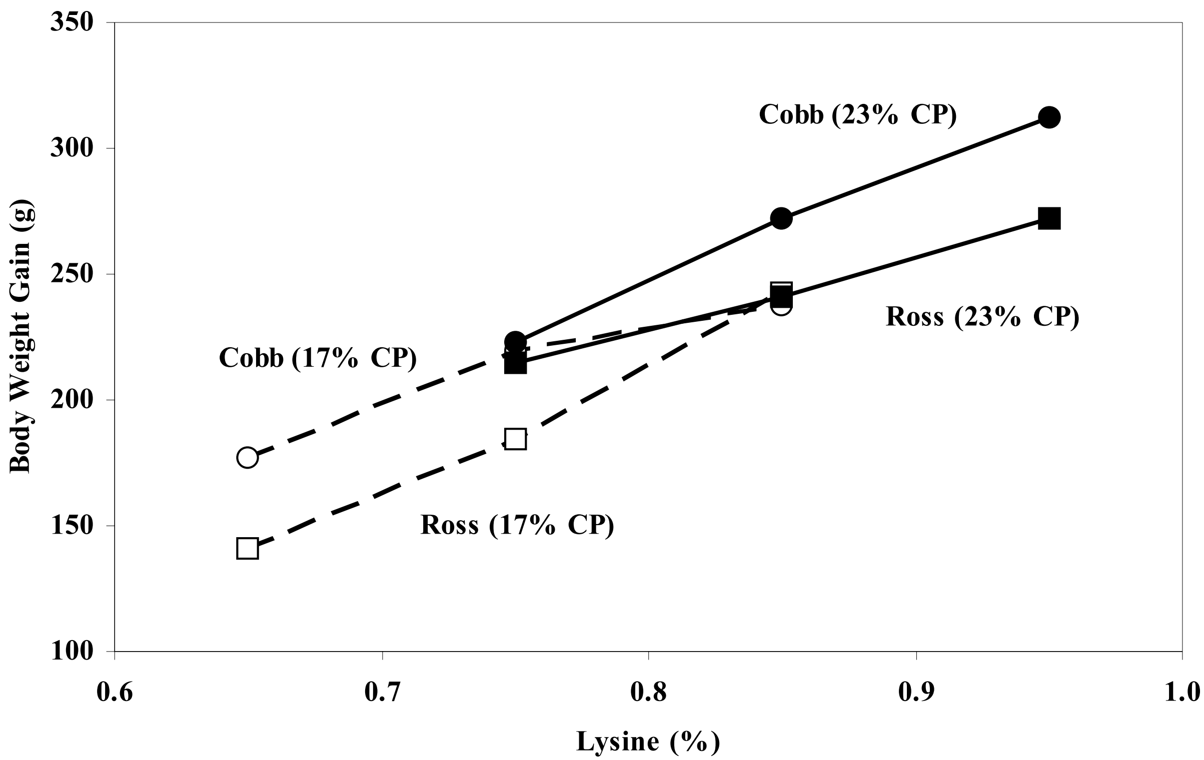


FIGURE 5.2. Three-way interaction between the effects of dietary CP and lysine levels and broiler genotype on 7 to 21 d feed conversion ratio (FCR), Experiment 1. ○ Cobb x Cobb 17% CP; ● Cobb x Cobb 23% CP; □ Ross 308 17% CP; ■ Ross 308 23% CP.

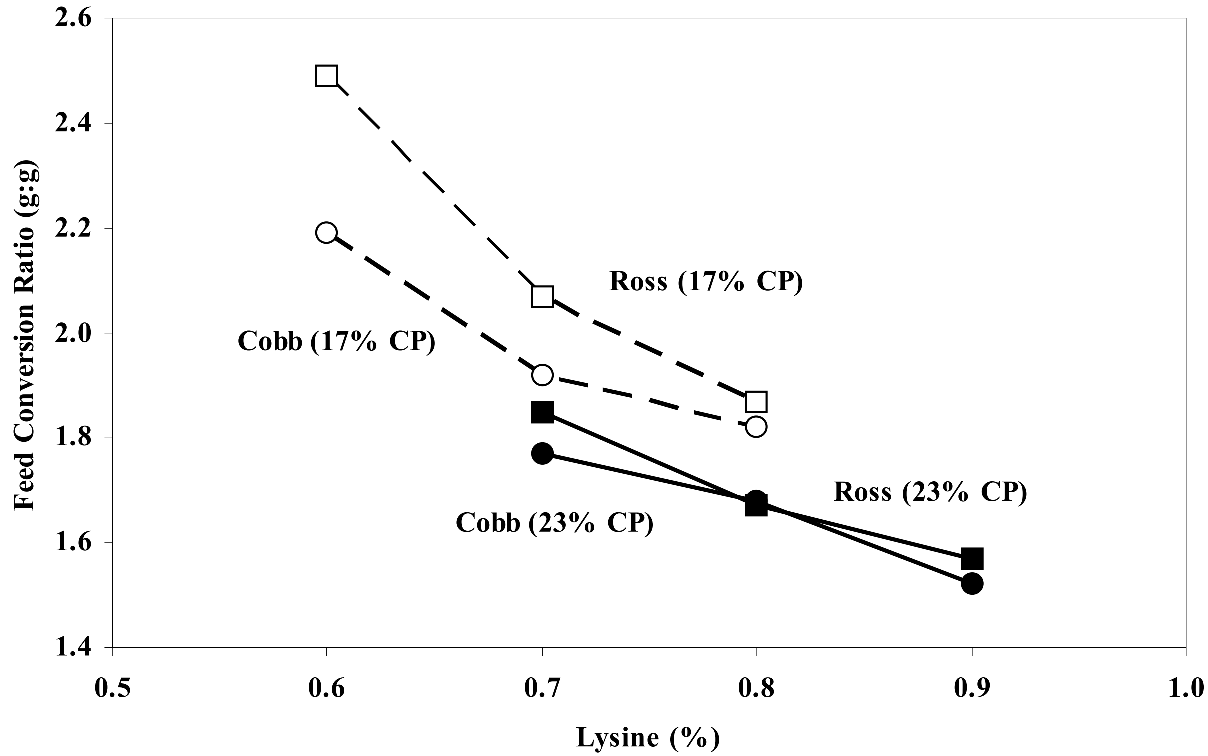


FIGURE 5.3. Three-way interaction between the effects of dietary CP and lysine levels and broiler genotype on 7 to 21 d body weight gain (BWG), Experiment 2. ○ Ross 508 17% CP; ● Ross 508 23% CP; □ Arbor Acres 17% CP; ■ Arbor Acres 23% CP.

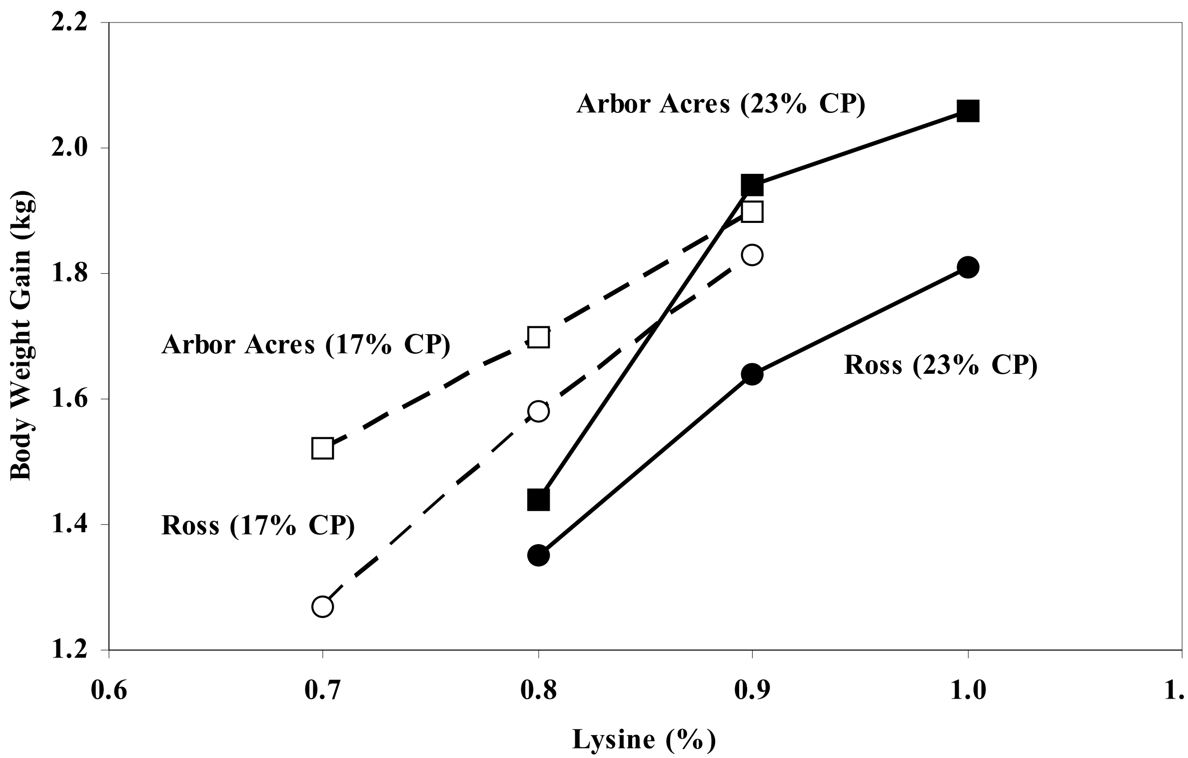
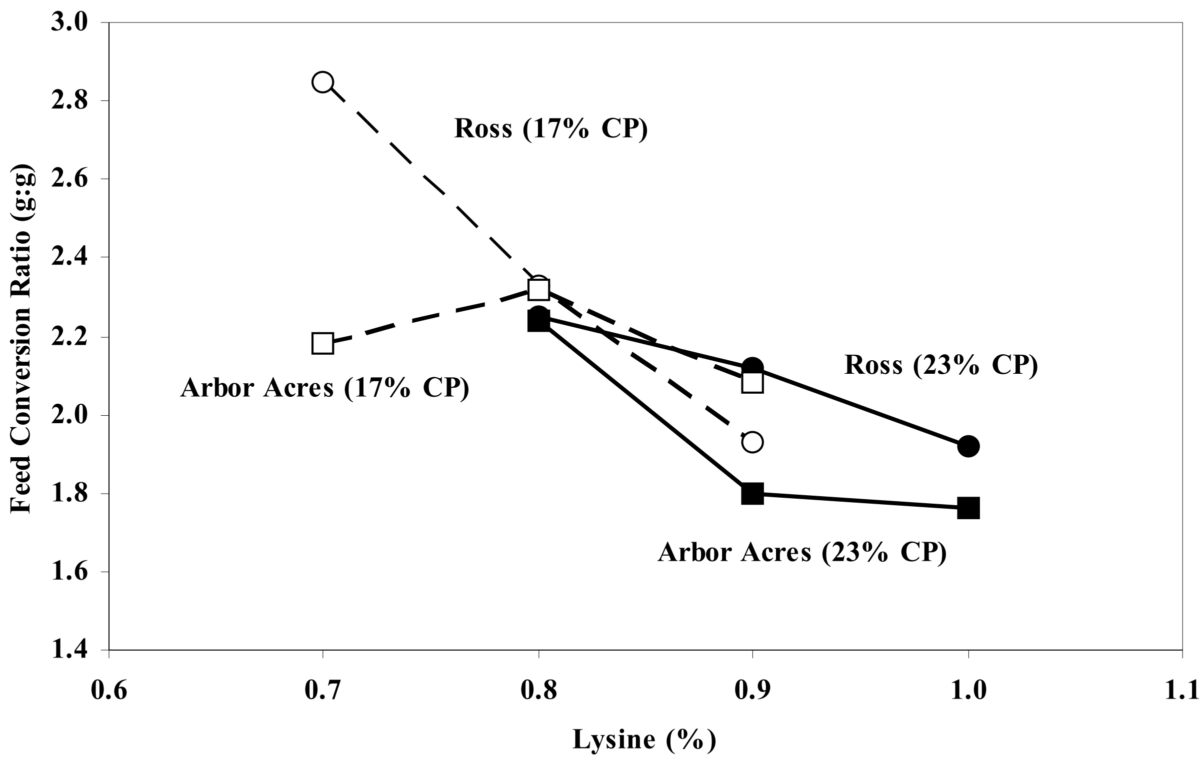


FIGURE 5.4. Three-way interaction between the effects of dietary CP and lysine levels and broiler genotype on 7 to 21 d feed conversion ratio (FCR), Experiment 2. ○ Ross 508 17% CP; ● Ross 508 23% CP; □ Arbor Acres 17% CP; ■ Arbor Acres 23% CP.



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CHAPTER 6

ECONOMICALLY OPTIMAL DIETARY CRUDE PROTEIN AND LYSINE LEVELS FOR STARTING BROILER CHICKS[3]

[1]Sterling, K. G., D. Vendenov, G. M. Pesti, and R. I. Bakalli. To be published in Poultry Science, 2003.

ABSTRACT

An experiment was conducted to quantitate the growth response of broiler chicks to cumulative dietary lysine and crude protein intakes. Data were analyzed for linear, quadratic and interaction response terms to determine if diminishing marginal returns of dietary lysine and crude protein could be identified. The experiment was a completely randomized design with an incomplete 4 x 4 factorial arrangement of treatments with three replicate pens of six chicks each. On d 7 chicks were fed one combination of dietary lysine and CP (17, 20, 23 and 26% CP and 3.5, 4.0, 4.5, and 5.0 g lysine per 100 g CP) in a diet containing 3,200 kcal/kg ME, until 17 d. There were significant linear and quadratic effects of dietary CP intake and quadratic effects of dietary lysine intake on BWG confirming that a diminishing response existed (R^2 = 0.92 and 0.95, respectively). A significant interaction between dietary CP and lysine (both % of diet and grams of intake bases) for BWG complicates economic modeling since responses must be considered together.

A quadratic growth response equation describing BWG as a function of dietary lysine and CP intake was used to develop and demonstrate a quadratic programming model. This model was used to formulate a starter broiler diet that gives the optimal dietary lysine and CP levels required to maximize the difference between returns from BWG and feed costs. The model also included linear constraints to select ingredients needed to meet fixed nutrient specifications such as the dietary energy, vitamin and mineral levels, and the calcium to phosphorus ratio.

As the price of SBM increased, from 50 to 300% of reference, the level of CP to

maximize profits varied from 24.5 to 18.2% and lysine from 1.35 to 0.92%. In general, increasing the price of SBM decreased the dietary CP levels that gave maximum BWG and the level of dietary lysine decreased proportionally. In SBM-based diets, the level of dietary lysine that maximized BWG was less than or equal to the level reached by the proportions of corn and SBM needed to meet dietary CP constraints. That is, a typical corn and SBM starter diet provided dietary lysine levels that either met or exceeded the requirement. In CGM-SBM-based diets, substitutions between SBM and CGM were made to meet the most profitable dietary CP level as dietary lysine from SBM increases as the price of CGM increased. However, only when the price of L-lysine-HCl decreased to 50% of reference prices, did L-lysine-HCl incorporation in the solution became profitable. Increasing the price of CGM did not decrease the dietary CP level that maximized returns, however, dietary lysine usage increased. Savings from using maximum-profit versus least-cost formulation models could approach $637,000 per year for a single poultry complex under some economic situations for the starter diet alone.

INTRODUCTION

The concept of feeding economically optimal levels of nutrients based on diminishing returns functions is not new, but still has been rarely used in nutrition (Almquist, 1953). Almquist (1953) used log-linear diminishing returns models to describe two-dimensional input-output relationships. Several other non-linear models have been developed to describe diminishing returns functions of nutrient inputs (Pilbrow and Morris 1974; Morgan et al., 1975; Lerman and Bie, 1975; Robbins et al., 1979). Pesti et al. (1986) used a quadratic polynomial to describe a response model with feed consumption and body wight gain as functions of two inputs (CP and ME). They observed quadratic growth responses to dietary energy and crude protein (CP) indicating diminishing marginal productivity.

This relationship is an example of nutrient substitution. That is, similar body weights can be achieved with varying combinations of dietary energy and CP. The relationship between dietary lysine and CP levels not unlike other substitution examples in nutrition such as phytin phosphorus and phytase, methionine, cystine, choline and betaine, phenylalanine and tryosine, and tryptophan and niacin. Of course, the substitution between lysine and CP is only valid povided another amino acid or nutrient becomes doesn't become limiting. It is clear from the studies of Morris et al. (1987) and Surisdiarto and Farrell (1991) that the level of lysine can be increased in a low % CP diet to produce similar results to increasing dietary CP in a low lysine diet. For example, a similar weight gain (16.2 vs. 15.9 g/d, respectively) can be achieved at 18 and 26% CP with dietary lysine levels of 50 and 40 g/kg of dietary CP, respectively (Morris et al., 1987). Similarly, Fisher et al. (1960) found an 11% CP diet with 4% lysine and an amino acid mixture produced the same growth of animals receiving a 14 and 17% CP diet with 2.7% lysine. More recently, Sterling et al. (2003) found Ross chicks fed 17 and 23% CP diet with 0.8% lysine had a similar BWG. However, feed intake and FCR of the chicks fed the 17% CP level was higher.

The requirement for nutrients, including lysine is usually defined as the minimum dietary level required for maximum performance. Maximum performance is difficult to define because there are often several response criteria for each nutrient. There may be different "maximum responses" for growth, feed efficiency, carcass composition, and bone ash, etc. The choice of response parameters to use in defining requirements is important. Leclercq (1998) stated that the required level of lysine is highest for minimizing abdominal fat pad percentage followed by minimizing feed conversion ratio (FCR), and maximizing breast meat yield and BWG. Nutritionists usually build in some margin of error above the "requirement" and therefore feed a level in excess of the maximum response.

The mathematical model used will also influence the estimated requirement. Barbour and Latshaw (1993) found the dietary lysine requirement to be higher when estimated by a quadratic response model compared to a two-slope model and depended on the dietary CP source. Vazquez and Pesti (1997) found the ascending quadratic with plateau model estimated a higher requirement for lysine than the ascending line with plateau model for both BWG and feed efficiency. Leclercq and Beaumont (2001) concluded, "because of the curvilinearity of performance responses to lysine concentration, determining the requirement is difficult."

In general, one value is necessary for setting a constant ratio of an amino acid requirement to the dietary level of CP (Scott et al., 1982). This is to ensure that the essential amino acids are balanced when CP increases in the diet. In addition, one value for the lysine requirement is required when setting ideal ratios of the essential amino acids to lysine (Han and Baker, 1994). Finally, one value is required for least-cost linear feed formulation programs.

Leclercq and Beaumont (2001) also concluded, “the only way to accurately assess the optimum lysine concentration is thus to use an economic approach and choose the concentration which minimizes feed costs." However, least-cost feed formulation implicitly assumes constant marginal productivity. It is reasonable to assume that with changing market prices for poultry meat and feedstuffs, varying combinations of dietary lysine and crude protein can prove to be the more profitable than simply formulating for the least-cost diet. The NRC (1994) committee concluded, "It would be desirable to have mathematical models available that would facilitate the selection of the most economical combinations of dietary concentrations of protein/amino acids (and other nutrients) and energy to achieve poultry production goals." A study examining the effects of crude protein and lysine levels on the difference between returns from body growth and feed cost may provide a rationale for formulating diets based on market situations that maximize profits rather than minimizing feed costs alone.

This study had three objectives: 1) to quantitate the response of broiler chickens to varying levels of dietary lysine and crude protein in broiler starter diets, 2) to provide data used to determine the magnitude of diminishing marginal returns between dietary CP and lysine, and 3) to provide data used to develop a quadratic feed formulation model.

MATERIALS AND METHODS

Growth study Cobb x Cobb[4] (n = 288) male broiler chicks were reared in battery brooders[5] and fed a commercial starter diet from 0 to 7 d of age. All chicks were fed a

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[4]Cobb-Vantress Inc., Siloam Springs, AR.

[5]Petersime Incubator Company, Gettysburg, OH.

crumbled, broiler starter diet formulated according to NRC (1994) recommendations to contain 23% CP and 3,200 kcal/kg ME prior to being placed on the test diets. On d 7, chicks were weighed, neck-banded and allotted to their respective treatments in a manner that ensured a similar weight and weight range between replicates. Chicks were fed a mash diet (Table 6.1) representing one combination of dietary lysine and CP (17% CP with 0.6, 0.7, 0.8 and 0.9% lysine, 20% CP with 0.7, 0.8, 0.9, 1.0% lysine, 23% CP with 0.8, 0.9, 1.0 and 1.1% lysine, and 26% CP with 0.9, 1.0, 1.1, and 1.2% lysine) from 7 to 17 d. On d 17 chicks and residual feed were weighed and FCR calculated. In addition, 3 chicks per pen were weighed, sacrificed by asphyxiation with CO_2 and abdominal fat pads were excised and weights recorded.

Statistical Methods

The experimental design was a completely randomized design with an incomplete factorial arrangement of treatments. The factorial included four dietary crude protein levels and four dietary levels of lysine per CP level. The experimental unit was the pen mean. Analyses of variance and regression analyses were employed with models that included all linear and quadratic terms as well as any possible interactions. All analyses were conducted using the General Linear Models procedure of SAS (SAS Institute, 1998). Whent significant interactions between dietary lysine and CP were observed, the model for the given variable (e.g., BWG) was subjected to surface analyses plots using the GContour Procedure of SAS (SAS Institute, 1998).

The Programming Model

This program takes the technically derived equation for broiler growth, adds economic data on the cost of feed ingredients and the value of live broilers, and calculates the levels of protein and lysine that maximize profits (returns over feed cost). The quadratic production function was derived from the response of the chicks to various dietary lysine and CP levels as:

$$BWG = f(LI,CPI) = a_o + a_1 \text{ x } LI + a_2 \text{ x } LI^2 + a_3 \text{ x } CPI + a_4 \text{ x } CPI^2 + a_5 \text{ x } (LI \text{ x } CPI)$$

where BWG = ouput (body weight gain), and LI and CPI are cumulative nutrient inputs (lysine an CP intakes). “The linear and quadratic parts of the equation account for the diminishing marginal productivity of each input. The interaction term (LI x CPI) incorporates the effect of the marginal physical product of one being a function of the concentration of the other input” (Pesti et al., 1986).

This function was used to create a windows user-friendly poultry program for economic modeling (WUPP’ EM) in a Microsoft® Excel (2002) worksheet (Appendix B). The composition matrix used in this program is listed in Table 6.5. The composition matrix of ingredients used in the quadratic programming model is listed in Table 6.4. The price of SBM and CGM were changed and the program solved for the maximum profit between 17 and 26% CP and 0.6 and 1.2% lysine. Reference prices for corn, SBM, and CGM were obtained from the October 14, 2002 issue of Feedstuffs. Reference prices for DL-methionine, L-lysine HCl, L-tryptophan, and L-threonine were obtained from a commercial producer for one week in the Fall of 2002.

RESULTS AND DISCUSSION

All statistical analyses were based on nutrient values estimated from ingredient composition tables (NRC, 1994). The analyzed nutrient values of dietary lysine and CP were in close agreement with calculated values (Table 6.1).

Performance

The performance data of chicks as measured by BWG, feed intake and FCR is listed in Table 6.2. A factorial analyses of the data revealed a linear effect of dietary lysine level on BWG, feed intake, and FCR (Table 6.3). BWG increased as dietary lysine and CP levels increased and as dietary lysine levels increased FCR improved. Feed intake increased at every dietary lysine level except the two highest levels of the 26% CP diet (Table 6.2). A significant effect of dietary CP level on BWG and feed intake, but not FCR, was observed (Table 6.3). Similar BWG was achieved when chicks were fed 20 and 23% CP with 0.9% lysine and 23 and 26% CP with 1.1% lysine. Feed intake was similar between the 20 and 23% CP treatment groups. However, chicks fed the 26% CP diet with 1.1% lysine consumed less feed and had a lower FCR when compared to chicks fed the 23% CP diet with 1.1% lysine (Table 6.2) indicating a response to CP. Abdominal fat pad weights increased as the dietary lysine level increased up to 1.0%, and increased then decreased as dietary CP levels increased (Table 6.3). The increase in abdominal fat pad weights is probably related to an increase in body weight as dietary lysine level increased. Abdominal fat pad percentages increased from 0.6 to 0.8% lysine and decreased from 0.9 to 1.2% lysine. The increase in abdominal fat pad percentage from 0.6 to 0.8% lysine may also be connected with improvements in body weight.

However, the decrease in abdominal fat pad percentage after 0.9% lysine is probably more related to a more efficient use of lysine. That is, less of the excess amino acids (in relation to the first limiting amino acid) are being oxidized. Lysine has been reported to have an effect on carcass composition when fed at levels above those required to maximize body weight gain (Leclercq, 1998). However, these results do not confirm those of Grisoni (1991) and Han and Baker (1994) probably because in their studies an insufficient number of lysine levels were tested.

Regression analyses showed significant linear effects due to dietary lysine levels for all response parameters. In addition, significant bi-phasic (increase followed by a decrease) responses were observed as dietary lysine levels increased (Table 6.3). A quadratic effect due to dietary CP level was noted for BWG and FCR. The dietary lysine by CP interaction was significant for BWG when regressed as a function of dietary lysine and CP levels and intake (Tables 6.3 and 6.4, Figure 6.1).

Economic Analysis

As the price of SBM increased its dietary usage decreased and the dietary CP level decreased (Table 6.5 and 6.6). The level of dietary lysine increased proportionally as the dietary usage of SBM increased. However, the formulated levels of lysine may or may not be affecting profits since excessive levels are provided by SBM. Therefore, it is possible a trade off between crystalline lysine and dietary CP would occur with an ingredient with a similar CP level but lower lysine level than SBM. Corn gluten meal is lower in lysine but higher in CP. It is more profitable to have a higher CP level when CGM is incorporated, thus the CP level is more important in determining the maximum profit (Table 6.8). Increasing the price of CGM decreased its usage and increased the usage of SBM (Table 6.8). In addition, as the price of CGM increased the level of dietary lysine increased from 1.27 to 1.38% of the diet. However, the dietary CP level remained unchanged. The addition of crystalline lysine only became economical when the price dropped to 75% of reference value (Table 6.9). However, the level of lysine in the formulation remained at 1.27%.

In Tables 6.7 and 6.10, least-cost formulation at NRC (1994) recommendations are compared to the maximum-profit diet formulated using the WUPP'EM. In both examples (SBM-based diets in Table 6.7 and SBM- and CGM-based diets in Table 6.10), the diet formulated using WUPP'EM was more profitable. If the least-cost formulation model is used, the minimum feeding levels of CP and lysine are always the same, the minimum requirement (Table 6.7 and 6.10). The producer can either afford to feed CP and lysine at the minimum levels, or they cannot afford to feed them at any level. Feeding higher levels is not expected to result in any further response and is therefore wasteful.

If the maximum-profit formulation model is used, the economically optimal CP and lysine levels may change depending on the prices of CP and lysine, and the value of the birds (Table 6.7 and 6.10). The responses detailed above in Table 6.2 and Figure 6.1 follow the law of diminishing returns and basic principles of production economics: If the price of the inputs increases, their use tends to decrease; If the value of the product increases, the level of output tends to increase, and conversely.

Differences in profits in Table 6.11 will depend on the LC model chosen. For this example, the NRC (1994) recommended dietary CP and lysine levels were arbitrarily chosen. In addition, a liveweight equivalent price (Poultry Yearbook, 2000) that reflects the price of finished broiler chickens was used because of the difficulty in placing a value on BWG. The potential savings from using the MP diet are very large, especially considering that the calculations in Table 6.11 are only from savings during the 7 to 17d period. Production functions are needed for larger birds during the growing and finishing periods to truly demonstrate the potential savings to commercial producers.

It is important that producers develop their production functions with the genetic stocks and under the conditions they will be using commercially. Sterling et al. (2003) have demonstrated three-way interactions between dietary levels of CP and lysine and genotype. They concluded that the response of two genotypes to various dietary levels of CP and lysine were quantitatively different.

It seems reasonable to conclude that savings will be much larger during the growing and finishing periods when birds eat much more feed and less efficiently use CP and lysine. Parameters that need to be estimated in growing and finishing diets include carcass composition and mortality. Sterling et al. (2003) have shown that increasing dietary CP and lysine levels change carcass composition by increasing breast meat yield and decreasing abdominal fat pad percentage. Mortality tends to increase with age, especially from Sudden Death Syndrome which generally kills the largest birds. Therefore, there is added an economic value from faster growth because birds will be market weight at an earlier age.

The quadratic programming model workbook (WUPP'EM) in (Appendix B) gives producers a working tool to demonstrate the interdependencies of costs, technical response functions and the value of broiler meat. Since many nutrition students and nutrition practitioners already understand and use Microsoft® Excel, it is hoped that this workbook will serve as a foundation for the development of improved models. The same linear restrictions can be added to the maximum-profit as the least-cost models. Therefore, the maximum-profit model should only give the same or better, never worse, formulations compared to current least-cost feed formulation models.

TABLE 6.1. Composition of diets used in Experiment

	Diets			
	CP (% of diet)			
	17	20	23	26
Ingredients[1]	---------------------------- (%)	------------------------------		
Corn, grain	75.56	69.13	62.49	56.06
Soybean meal	11.01	13.73	16.54	19.26
CGM-60% CP	7.76	11.28	14.9	18.42
Poultry fat (stabilized)	1.31	1.53	1.75	1.97
Di-calcium phosphate	2.05	2.01	1.98	1.94
Limestone	1.36	1.36	1.37	1.37
DL-Methionine	0.02	0.02	0.03	0.03
L-Arginine HCl	0.09	0.11	0.12	0.14
Common salt	0.46	0.46	0.46	0.46
Choline Cl-70%	0.05	0.04	0.03	0.02
Vitamin premix[2]	0.25	0.25	0.25	0.25
Mineral premix[3]	0.08	0.08	0.08	0.08
Calculated composition[1]				
ME (kcal/g)	3.2	3.2	3.2	3.2
Crude protein (%)	17.0	20.0	23.0	26
Ether Extract (%)	4.5	4.6	4.7	4.8
Lysine (%)	0.60	0.70	0.80	0.9
Threonine (%)	0.59	0.70	0.80	0.91
Methionine + Cystine (%)	0.67	0.79	0.90	1.02
Analyzed compostition[4]				
Crude protein (%)	15.8	19.5	25	26.5
Ether Extract (%)	4.3	4.4	4.5	4.3
Lysine (%)	0.58	0.68	0.8	0.93
Threonine (%)	0.6	0.72	0.83	0.96
Methionine + Cystine (%)	0.64	0.79	0.9	1.02

[1]Based on NRC (1994) feed composition tables.

[2]Vitamin premix provides the following per kilogram of diet: vitamin A, 5,500 IU from all trans-retinyl acetate; cholecalciferol, 1,100 IU; vitamin E, 11 IU from all-rac-α-tocopherol acetate; riboflavin, 4.4 mg; Ca pantothenate, 12 mg; nicotinic acid, 44 mg; choline Cl, 220 mg; vitamin B_{12}, 6.6 µg; vitamin B6, 2.2 mg; menadione, 1.1 mg (as MSBC); folic acid, 0.55 mg; di-biotin, 0.11 mg; thiamine, 1.1 mg (as thiamine mononitrate); ethoxyquin, 125 mg.

[3]Trace mineral premix provides the following in milligrams per kilogram of diet: Mn, 60; Zn, 50; Fe, 30; Cu, 5; I, 1.5.

[4]Degussa-Hüls Corporation, Allendale, NJ 07401.

TABLE 6.2. Relationship between dietary CP and lysine on body weight gain (BWG), feed intake, feed conversion ratio (FCR), and abdominal fat pat percentage of male broiler chicks (7 to 17 d)[1]

CP	Lysine	BWG	Feed Intake	FCR	Abdominal Fat Pad	
--------------- (%)	----------------	---------- (g)	----------	(g/g)	(g)	(% of BW)
17	0.6	171.8 ± 6.25	414.9 ± 21.80	2.40 ± 0.06	4.42 ± 0.34	1.28 ± 0.15
17	0.7	260.6 ± 6.40	531.7 ± 20.80	2.05 ± 0.05	8.19 ± 0.92	1.81 ± 0.14
17	0.8	341.8 ± 2.38	611.2 ± 5.60	1.80 ± 0.00	8.55 ± 1.08	1.74 ± 0.18
17	0.9	348.7 ± 18.62	639.0 ± 20.48	1.83 ± 0.15	8.40 ± 0.07	1.56 ± 0.05
20	0.7	227.9 ± 11.70	472.0 ± 53.0	2.05 ± 0.15	5.93 ± 0.06	1.46 ± 0.10
20	0.8	284.6 ± 11.35	503.9 ± 12.30	1.77 ± 0.03	7.41 ± 0.06	1.62 ± 0.04
20	0.9	364.8 ± 8.41	590.0 ± 11.56	1.60 ± 0.00	8.25 ± 0.06	1.48 ± 0.09
20	1.0	393.0 ± 9.10	602.7 ± 8.20	1.53 ± 0.03	8.22 ± 0.06	1.45 ± 0.06
23	0.8	272.8 ± 21.87	491.9 ± 36.29	1.80 ± 0.00	6.75 ± 0.78	1.46 ± 0.09
23	0.9	362.3 ± 6.43	590.4 ± 22.25	1.63 ± 0.03	7.59 ± 0.34	1.40 ± 0.04
23	1.0	417.0 ± 11.23	611.7 ± 13.11	1.47 ± 0.03	8.10 ± 0.59	1.37 ± 0.08
23	1.1	441.4 ± 4.36	623.2 ± 1.90	1.40 ± 0.00	7.59 ± 0.26	1.21 ± 0.03
26	0.9	320.9 ± 5.86	524.0 ± 12.87	1.63 ± 0.03	6.04 ± 0.50	1.26 ± 0.09
26	1.0	382.9 ± 15.47	637.7 ± 34.78	1.67 ± 0.17	7.10 ± 0.82	1.24 ± 0.12
26	1.1	438.0 ± 18.87	608.0 ± 16.78	1.37 ± 0.03	6.66 ± 0.20	1.09 ± 0.01
26	1.2	432.3 ± 26.70	589.8 ± 24.08	1.37 ± 0.03	7.00 ± 0.10	1.06 ± 0.03

[1]Means ± Standard error of the mean for six chicks per replicate per treatment, two replicates were discarded (one each in 17 and 20% CP diets)

TABLE 6.3. Relationship between dietary CP and lysine on body weight gain (BWG), feed intake, feed conversion ratio (FCR), and abdominal fat pat percentage of male broiler chicks (7 to 17 d)[1]

Main Effects		BWG	Feed Intake	FCR	Abdominal Fat Pad	
--------------- (%) ----------------		---------- (g) ----------		(g/g)	(g)	(% of BW)
Crude protein level	n					
17	11	282.6 ± 24.09	550.8 ± 29.67	2.02 ± 0.09	7.15 ± 0.61	1.56 ± 0.08
20	11	325.7 ± 20.08	548.5 ± 18.93	1.71 ± 0.06	7.53 ± 0.36	1.49 ± 0.04
23	12	373.4 ± 20.29	579.3 ± 18.29	1.58 ± 0.05	7.51 ± 0.27	1.36 ± 0.04
26	12	393.5 ± 16.20	589.9 ± 16.12	1.51 ± 0.06	6.69 ± 0.24	1.16 ± 0.04
Lysine level						
0.6	3	171.8 ± 6.25	414.9 ± 21.80	2.40 ± 0.06	4.42 ± 0.34	1.28 ± 0.15
0.7	4	244.3 ± 10.90	501.9 ± 28.94	2.05 ± 0.06	6.45 ± 0.49	1.52 ± 0.10
0.8	9	299.7 ± 12.84	535.7 ± 22.02	1.79 ± 0.01	7.57 ± 0.47	1.61 ± 0.07
0.9	12	349.2 ± 7.07	585.9 ± 14.40	1.68 ± 0.04	7.57 ± 0.34	1.42 ± 0.05
1	9	397.6 ± 7.94	617.4 ± 12.17	1.56 ± 0.06	7.79 ± 0.35	1.35 ± 0.06
1.1	6	439.7 ± 8.69	615.6 ± 8.28	1.38 ± 0.02	7.13 ± 0.25	1.15 ± 0.03
1.2	3	432.3 ± 26.70	589.8 ± 24.08	1.37 ± 0.03	7.01 ± 0.10	1.06 ± 0.03
ANOVA	df	---------------------------------- Probabilities ----------------------------------				
Lysine	3	***0.0001***	***0.0001***	***0.0001***	***0.0001***	***0.0032***
Crude protein	6	***0.0419***	***0.0002***	0.3340	***0.0004***	***0.002***
Lysine x Crude protein	6	0.3452	0.1786	0.2703	0.8215	0.9019
Error	45					

TABLE 6.3. Continued.

Main Effects		BWG	Feed Intake	FCR	Abdominal Fat Pad	
--------------- (%) ----------------		---------- (g) ----------		(g/g)	(g)	(% of BW)
REGRESSION						
Lysine	1	***0.0001***	***0.0001***	***0.0001***	***0.0001***	***0.0003***
Lysine x Lysine	1	***0.0001***	***0.0005***	***0.0234***	***0.0018***	***0.0134***
Crude protein	1	0.3826	***0.0026***	0.0695	0.7902	0.5538
Crude protein x Crude protein	1	***0.0296***	0.7868	***0.0198***	0.1322	0.3995
Lysine x Crude protein	1	***0.003***	0.0535	0.1667	0.0978	0.2323
Error	45					
Coefficient of determination (R^2)		0.921	0.761	0.8537	0.6343	0.6115

[1]Means ± Standard error of the mean for six chicks per replicate per treatment, two replicates were discarded (one each in 17 and 20% CP diets)

TABLE 6.4. Estimates of the coefficients of regression for the body weight gain (BWG) of male broiler chicks (7 to 17 d) fed diets with various dietary lysine and crude protein levels[1]

Source of variation	Estimate	Standard Error	Pr > |t|
Intercept	-183.8462	51.0179	0.0009
Cumulative CP Intake (g)	5.1115	1.5782	0.0024
Cumulative Lysine Intake (g)	34.8109	27.6099	0.2147
CP Intake x CP Intake	-0.069	0.0149	0.0001
Lysine Intake x Lysine Intake	-25.5771	7.382	0.0013
CP Intake x Lysine Intake	2.3089	0.5959	0.0004
Coefficient of Determination (R^2) = 0.9515			

[1]Equation used to create surface plot in Figure 6.1.

TABLE 6.5. Composition matrix of ingredients used in the quadratic programming models[1]

Ingredient	CP	ME	Calcium	Available phosphorus	Sodium	Lysine	Methionine	TSAA	Cost[2]	Minimum	Maximum
	(%)	(kcal/g)	----------	----------	(%)	----------	----------	----------	($/cwt)	----- (%)	-----
Corn	8.8	3.35	0.02	0.1	0.02	0.26	0.18	0.36	5.5		
Soybean meal	48.5	2.44	0.27	0.24	0.03	2.96	0.67	1.39	10.65		
Corn gluten meal	62	3.72	....	0.19	0.02	1	1.91	3.02	13.25		
Poultry fat	....	8.2	....	....	....	....	....	....	9.25		
Limestone	....	....	38	....	0.05	....	....	....	1.53		
Deflourinated phosphorus	....	....	32	18	4.9	....	....	....	12.75		
Common salt	....	....	0.3	....	39	....	....	....	2.78		
Vitamin premix	....	....	....	....	....	....	....	....	168	0.25	0.25
Mineral premix	....	....	....	....	....	....	....	....	26	0.08	0.08
DL-Methionine	57.52	3.68	....	....	....	....	98	98	115		
L-Lysine HCl	94.4	4.6	....	....	....	74.42	....	....	80		
L-Threonine	73.5	3.15	....	....	....	....	....	....	115		
L-Tryptophan	85.75	5.46	....	....	....	....	....	....	113.6		
Minimum	17	3.2	1	0.45	0.2	0.7	0.37	0.67			
Maximum	26	....	....	....	....	1.2	....	....			

[1]In the quadratic programming model, dietary crude protein and lysine were allowed to vary between 17 and 26% CP, and methionine, TSAA, threonine, TAAA, and tryptophan were set at 2.17, 3.91, 3.48, 5.83, and 0.87 g amino acid per 100 g. crude protein, respectively.

[2]Reference prices for corn, SBM, and CGM were obtained from the October 14, 2002 issue of Feedstuffs. Reference prices for DL-methionine, L-lysine HCl, L-tryptophan, and L-threonine were obtained from a commercial amino acid manufacturer for one week in the Fall of 2002.

TABLE 6.6. Effect of Soybean meal (SBM) prices on the dietary lysine and crude protein concentrations that maximize profits

Cost ($/cwt)			Usage level (%)			Nutrient level (%)						
Corn	SBM	L-Lysine HCl	Corn	SBM	L-Lysine HCl	CP level	Lysine level	Diet Cost ($/cwt)	Profit/bird (cents/bird)[1]	BWG	FCR	Lysine to CP ratio
Increase SBM Price from 50 to 300% of Reference												
5.5	6.39	80	49.5	41.3	0	24.5	1.35	6.83	0.2355	442.1	1.47	5.51
5.5	8.52	80	51.7	39.4	0	23.8	1.3	7.63	0.223	443.6	1.5	5.47
5.5	10.7	80	53.6	37.8	0	23.1	1.26	8.37	0.2109	444.1	1.52	5.43
5.5	12.8	80	55.5	36.2	0	22.5	1.22	9.04	0.1991	444.2	1.54	5.39
5.5	14.9	80	57.3	34.7	0	21.9	1.17	9.64	0.1877	443.9	1.56	5.35
5.5	17	80	59.1	33.1	0	21.4	1.13	10.19	0.1766	443.1	1.59	5.31
5.5	19.2	80	60.9	31.6	0	20.8	1.1	10.66	0.1658	442.1	1.61	5.26
5.5	21.3	80	62.5	30.2	0	20.3	1.06	11.1	0.1554	440.3	1.64	5.22
5.5	23.4	80	64.1	28.9	0	19.7	1.02	11.49	0.1453	438.2	1.67	5.18
5.5	25.6	80	65.8	27.5	0	19.2	0.98	11.8	0.1356	435.8	1.7	5.13
5.5	27.7	80	67.4	26.1	0	18.7	0.95	12.07	0.1262	432.9	1.74	5.08
5.5	29.8	80	68.9	24.8	0	18.2	0.92	12.3	0.1171	429.5	1.78	5.03

[1]The price per bird is an annual average liveweight equivalent price for 2000 (0.3425 cents/pound) found in TABLE 92-Broilers: Liveweight equivalent price, Poultry Yearbook (2000).

TABLE 6.7. Outputs (diet formulations) and predicted performance of broilers from least cost (LC) and maximum profit (MP) programming with soybean meal.

Ingredient	LC[1]	MP
	(g/kg)	
Corn	54.04	53.6
Soybean meal (48%CP)	37.39	37.77
Poultry fat	5.74	5.81
Limestone	0.61	0.61
Defluorinated Phosphate	1.42	1.42
Common Salt	0.28	0.28
Vitamin Premix	0.25	0.25
Mineral Premix	0.08	0.08
DL-Methionine	0.19	0.19
L-Lysine	0	0
Calculated Composition		
Crude Protein (%)	23	23.14
ME (kcal/kg)	3200	3200
Lysine (%)	1.25	1.26
Lysine to CP ratio	5.42	5.43
Performance		
BWG/bird (g)	444.8	444.11
Feed intake/bird (g)	678.37	673.57
FCR (g/g)	1.53	1.52
Costs		
Diet ($/cwt)	8.34	8.37
Profit/bird ($/100 birds)	2.11	2.11

[1]Basesd on NRC (1994) recommendations for a 1- to 3-week-old broiler.

TABLE 6.8. Effect of corn gluten meal (CGM) prices on the dietary lysine and crude protein concentrations that maximize profits.

Cost ($/cwt)			Usage level (%)			Nutrient level (%)						
Corn	SBM	CGM	Corn	SBM	CGM	CP level	Lysine level	Diet Cost ($/cwt)	Profit/bird (cents/bird)[1]	BWG	FCR	Lysine to CP ratio
Increase CGM Price from 75 to 350% of Reference												
5.5	10.7	6.63	43.4	25.6	15.19	26	1.26	7.79	0.25	477.2	1.39	4.86
5.5	10.7	9.94	55.4	25.2	13.8	26	1.27	8.29	0.24	475.3	1.38	4.87
5.5	10.7	13.25	49.4	36.5	6.22	26	1.27	8.71	0.23	473.9	1.37	4.89
5.5	10.7	16.56	49.1	37	5.86	26	1.28	8.91	0.23	472.9	1.36	4.93
5.5	10.7	19.88	48.8	37.5	5.49	26	1.29	9.09	0.23	471.6	1.36	4.97
5.5	10.7	23.19	48.6	38.1	5.12	26	1.3	9.24	0.22	470.1	1.35	5.01
5.5	10.7	26.5	48.3	38.6	4.75	26	1.31	9.37	0.22	468.4	1.35	5.06
5.5	10.7	29.81	48	39.1	4.37	26	1.33	9.47	0.22	466.4	1.35	5.1
5.5	10.7	33.13	47.7	39.7	3.98	26	1.34	9.55	0.22	464.1	1.35	5.14
5.5	10.7	39.75	47.2	40.7	3.2	26	1.36	9.62	0.22	458.9	1.34	5.23
5.5	10.7	43.06	46.9	41.3	2.8	26	1.37	9.62	0.21	455.9	1.34	5.28
5.5	10.7	46.37	46.6	41.9	2.4	26	1.38	9.58	0.21	452.7	1.35	5.32

[1]The price per bird is an annual average liveweight equivalent price for 2000 (0.3425 cents/pound) found in TABLE 92-Broilers: Liveweight equivalent price, Poultry Yearbook (2000).

TABLE 6.9. Effect of L-lysine HCl price on the dietary lysine and crude protein concentrations that maximize profits in the maximum profits diet in TABLE 3.

Cost ($/cwt)	Usage level (%)				Nutrient level (%)						
L-Lysine	Corn	SBM	CGM	L-Lysine HCl	CP Level	Lysine level	Diet Cost ($/cwt)	Profit/bird (cents/bird)[1]	BWG	FCR	Lysine to CP ratio
					Decrease L-lysine HCl Price from 100 to 50% of Reference						
80	49.4	36.5	6.22	0	26	1.2718	8.71	0.2329	473.8	1.37	5.27
70	49.4	36.5	6.22	0	26	1.2718	8.71	0.2329	473.8	1.37	5.27
60	55.4	25.3	13.75	0.33	26	1.2724	8.69	0.2333	473.9	1.37	5.27
50	55.4	25.3	13.74	0.33	26	1.2733	8.65	0.2337	474	1.37	5.27
40	55.4	25.3	13.73	0.33	26	1.2742	8.62	0.2342	474.1	1.37	5.27

[1]The price per bird is an annual average liveweight equivalent price for 2000 (0.3425 cents/pound) found in TABLE 92-Broilers: Liveweight equivalent price, Poultry Yearbook (2000).

TABLE 6.10. Outputs (diet formulations) and predicted performance of broilers from least cost (LC) and maximum profit (MP) programming with Corn gluten meal.

Ingredient	LC[1]	MP
	(g/kg)	
Corn	57.05	49.35
Soybean meal (48%CP)	31.64	36.53
Corn gluten meal (60% CP)	4.12	6.22
Poultry fat	4.37	5.11
Limestone	0.64	0.64
Defluorinated Phosphate	1.44	1.4
Common Salt	0.28	0.28
Vitamin Premix	0.25	0.25
Mineral Premix	0.08	0.08
DL-Methionine	0.13	0.15
L-Lysine	0	0
L-Tryptophan	0	0
Calculated Composition		
Crude Protein (%)	23	26
ME (kcal/kg)	3200	3200
Lysine (%)	1.13	1.27
Lysine to CP ratio	4.9	4.89
Performance		
BWG/bird (g)	471.83	473.89
Feed intake/bird (g)	725.06	649.3
FCR (g/g)	1.54	1.37
Costs		
Diet ($/cwt)	8.25	8.71
Profit/bird ($/100 birds)	2.24	2.33

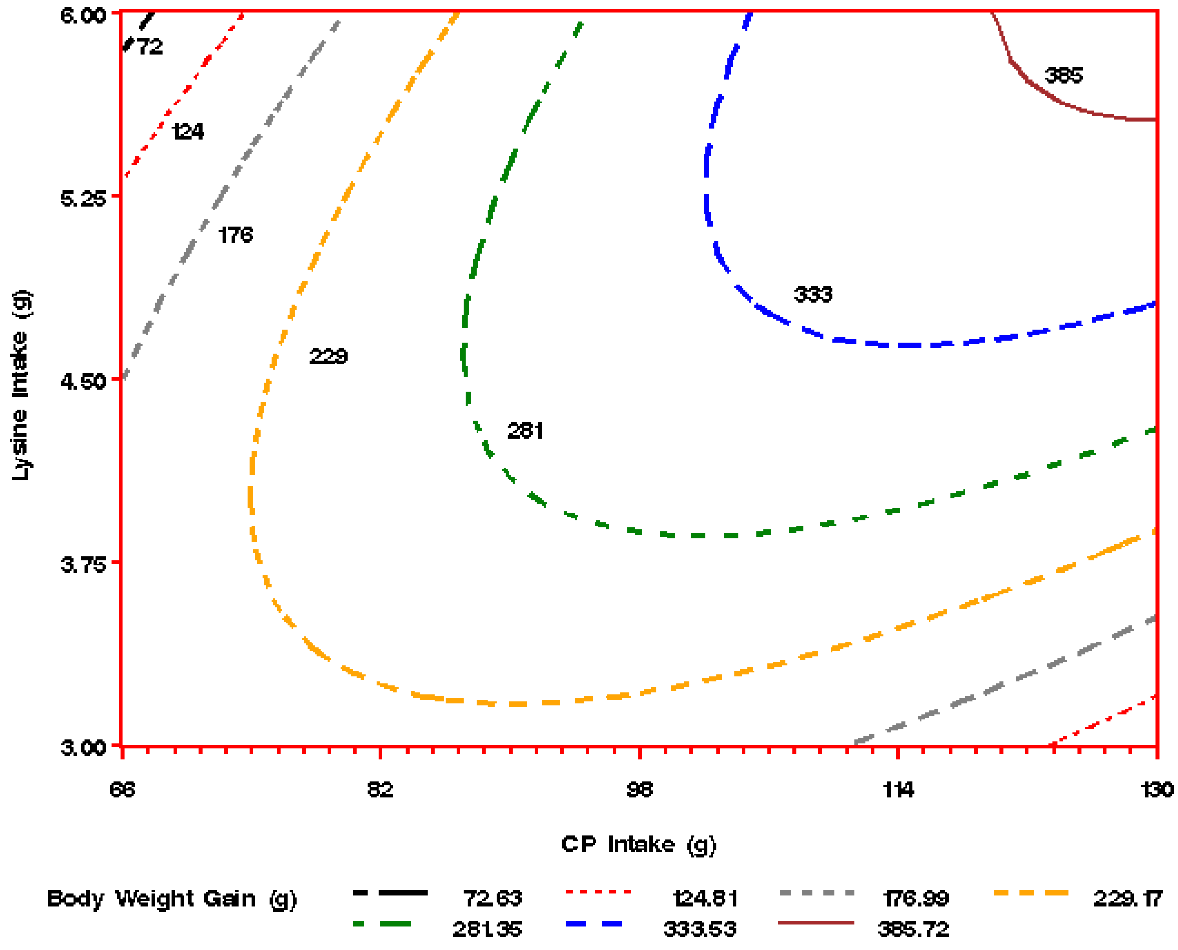
[1]Basesd on NRC (1994) recommendations for a 1- to 3-week-old broiler.

TABLE 6.11. Difference in profits between least cost (LC) and maximum profits (MP) formulations for starter rations fed to male broiler chicks (7 to 17d)

	SBM			CGM		
	Costs ($/cwt)[3]					
	Low	Medium	High	Low	Medium	High
	Profits/bird ($/bird)[1]					
LC	0.2291	0.1649	0.112	0.2291	0.2169	0.2113
MP	0.2355	0.1658	0.1171	0.246	0.2227	0.2129
Difference	0.0064	0.0009	0.0051	0.0169	0.0058	0.0016
Complex[2]						
Profits[4] /week	8000	1125	6375	21125	7250	2000
Profits[4] /year	416000	58500	331500	637000	377000	104000

[1]Represents marginal profits for the 10 day period.
[2]One Complex = 1.25×10^6 broilers/week and 65×10^6 broilers/year.
[3]The low, medium and high prices ($/cwt) are 6.39, 19.2, and 29.8 and 9.94, 26.5, 46.4 for SBM and CGM, respectively.
[4]Represents the difference in profits between formulations.

FIGURE 6.1. Surface plot of body weight gain (BWG) as a function of dietary CP and lysine intake.


6.00
5.25
4.50
3.75
3.00
Lysine Intake (g)
66
82
98
114
130
CP Intake (g)
72
124
176
229
281
333
385
Body Weight Gain (g)
72.63
124.81
176.99
229.17
281.35
333.53
385.72

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CHAPTER 7

CONCLUSIONS

Results from this dissertation reveal an important relationship between dietary CP and lysine. The first study demonstrated the effects of increasing dietary CP level and source on carcass composition. Protein source and protein level affected various carcass parts on an absolute and percentage of carcass weight basis. The results are qualitatively similar to what Frapps (1943) observed in the 1940's and Smith and Pesti (1998) observed in the 1990's. Male and female broilers fed CSM diets generally had smaller meat parts and larger abdominal fat pads than broilers fed SBM diets at the same protein level. Broilers fed higher protein levels with CSM had responses similar to broilers fed diets with lower protein level from SBM.. Clearly, very good broiler performance can be achieved by feeding combinations of corn, CSM, and ABP meals, especially for males.

The results of the second study indicate that the differences in literature regarding the lysine requirement of broiler chicks could not be explained by either the graded supplementation or diet dilution methods. The lysine requirement of broiler chicks was found to be a direct proportion of the dietary CP level within a practical range. Therefore, the practice of keeping amino acid requirements as a proportion of the dietary CP content appears to be adequate for practical feed formulation.

In the third study it was concluded that different genotypes respond differently to various dietary CP and lysine levels. This was confirmed by the three-way interaction observed between the three main effects. Differences in genotype were noted on efficiency of utilization in that some genotypes better utilized low lysine, crude protein diets. This may indicate a higher lysine requirement for some genotypes.

In the final study, the relationship between dietary CP and lysine was studied in broiler chicks fed a starter diet with various levels of each. The response of these chicks to the dietary CP and lysine levels followed the "law of diminishing returns." Therefore the substitution of lysine for dietary CP and vice versa, resulted in a similar BWG. Maximum profit diets formulated using the quadratic program based on this relationship could significantly increase returns over the least-cost formulation models under some economic situations for the starter diet alone. It is hoped that the quadratic programming model workbook (WUPP'EM) will serve as a foundation for the development of improved models.

These results suggest that the relationship between dietary CP and lysine exists. Therefore, this relationship should be considered by poultry nutritionists when determining optimum dietary levels of each.

In addition, the implications of this research are that relationships between dietary CP and other amino acids may exists (e.g., dietary CP and methionine). Therefore, the response of broiler chicks of differing genotypes and the interactions between genotype, dietary CP and other amino acids may also exist.

APPENDICES

TABLE A-1. A comparison of the lysine requirement of young broiler chicks.

Experiment or Authors	Age (d)	Sex	Breed	Diet Type	Parameter	Dietary CP (% of diet)	Lysine (% of diet)	Lysine (% of CP)
Almquist and Mecchi (1942)	NS	NS	NS	Corn, Edestin, Casein	Growth	NS	0.9	----
Grau et al. (1946)	14 to 24	NS	NS	Sesame seed meal	Growth	20	0.96	4.8
Grau (1948)	14 to 22	NS	White Leghorn	Sesame seed meal	Growth	20	0.87	4.35
Grau and Kamei (1950)	14 to 22	NS	White Leghorn	Sesame seed meal	Growth	20	0.85	4.25
Milligan et al. (1951)	42	Straigh t-run	White Leghorn	Cottonseed Meal	Growth	21	1	4.76
Bird (1953)	56 to 63	NS	Rhode Island Red	Sesame seed meal	Growth, Feed efficiency	16	0.72	4.5
Edwards et al. (1956)	28 d	Males	White Leghorn	Wheat Gluten	Growth, Feed efficiency	20.5	0.9	4.39

TABLE A-1. Continued.

Experiment or Authors	Age (d)	Sex	Breed	Diet Type	Parameter	Dietary CP (% of diet)	Lysine (% of diet)	Lysine (% of CP)[1]
Edwards et al. (1956)	28 d	Males	White Leghorn	Sesame seed meal	Growth, Feed efficiency	20.5	1.10, 1.20	5.37, 5.85
	42 d	Males	Rhode Island Red x Barred Plymouth Rock	Sesame seed meal	Growth, Feed efficiency	20.5	1.10, 1.00	5.37, 4.88
	42 d	Males	Rhode Island Red x Barred Plymouth Rock	Sesame seed meal	Growth, Feed efficiency	20.5	1.00, 1.10	4.88, 5.37
Schwartz et al. (1958)[3]	0 to 14	Males	Indian River broiler-type	Sesame seed meal	Growth, Feed efficiency	20	1.1	5.5

[3]Based on productive energy value of 975 (cal/lb).

TABLE A-1. Continued.

Experiment or Authors	Age (d)	Sex	Breed	Diet Type	Parameter	Dietary CP (% of diet)	Lysine (% of diet)	Lysine (% of CP)[1]
Schwartz et al. (1958)[3]	14 to 28	Males	Indian River broiler-type	Sesame seed meal	Growth, Feed efficiency	20	1.1	5.5
Schwartz et al. (1958)	28 to 42	Males	Indian River broiler-type	Sesame seed meal	Growth, Feed efficiency	20	1	5
	42 to 56	Males	Indian River broiler-type	Sesame seed meal	Growth, Feed efficiency	20	0.9	4.5
	56 to 77	Males	Indian River broiler-type	Sesame seed meal	Growth, Feed efficiency	20	0.8	4
Griminger and Scott (1959)	14 to 28	Females	Indian River broiler-type	Sesame seed meal	Growth, Feed efficiency	NS	1.03, 1.13	----
Klain et al. (1960)	7 to 14	NS	New Hampshire x Columbian	Crystalline amino acid	Growth, Feed efficiency	28.7	1.01	3.52
Dean and Scott (1965)	7 to 14	Males	New Hampshire x Columbian	Crystalline amino acid	Growth, Feed efficiency	18	1.12	6.22

TABLE A-1. Continued.

Experiment or Authors	Age (d)	Sex	Breed	Diet Type	Parameter	Dietary CP (% of diet)	Lysine (% of diet)	Lysine (% of CP)[1]
Zimmerman and Scott (1965)	7 to 14	Males	New Hampshire x Columbian	Crystalline amino acid	Growth, Feed efficiency, Plasma amino acids	NS	0.83	----
	14 to 21	Males	New Hampshire x Columbian	Crystalline amino acid	Growth, Feed efficiency, Plasma amino acids	NS	0.7	----
	21 to 28	Males	New Hampshire x Columbian	Crystalline amino acid	Growth, Feed efficiency, Plasma amino acids	NS	0.67	----
	28 to 35	Males	New Hampshire x Columbian	Crystalline amino acid	Growth, Feed efficiency, Plasma amino acids	NS	0.59	----
Boomgaardt and Baker (1970)	6	Female	New Hampshire x Columbian	Crystalline amino acid	Growth	20.3	0.93	4.58

TABLE A-1. Continued.

Experiment or Authors	Age (d)	Sex	Breed	Diet Type	Parameter	Dietary CP (% of diet)	Lysine (% of diet)	Lysine (% of CP)[1]
Hewitt and Lewis (1972)	7 to 21	Males	NS	Semi-purified Corn and Soybean meal	Growth, Feed efficiency	18	0.85	4.72
Velu et al. (1972)	8 to 21	Males	New Hampshire x Columbian	Crystalline amino acid	Growth, Feed efficiency	NS	0.95	----
Twinning et al. (1973)	49 to 63	Males	Ledbrest x Arbor Acres	Sesame seed meal, Corn gluten meal, and Soybean meal	Growth, Feed efficiency	21	0.68	3.24
Chung et al. (1973)	7 to 21	Males	White Leghorn	Sesame seed meal	BWG	19	0.94	4.95
	35 to 42	Males	White Leghorn	Sesame seed meal	BWG	17	0.7	4.12

TABLE A-1. Continued.

Experiment or Authors	Age (d)	Sex	Breed	Diet Type	Parameter	Dietary CP (% of diet)	Lysine (% of diet)	Lysine (% of CP)[1]
Boomgaardt and Baker (1973a)	14 to 28	Males	New Hampshire x Columbian	Sesame seed meal	BWG	18.5	0.88	4.76
	14 to 28	Males	New Hampshire x Columbian	Sesame seed meal	BWG	23	1.05	4.57
Boomgaardt and Baker (1973b)	14 to 28	Males	New Hampshire x Columbian	Sesame seed meal	BWG, Feed efficiency	23	1.06, 1.09	4.61, 4.74
	42 to 56	Males	New Hampshire x Columbian	Sesame seed meal	BWG, Feed efficiency	20	0.92, 0.99	4.60, 4.95
Woodham and Deans (1975)	7 to 14	NS	Ross I broiler hybrids	Peanut, Sunflower, Meat and Fish meals	Total Protein Efficiency (TPE)	18	0.87	4.83

TABLE A-1. Continued.

Experiment or Authors	Age (d)	Sex	Breed	Diet Type	Parameter	Dietary CP (% of diet)	Lysine (% of diet)	Lysine (% of CP)[1]
Thomas et al. (1977)	49 to 63	Females	Vantress x Arbor Acres	Sesame seed meal and Corn gluten meal	Growth, Feed efficiency	20	0.64	3.2
	49 to 63	Males	Vantress x Arbor Acres	Sesame seed meal and Corn gluten meal	Growth, Feed efficiency	20	0.69, 0.66	3.45, 3.30
McNaughton et al. (1978)[2]	14	Males	Broiler-type	Sesame seed meal	Growth, Feed efficiency	20	1.05, 1.00	5.25, 5.00
	28	Males	Broiler-type	Sesame seed- Corn gluten meal	Growth, Feed efficiency	20	0.95	4.75
	14	Males	Broiler-type	Corn gluten- Soybean meal	Growth, Feed efficiency	21	1.05	5

TABLE A-1. Continued.

Experiment or Authors	Age (d)	Sex	Breed	Diet Type	Parameter	Dietary CP (% of diet)	Lysine (% of diet)	Lysine (% of CP)[1]
McNaughton et al. (1978)[2]	28	Males	Broiler-type	Corn gluten-Soybean meal	Growth, Feed efficiency	21	1.00, 0.95	4.76, 4.52
	28	Males	Broiler-type	Corn gluten-Soybean meal	Plasma amino acids	21	0.95	4.52
Attia and Latshaw (1979)	1 to 21	NS	Broiler-type	Cottonseed meal	BWG, Feed efficiency	21	1.09	5.19
Burton and Waldroup (1979)	28	NS	Broiler-type	Corn gluten meal, Soybean meal	Growth, Feed efficiency	20	1.1	5.5
Holsheimer (1981)	35 to 42	Males	Cornish x White Plymouth Rock	Soybean meal	Growth, Feed efficiency	22	0.99	4.5

TABLE A-1. Continued.

Experiment or Authors	Age (d)	Sex	Breed	Diet Type	Parameter	Dietary CP (% of diet)	Lysine (% of diet)	Lysine (% of CP)[1]
Morris et al (1987)	7 to 21	Males	Ross I broilers	Corn gluten meal, Soybean meal, Peanut meal	BWG, Feed efficiency	14 to 28	----	5.3
	7 to 21	Straight-run	Ross I broilers	Corn gluten meal, Soybean meal, Peanut meal	BWG, Feed efficiency	14 to 28	----	5.5
Abebe and Morris (1990)	7 to 21	Males	Ross I broilers	Corn gluten meal, Soybean meal, Peanut meal	BWG, Feed efficiency	20	1.07	5.35
	7 to 21	Males	Ross I broilers	Corn gluten meal, Soybean meal, Peanut meal	BWG, Feed efficiency	22	1.03	4.68

TABLE A-1. Continued.

Experiment or Authors	Age (d)	Sex	Breed	Diet Type	Parameter	Dietary CP (% of diet)	Lysine (% of diet)	Lysine (% of CP)[1]
Abebe and Morris (1990)	7 to 21	Males	Ross I broilers	Corn gluten meal, Soybean meal, Peanut meal	BWG, Feed efficiency	24	1.1	4.58
	7 to 21	Males	Ross I broilers	Corn gluten meal, Soybean meal, Peanut meal	BWG, Feed efficiency	26	1.19	4.59
	7 to 21	Males	Ross I broilers	Corn gluten meal, Soybean meal, Peanut meal	BWG, Feed efficiency	28	1.25	4.46
	7 to 21	Straight-run	Ross I broilers	Corn gluten meal, Soybean meal, Peanut meal	BWG, Feed efficiency	20	0.93	4.65

TABLE A-1. Continued.

Experiment or Authors	Age (d)	Sex	Breed	Diet Type	Parameter	Dietary CP (% of diet)	Lysine (% of diet)	Lysine (% of CP)[1]
Abebe and Morris (1990)	7 to 21	Straight-run	Ross I broilers	Corn gluten meal, Soybean meal, Peanut meal	BWG, Feed efficiency	22	1.02	4.64
	7 to 21	Straight-run	Ross I broilers	Corn gluten meal, Soybean meal, Peanut meal	BWG, Feed efficiency	25	1.06	4.24
	7 to 21	Straight-run	Ross I broilers	Corn gluten meal, Soybean meal, Peanut meal	BWG, Feed efficiency	28	1.26	4.5
Surisdiarto et al. (1991)	21	NS	Broiler-type	Varied	BWG, Feed efficiency	23	1.32, 1.32	5.74
	21	NS	Broiler-type	Varied	BWG, Feed efficiency	23	1.33, 1.30	5.78, 5.65

TABLE A-1. Continued.

Experiment or Authors	Age (d)	Sex	Breed	Diet Type	Parameter	Dietary CP (% of diet)	Lysine (% of diet)	Lysine (% of CP)[1]
Han and Baker (1991)	8 to 22	Males	New Hampshire x Columbian	Soybean meal, Feather meal	BWG, Feed efficiency	23	1.01, 1.21	4.39, 5.26
	8 to 22	Males	Hubbard x Hubbard	Soybean meal, Feather meal	BWG, Feed efficiency	23	1.01, 1.21	4.39, 5.26
Barbour and Latshaw (1993)	21	Straight-run	Broiler-type	Peanut meal	BWG, Feed efficiency	18	0.9	5
	21	Straight-run	Broiler-type	Adjusted Peanut meal	BWG, Feed efficiency	18	1.11	6.17
	21	Straight-run	Broiler-type	Sesame seed meal	BWG, Feed efficiency	18	0.99	5.5
Han and Baker (1993)[3]	8 to 22	Males	New Hampshire x Columbian	Feather-Soybean meal	BWG	23	1	4.35
	8 to 22	Females	New Hampshire x Columbian	Feather-Soybean meal	BWG	23	0.93	4.04

TABLE A-1. Continued.

Experiment or Authors	Age (d)	Sex	Breed	Diet Type	Parameter	Dietary CP (% of diet)	Lysine (% of diet)	Lysine (% of CP)[1]
Han and Baker (1993)[3]	8 to 22	Males	New Hampshire x Columbian Light	Feather-Soybean meal	BWG	23	1.06	4.61
	8 to 22	Females	New Hampshire x Columbian Light	Feather-Soybean meal	BWG	23	0.93	4.04
	8 to 22	Males	New Hampshire x Columbian Heavy	Feather-Soybean meal	BWG	23	1.08	4.7
	8 to 22	Females	New Hampshire x Columbian Heavy	Feather-Soybean meal	BWG	23	0.9	3.91

TABLE A-1. Continued.

Experiment or Authors	Age (d)	Sex	Breed	Diet Type	Parameter	Dietary CP (% of diet)	Lysine (% of diet)	Lysine (% of CP)[1]
Han and Baker (1994)	22 to 42	Males	Ross x Ross	Soybean meal, Feather meal	BWG, Feed efficiency	20	0.85, 0.89	4.25, 4.45
Han and Baker (1994)	22 to 42	Females	Ross x Ross	Soybean meal, Feather meal	BWG, Feed efficiency	20	0.78, 0.85	3.90, 4.25
Hurwitz et al. (1998)	1 to 28	Males	Cobb	Cottonseed meal, Corn gluten meal, Sunflower meal	BWG, Feed efficiency	18	0.95, 0.97	5.28, 5.39
	1 to 28	Males	Cobb	Cottonseed meal, Corn gluten meal, Sunflower meal	BWG, Feed efficiency	20	1.03, 1.05	5.15, 5.25

TABLE A-1. Continued.

Experiment or Authors	Age (d)	Sex	Breed	Diet Type	Parameter	Dietary CP (% of diet)	Lysine (% of diet)	Lysine (% of CP)[1]
Hurwitz et al. (1998)	1 to 28	Males	Cobb	Cottonseed meal, Corn gluten meal, Sunflower meal	BWG, Feed efficiency	23	1.13, 1.11	4.91, 4.82
Labadan et al. (2001)	0 to 14	Males	Ross x Avian	Corn gluten meal, Soybean meal	BWG, Feed efficiency, Breast meat yield	22	1.28, 1.32, 1.21	5.82, 6.00, 5.50
	14 to 28	Males	Ross x Avian	Corn gluten meal, Soybean meal	BWG, Feed efficiency, Breast meat yield	21	1.13, 1.21, NS	5.38, 5.76, ND
	21 to 42	Males	Ross x Avian	Corn gluten meal, Soybean meal	BWG, Feed efficiency, Breast meat yield	20	0.99, 0.99, 1.00	4.95, 4.95, 5.00

TABLE A-1. Continued

Experiment or Authors	Age (d)	Sex	Breed	Diet Type	Parameter	Dietary CP (% of diet)	Lysine (% of diet)	Lysine (% of CP)[1]
Labadan et al. (2001)	35 to 56	Males	Ross x Avian	Corn gluten meal, Soybean meal	BWG, Feed efficiency, Breast meat yield	18	0.81, 0.81, ND	4.50, 4.50, ND
Kidd and Fancher (2001)	19 to 41	Males	Ross 508	Soybean meal, Corn Gluten meal	BWG	20	1.19	5.95
Kidd and Fancher (2001)	19 to 42	Males	Ross 508	Soybean meal, Corn Gluten meal	BWG, Feed efficiency	20	1.22	6.1
Sterling et al. (2002)	10 to 20	Males	Ross x Ross	Cottonseed meal	BWG	19	1.02	5.36
	10 to 20	Males	Ross x Ross	Cottonseed meal	FCR	19	1.03	5.42
Sterling et al. (2003)	9 to 18	Males	Cobb x Cobb	Corn Gluten meal	BWG	17	0.75	4.41
	9 to 18	Males	Cobb x Cobb	Corn Gluten meal	BWG	23	0.97	4.22

TABLE A-1. Continued.

Experiment or Authors	Age (d)	Sex	Breed	Diet Type	Parameter	Dietary CP (% of diet)	Lysine (% of diet)	Lysine (% of CP)[1]
	9 to 18	Males	Cobb x Cobb	Corn Gluten meal	FCR	17	0.73	4.29
	9 to 18	Males	Cobb x Cobb	Corn Gluten meal	FCR	23	0.98	4.26
Sterling et al. (2003)	10 to 18	Males	Cobb x Cobb	Corn Gluten meal	BWG	18.5	0.9	4.86
Sterling et al. (2003)	10 to 18	Males	Cobb x Cobb	Corn Gluten meal	BWG	23	1.04	4.52
	10 to 18	Males	Cobb x Cobb	Corn Gluten meal	FCR	18.5	0.74	4
	10 to 18	Males	Cobb x Cobb	Corn Gluten meal	FCR	23	1.09	4.74

Appendix B. Spreadsheets for WUPP'EM progam.

Windows User-friendly Poultry Program for Economic Modeling

WUPP'EM

Version 0.90

Dmitry Vedenov
Kimberly Sterling
Gene Pesti

The Universtiy of Georgia

This program takes the technically derived equation for broiler growth,
adds economic data on the cost of feed ingredients and the value of
live broilers, and calculates the levels of protein and lysine
that maximize profits (returns over feed cost).

In this example, data was derived from a starting chick experiment,
so birds are only about 450 grams in weight.

For commercial production, data from larger birds needs to be derived.

The technical equation coefficients are input on the "Equation"
spreadsheet.
From there, they are transferred to the "Formulate" spreadsheet.

Ingredient information should be input on the "Ingredients" spreadsheet
From there, it is transferred to the "Formulate" spreadsheet.
Ingrredient costs are input directly on the "Formulate" spreadsheet.

Nutrient information should be input on the "Nutrients" spreadsheet.
From there, it is transferred to the "Formulate" spreadsheet.

The "Solver" add-in can be used to maximize profits (cell I19) by
changing the amounts of feed ingredients in the solution subject to
ingredient
and nutrient constraints. Different amounts of feed ingredients result in
different protein and lysine intakes, and therefore different amounts of
body weight, according to the technical growth equation input on the "Equation"
spreadsheet.

The "Solver" results sometimes depend on its starting point. By pressing the
"Ctrl" and "S" keys together before starting "Solver", a new starting point
will be coppied in to the problem (the data in cells I12 to L23).

By pressing the "Ctrl" and "C" keys together, the current results are copied
into the "Output" spreadsheet.

Change the Body Weight = F(Protein Intake, Lysine Intake) equation
from this Spreadsheet

Parameter	Coefficient
Intercept	-183.8462165
Protein Intake	5.1114562
Lysine Intake	34.8109280
Protein Intake Squared	-0.0690259
Lysine Intake Squared	-25.5770950
Protein Intake x Lysine Intake	2.3088639

	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y
1														

2	Chlorine	Sodium	Choline	CP:THR	THR	CP:MET	MET	CP:TSAA	TSAA	PHE	CP:TRP	TAAA	CP:TRP	TRP
3				28.75		46.00		25.56			17.16		115.00	
4	0.04	0.02	0.62	-0.02	0.29	-0.01	0.18	0.02	0.36	0.38	0.17	0.68	-0.02	0.1
5	0.05	0.03	2.73	0.18	1.87	-0.38	0.67	-0.51	1.39	2.34	1.46	4.29	0.32	0.74
6	0.05	0.02	0.33	-0.19	1.97	0.56	1.91	0.59	3.02	3.77	3.10	6.71	-0.29	0.25
7	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	0.03	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
9	0	4.90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
10	60	39.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
11	0	0.00	88.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
12	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
13	0	0.00	0.00	-2.00	0.00	96.75	98.00	95.75	98.00	0.00	-3.35	0.00	-0.50	0
14	19.43	0.00	0.00	-3.28	0.00	-2.05	0.00	-3.69	0.00	0.00	-5.50	0.00	-0.82	0
15	0	0.00	607.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0

MAKING CHANGES TO NURIENT NAMES AND LIMITES FORM THIS SPREADSHEET

	Min.	Actual	Max.	Units
Dry Matter	0	90.08	100	%
Metabolizable Energy	3.2	3.2	100	%
Protein	17	19.97	26	%
LYS	0	1.04	100	%
Ether Extract	0	7	100	%
Linoleic Acid	0.45	2.35	100	%
Crude Fiber	0.2	2.54	100	%
Calcium	0.8	0.8	100	%
Total Phosphorus	0	0.63	100	%
Avail. Phosphorus	0.4	0.4	2	%
Chlorine	0.2	0.2	2	%
Sodium	0.2	0.2	5	%
Choline	0.55	1.42	2	mg/g
CP:THR	0	0.04	100	
THR	0	0.74	100	%
CP:MET	0	0.02	100	
MET	0	0.45	100	%
CP:TSAA	0	0	100	
TSAA	0	0.78	100	%
PHE	0	0.93	100	%
TYR	0	0.53	100	%
TAAA	0	1.7	100	%
CP:TRP	0	0.08	100	
TRP	0	0.26	100	%

	A	B	C	D	E	F	G
1	WUPP'EM		MAKE NO CHANGES FROM THIS PAGE				
2			EXCEPT INGREDIENT COSTS				
3							
4	Ingredients	Cost	Min.	% in Mix	Max.		
5	=Ingredients!B5	=(3.08/56)*100	0	=P13/SUM($P$13:$P$24)	1		Protein Level =
6	=Ingredients!B6	=J3*K3*0.01	0	=P14/SUM($P$13:$P$24)	1		Lysine Level =
7	=Ingredients!B7	=265/20	0	=P15/SUM($P$13:$P$24)	0		
8	=Ingredients!B8	9.25	0	=P16/SUM($P$13:$P$24)	1		Diet Cost =
9	=Ingredients!B9	1.525	0	=P17/SUM($P$13:$P$24)	1		
10	=Ingredients!B10	12.75	0	=P18/SUM($P$13:$P$24)	1		*Mix Parameters:*
11	=Ingredients!B11	2.775	0	=P19/SUM($P$13:$P$24)	1		Total Consumption, g
12	=Ingredients!B12	168	0.0025	=P20/SUM($P$13:$P$24)	0.0025		Price, $
13	=Ingredients!B13	26	0.0008	=P21/SUM($P$13:$P$24)	0.0008		
14	=Ingredients!B14	100	0	=P22/SUM($P$13:$P$24)	1		
15	=Ingredients!B15	=J4*K4*0.01	0	=P23/SUM($P$13:$P$24)	1		Projected Body Weight Gain, g
16	=Ingredients!B16	90	0	=P24/SUM($P$13:$P$24)	1		Liveweight equivalent price, $/lb
17							*Revenue*
18	*Mix Total, %*			=SUM(E6:E17)			
19	*Mix Total, g*						*Profit*
20							
21	*To copy the current data to the output sheet*						*Feed conversion ratio*
22	*Press the Control and C keys together*						
23							
24							
25							
26							

	H	I	J	K	L	M
1		Ref. $	Pct. Ref.			
2	SBM	=213/20	100			
3	L-Lys HCl	110	100			
4						
5		=V4				
6		=W4				
7						
8		=SUMPRODUCT(C6:C17,E6:E17)				
9						
10		Per chicken				
11		=SUM(P13:P24)				
12		=SUMPRODUCT(C6:C17,P13:P24)/45400				453.88836752012
13						211.357439084041
14						0
15		=AS20+AS21*V27+AS22*W27+AS23*V27*V27+AS24*W27*W27+AS25*V27*W27	Ref. $	Pct. Ref.		30.7789788753746
16		=K17*L17*0.01	0.3425	100		4.41633992648096
17		=MAX(J16*J17/454,0)				10.5797461200373
18						1.94346059306879
19		=J18-J13				1.79093784695147
20						0.573100109995658
21		=J12/J16				1.04678095183866
22						0
23						0
24						
25						
26						

	N	O	P	Q	R	S
1						=Nutrients!C9
2					=Nutrients!D8	=Nutrients!D9
3					=Nutrients!E8	=T26
4					=Nutrients!F8	=Nutrients!F9
5					=Nutrients!G8	%
6					Max Intake, g	
7						
8						
9						
10		Weight, g	Weight in 1kg of feed			=Ingredients!C3
11						
12		453.88836752012	=E6*1000			=Ingredients!C5
13		211.357439084041	=E7*1000			=Ingredients!C6
14		0	=E8*1000			=Ingredients!C7
15		30.7789788753746	=E9*1000			=Ingredients!C8
16		4.41633992648096	=E10*1000			=Ingredients!C9
17		10.5797461200373	=E11*1000			=Ingredients!C10
18		1.94346059306879	=E12*1000			=Ingredients!C11
19		1.79093784695147	=E13*1000			=Ingredients!C12
20		0.573100109995658	=E14*1000			=Ingredients!C13
21		1.04678095183866	=E15*1000			=Ingredients!C14
22		0	=E16*1000			=Ingredients!C15
23		0	=E17*1000			=Ingredients!C16
24						
25						=SUMPRODUCT($E$6:$E$17,T13:T24)
26			=SUM(Q13:Q24)			

	T	U	V
1	=Nutrients!C10	=Nutrients!C11	=Nutrients!C12
2	=Nutrients!D10	=Nutrients!D11	=Nutrients!D12
3	=U26	=V26	=W26
4	=Nutrients!F10	=Nutrients!F11	=Nutrients!F12
5	%	%	%
6			
7	250	10	
8	=V27	=W27	
9			
10	Metabolizable Energy	Protein	LYS
11			
12	=Ingredients!D5	=Ingredients!E5	=Ingredients!F5
13	=Ingredients!D6	=Ingredients!E6	=Ingredients!F6
14	=Ingredients!D7	=Ingredients!E7	=Ingredients!F7
15	=Ingredients!D8	=Ingredients!E8	=Ingredients!F8
16	=Ingredients!D9	=Ingredients!E9	=Ingredients!F9
17	=Ingredients!D10	=Ingredients!E10	=Ingredients!F10
18	=Ingredients!D11	=Ingredients!E11	=Ingredients!F11
19	=Ingredients!D12	=Ingredients!E12	=Ingredients!F12
20	=Ingredients!D13	=Ingredients!E13	=Ingredients!F13
21	=Ingredients!D14	=Ingredients!E14	=Ingredients!F14
22	=Ingredients!D15	=Ingredients!E15	=Ingredients!F15
23	=Ingredients!D16	=Ingredients!E16	=Ingredients!F16
24			
25	=SUMPRODUCT($E$6:$E$17,U13:U24)	=SUMPRODUCT($E$6:$E$17,V13:V24)	=SUMPRODUCT($E$6:$E$17,W13:W24)
26		=SUMPRODUCT(P13:P24,V13:V24)/100	=SUMPRODUCT(P13:P24,W13:W24)/100

	W	X	Y
1	=Nutrients!C13	=Nutrients!C14	=Nutrients!C15
2	=Nutrients!D13	=Nutrients!D14	=Nutrients!D15
3	=X26	=Y26	=Z26
4	=Nutrients!F13	=Nutrients!F14	=Nutrients!F15
5	%	%	%
6			
7			
8			
9			
10	Ether Extract	Linoleic Acid	Crude Fiber
11			
12	=Ingredients!G5	=Ingredients!H5	=Ingredients!I5
13	=Ingredients!G6	=Ingredients!H6	=Ingredients!I6
14	=Ingredients!G7	=Ingredients!H7	=Ingredients!I7
15	=Ingredients!G8	=Ingredients!H8	=Ingredients!I8
16	=Ingredients!G9	=Ingredients!H9	=Ingredients!I9
17	=Ingredients!G10	=Ingredients!H10	=Ingredients!I10
18	=Ingredients!G11	=Ingredients!H11	=Ingredients!I11
19	=Ingredients!G12	=Ingredients!H12	=Ingredients!I12
20	=Ingredients!G13	=Ingredients!H13	=Ingredients!I13
21	=Ingredients!G14	=Ingredients!H14	=Ingredients!I14
22	=Ingredients!G15	=Ingredients!H15	=Ingredients!I15
23	=Ingredients!G16	=Ingredients!H16	=Ingredients!I16
24			
25	=SUMPRODUCT($E$6:$E$17,X13:X24)	=SUMPRODUCT($E$6:$E$17,Y13:Y24)	=SUMPRODUCT($E$6:$E$17,Z13:Z24)
26			

	Z	AA	AB
1	=Nutrients!C16	=Nutrients!C17	=Nutrients!C18
2	=Nutrients!D16	=Nutrients!D17	=Nutrients!D18
3	=AA26	=AB26	=AC26
4	=Nutrients!F16	=Nutrients!F17	=Nutrients!F18
5	%	mg/g	%
6			
7			
8			
9			
10	Calcium	Total Phosphorus	Avail. Phosphorus
11			
12	=Ingredients!J5	=Ingredients!K5	=Ingredients!L5
13	=Ingredients!J6	=Ingredients!K6	=Ingredients!L6
14	=Ingredients!J7	=Ingredients!K7	=Ingredients!L7
15	=Ingredients!J8	=Ingredients!K8	=Ingredients!L8
16	=Ingredients!J9	=Ingredients!K9	=Ingredients!L9
17	=Ingredients!J10	=Ingredients!K10	=Ingredients!L10
18	=Ingredients!J11	=Ingredients!K11	=Ingredients!L11
19	=Ingredients!J12	=Ingredients!K12	=Ingredients!L12
20	=Ingredients!J13	=Ingredients!K13	=Ingredients!L13
21	=Ingredients!J14	=Ingredients!K14	=Ingredients!L14
22	=Ingredients!J15	=Ingredients!K15	=Ingredients!L15
23	=Ingredients!J16	=Ingredients!K16	=Ingredients!L16
24			
25	=SUMPRODUCT($E$6:$E$17,AA13:AA24)	=SUMPRODUCT($E$6:$E$17,AB13:AB24)	=SUMPRODUCT($E$6:$E$17,AC13:AC24)

	AC	AD	AE
1	=Nutrients!C19	=Nutrients!C20	=Nutrients!C21
2	=Nutrients!D19	=Nutrients!D20	=Nutrients!D21
3	=AD26	=AE26	=AF26
4	=Nutrients!F19	=Nutrients!F20	=Nutrients!F21
5	%	%	%
6			
7			
8			
9			
10	Chlorine	Sodium	Choline
11			
12	=Ingredients!M5	=Ingredients!N5	=Ingredients!O5
13	=Ingredients!M6	=Ingredients!N6	=Ingredients!O6
14	=Ingredients!M7	=Ingredients!N7	=Ingredients!O7
15	=Ingredients!M8	=Ingredients!N8	=Ingredients!O8
16	=Ingredients!M9	=Ingredients!N9	=Ingredients!O9
17	=Ingredients!M10	=Ingredients!N10	=Ingredients!O10
18	=Ingredients!M11	=Ingredients!N11	=Ingredients!O11
19	=Ingredients!M12	=Ingredients!N12	=Ingredients!O12
20	=Ingredients!M13	=Ingredients!N13	=Ingredients!O13
21	=Ingredients!M14	=Ingredients!N14	=Ingredients!O14
22	=Ingredients!M15	=Ingredients!N15	=Ingredients!O15
23	=Ingredients!M16	=Ingredients!N16	=Ingredients!O16
24			
25	=SUMPRODUCT($E$6:$E$17,AD13:AD24)	=SUMPRODUCT($E$6:$E$17,AE13:AE24)	=SUMPRODUCT($E$6:$E$17,AF13:AF24)
26			REQ'D

	Cost ($/100 Pounds)				Usage Level				Protein	Lysine	Diet	Profit	Body	FCR
	Corn	SBM	CGM	L-Lys	Corn	SBM	CGM	L-Lys	Level %	Level %	Cost $/cwt.	/Bird	Weight	
				Current Prices, "Least-Cost" Formulation with NRC (1994) "Requirements"										
18	5.5	10.65	13.25	110	54.04%	37.39%	0.00%	0.00%	23	1.247	8.313	0.21133	444.90	1.525
				Current Prices, "Maximum-Profit" Formulation										
17	5.5	10.65	13.25	110	53.51%	37.84%	0.00%	0.00%	23.17	1.259	8.342	0.21134	444.07	1.515
				Increase SBM Price from 50% to 300% of Current										
16	5.5	6.39	13.25	110	49.36%	41.35%	0.00%	0.00%	24.52	1.352	6.802	0.23593	442.05	1.472
15	5.5	8.52	13.25	110	51.59%	39.47%	0.00%	0.00%	23.79	1.302	7.604	0.22346	443.51	1.495
14	5.5	10.65	13.25	110	53.51%	37.84%	0.00%	0.00%	23.17	1.259	8.342	0.21134	444.07	1.515
13	5.5	12.78	13.25	110	55.38%	36.26%	0.00%	0.00%	22.5	1.217	9.014	0.19955	444.19	1.536
12	5.5	14.91	13.25	110	57.20%	34.72%	0.00%	0.00%	21.97	1.176	9.624	0.18810	443.88	1.559
11	5.5	17.04	13.25	110	58.98%	33.21%	0.00%	0.00%	21.39	1.136	10.17	0.17699	443.14	1.584
10	5.5	19.17	13.25	110	60.81%	31.66%	0.00%	0.00%	20.79	1.095	10.65	0.16621	442.15	1.613
9	5.5	21.30	13.25	110	62.43%	30.29%	0.00%	0.00%	20.27	1.058	11.09	0.15578	440.40	1.639
8	5.5	23.43	13.25	110	64.03%	28.93%	0.00%	0.00%	19.75	1.022	11.47	0.14569	438.28	1.669
7	5.5	25.56	13.25	110	65.68%	27.54%	0.00%	0.00%	19.21	0.985	11.79	0.13593	435.86	1.702
6	5.5	27.69	13.25	110	67.26%	26.20%	0.00%	0.00%	18.70	0.950	12.07	0.12651	432.96	1.738
5	5.5	29.82	13.25	110	68.81%	24.89%	0.00%	0.00%	18.19	0.915	12.29	0.11743	429.64	1.776
				At 300% of Normal SBM Price, Lysine is Finally Used in the Solution										
4	5.5	31.95	13.25	110	72.52%	21.73%	0.00%	0.02%	17	0.847	11.97	0.10871	425.84	1.891
				Increasing L-Lysine HCl Price by 50% Removes it From the Solution										
3	5.5	31.95	13.25	165	70.31%	23.62%	0.00%	0.00%	17.70	0.881	12.47	0.10869	425.84	1.816
				Decreasing L-Lysine HCl Price by 50% Increases it in the Solution										
2	5.5	31.95	13.25	55	72.54%	21.71%	0.00%	0.03%	17	0.853	11.96	0.10895	425.27	1.890
				Increasing the Value of Live Weight by 50% Increases Bird Weight @ Maximum Profits										
1	5.5	10.65	13.25	110	62.81%	29.97%	0.00%	0.00%	20.14	1.050	7.845	0.38425	468.20	1.799