THE IMPACT OF DIET ENERGY AND AMINO ACID CONTENT ON THE FEED INTAKE AND PERFORMANCE OF BROILER CHICKENS

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ABSTRACT

Three experiments were conducted to understand the effect of dietary energy and amino acids, and their interactions on broiler performance. To ensure accuracy of feed formulation, a trial was completed at two ages (5 or 6 and 21 days of age) to determine the digestibility of feed ingredients to be used in research diets. Apparent metabolizable energy (AME) and apparent ileal amino acid digestibility (AID) values were applied to feed formulation on an age appropriate basis. The second experiment investigated the effect of dietary energy content and bird age on broiler feed intake. Diets containing 2700, 2800, 2900 and 3100 kcal/kg AME were fed to broiler chickens with the introduction of the range of energy diets starting at the beginning of starter (S; 0-10 day), grower (G; 11-25 day) or finisher (F; 26-35 day) phases. The digestible amino acid (DAA) content in all the diets met or exceeded Aviagen 2007 recommended values. The broiler chickens did not adjust their feed intake based on energy content of the diet and there was no effect of age of treatment introduction. A final study investigated the effect of dietary energy on broiler feed intake and also examined the relationship between dietary energy and DAA levels. The 4 x 3 factorial arrangement utilized diets containing 2700, 2800, 2900 and 3100 kcal/kg AME and three levels of digestible lysine (0-10 days - 1.14, 1.02 and 0.89%; 11-25 days - 0.99, 0.88 and 0.77%; 26-35 days - 0.87, 0.78 and 0.68%). Feed intake was not affected by dietary energy at the two highest lysine levels. Feed intake decreased with increasing energy levels at the lowest level of digestible lysine as did body weight, and carcass and BY (breast meat yield). Growth rate, feed efficiency and BY increased with AME level at the highest dietary lysine, but were not

affected at the moderate lysine content. In conclusion, broiler chickens in these experiments do not adjust their feed intake based on dietary energy levels and the results indicate that energy should be provided in the diet to meet maintenance requirements and match the protein synthesis capacity of the dietary level of amino acids.

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LIST OF ABBREVIATIONS

AA - Amino Acid/s

ADC - Apparent Digestibility Coefficient

AGRP - Agouti-Related Peptide

AID - Apparent Ileal Amino Acid Digestibility

AME - Apparent Metabolizable Energy

AMEn - Apparent Metabolizable Energy with Nitrogen Correction

BW - Body Weight

BY - Breast Meat Yield

CART - Cocaine- and Amephetamine-Regulated Transcript

CY - Carcass Yield

d - day/s

DAA - Digestible Amino Acid

F - Finisher

FE - Feed Efficiency

FI - Feed Intake

G - Grower

GE - Gross Energy

hr - hour/s

ME - Metabolizable Energy

NE - Net Energy

NPY - Neuropepetide Y

PDI - Pellet Durability Index

POMC - Pro-Opiomelanocortin

PROC GLM - General Linear Models Procedure

S - Starter

SEM - Standard Error of the Mean

SIAAD – Standardized Ileal Amino Acid Digestibility

TID - True Ileal Amino Acid Digestibility

TME - True Metabolizable Energy

TMEn - True Metabolizable Energy with Nitrogen Correction

1.0 Introduction

Broiler chickens require dietary energy and amino acid (AA) for maximum production and growth. These two nutrients are not only important for optimal performance, but are also for profitability since most of the feed is composed from these two nutrients. Determining accurate values of energy and AA in feed ingredients and then using these values in formulating diets that are close to the broiler chicken's nutrient requirement improves production efficiency.

Metabolizable energy (ME) is an energy measurement generally used in poultry nutrition for diet formulation (Sibbald, 1982). The two common methods to determine ME are apparent metabolizable energy (AME) and true metabolizable energy (TME). Both methods have their advantages and disadvantages and also are usually corrected for nitrogen retention. Having accurate values for ingredient ME is important because of the potential to affect poultry performance and meat yield (Summers et al., 1992; Leeson et al., 1996; Plumstead et al., 2007).

An important effect on diet ME is its impact on feed intake (FI). Chickens can change their FI according to the energy level of the diet in order to maintain similar energy intake (Leeson and Summers, 2005). In turn, this has implications for the levels of other nutrients in the diet because of the desirability of avoiding over and under formulation because of changes in FI. There are indications that the broiler's ability to maintain energy intake in response to changes in diet energy may be affected by bird age, with younger birds less able to adapt because of digestive tract limitations (Jones and Wiseman, 1985; Brickett et al., 2007; Kamran et al., 2008). However, others have suggested that because of the intense genetic selection for growth, modern broiler chickens may not be able to regulate their FI to meet their energy requirements (Plumstead et al., 2007). As with young birds, it may be that broiler FI may now be based on the physical limitations of the bird (gut capacity). The lack of clarity and the importance of this response to basic feed formulation support the need for further research in this area.

Indispensable and dispensable AA are important for growth and the requirement for both should be met in poultry diets. These AA also have to be balanced to maintain broiler performance and meat yield (Munks et al., 1945; Emmert and Baker, 1997; Baker, 2003). Not only should the indispensable and dispensable AA requirement be met and balanced, but feed formulation must also be based on digestible amino acid (DAA) instead of total AA to permit precise diet creation (Khaksar and Golian, 2009). Complicating accuracy of formulation is the variation of digestibility values due to the method of determination and the age of the bird used (Batal and Parsons, 2002; Garcia et al., 2007).

The importance of dietary energy and AA as individual nutrients in broiler diets is established above, but of equal significance is the relationship between them. This is particularly true if either nutrient class impacts FI as has been generally agreed to be the case for dietary energy. However, if broilers do not adapt to dietary energy (Plumstead et al., 2007), the relationship would more likely relate to the levels of each nutrient required for maintenance and growth. Understanding the impact of dietary energy on FI and as a consequence the relationship to AA has important implications on broiler feed formulation and prediction of broiler performance.

The research described in this thesis focused on the impact of dietary energy on FI as well as its relationship to AA. The hypothesis for this research was that FI regulation is age dependent. Young broiler chickens do not regulate their FI with different energy content of the diet due to the limited gut capacity and will change their FI based on dietary energy levels at an older age. Additionally, FI response to dietary energy will change according to the dietary AA content. The objective of this research was to clarify the relationship between dietary energy levels and FI in broiler chickens at different ages as well as to investigate the relationship between dietary energy and AA levels on broiler performance. This thesis will also summarize the importance of dietary energy and AA, methods to determine their digestibility, and their impact on poultry performance and meat yield.

2.0 Literature Review

2.1 Energy

Energy is an important nutrient that is required for optimum growth and performance of broiler chickens. While fat and protein are used as sources of energy, the majority of the energy in poultry diets is obtained from carbohydrates and in particular starch. ME is the energy estimate used in poultry nutrition and can be measured without (AME) or with correction for endogenous losses (TME). Historically, it has been accepted that chickens adjust their FI based on the energy level of the diet and the chickens eat to meet their energy requirement (Leeson and Summers, 2005). Whether this is still the case in intensively growth selected broiler chickens is not clear as contradictory results can be found in the scientific literature.

2.1.1 Definition of energy in animal feed

Energy is expensive, is a large portion of a poultry diet, and is important for animal maintenance, production and growth (Sibbald, 1982). The total energy in a diet is termed gross energy (GE) and is measured using a bomb calorimeter, which measures the heat of combustion. GE has little value in formulating animal diets because it does not account for how much of the energy is digested or utilized. Various definitions of energy are used in animal feeding and basic principles of their definition are shown in Figure 2.1. For energy to be utilized by the animal it must be digested, and subtraction of the undigested component of the diet from the GE yields digestible energy. This term has been commonly used in swine feeding. If the energy that is lost in urine is subtracted from dietary energy, the resulting value is termed ME. This takes into account energy that is absorbed, but subsequently excreted in the urine. ME is the primary method of defining dietary energy for poultry diets due to the difficulty of separating feces and urine in excreta. Because of its importance in feeding poultry, it will be discussed in more detail later in this chapter. Finally, if the energy required to utilize nutrients is accounted for and subtracted from ME, the resulting energy left for maintenance and production is defined as net energy (NE). NE has increasingly been chosen as the definition of choice in swine feeding, but it has not yet been adopted for use in poultry feeding.

2.1.2 Source of energy in poultry diets

Dietary components that provide energy to birds include carbohydrates, fat and protein. Most energy is derived from carbohydrate and in poultry this is mostly starch. Cereal grains such as corn, wheat and barley are the main sources of carbohydrates that are fed to birds. Fat (lipid) is found at low levels in many feed ingredients and also is added in concentrated forms such as vegetable oils and tallow to poultry diets. Fat is primarily in the form of triglycerides and can make an important contribution to feed ME because it has 2.25 times more GE than carbohydrates (Coon, 2002b). Fats included in the diet are thought to improve feed efficiency (FE) and growth of broiler chickens (Leeson and Summers, 2001). This is may be partially due to the slow digestion that occurs with addition of fat to a diet, which results in more efficient use of other nutrients. Fat can be highly palatable and as a result may increase FI and thereby improve broiler performance.

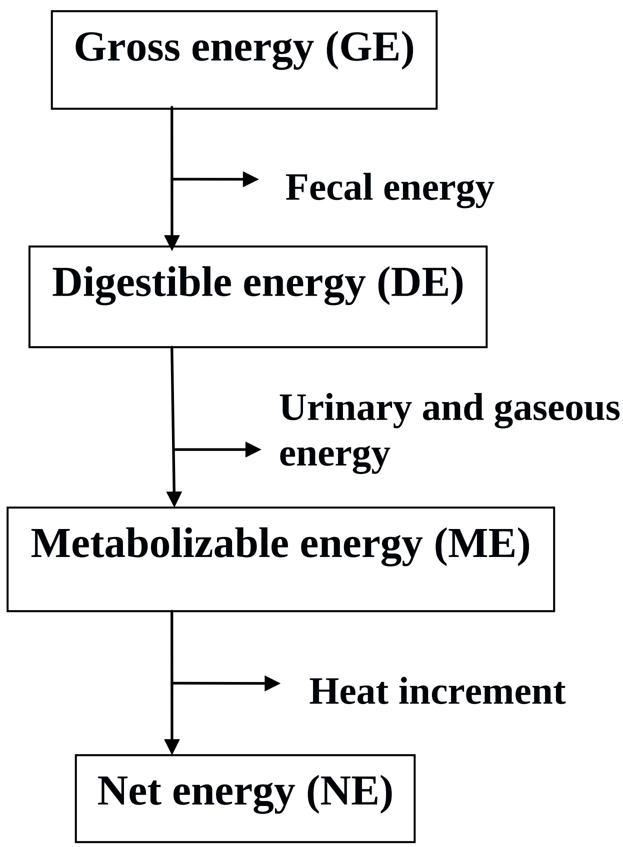

Figure 2.1. Energy partitioning used in animal feeding and nutrition (Sibbald, 1982).

Fat increases the ME content of the diet, but young chicks may not be able to digest and absorb them as effectively as older birds. Research found that White Leghorn male chicks do not utilize vegetable oil and animal fat efficiently when less than seven days (d) of age (Carew et al., 1972). This is particularly the case for fats that contain high levels of saturated long chain fatty acids. However, fat absorption increases as the chick ages (especially saturated animal fat) reaching its maximum absorption at two weeks of age. The reason for the limited fat absorption in young birds is not well understood, but may relate to levels of digestive tract lipase (Noy and Sklan, 1995).

Protein can be used as a source of energy when carbohydrate and fat sources are short of supply. However, protein is an inefficient source of energy. Protein use for energy involves AA catabolism to supply energy and excretion of part of the energy as uric acid. Hence, using protein as an energy source may result in reduction in growth and performance in chickens when dietary energy is insufficient to meet the bird's needs.

2.1.3 Measuring metabolizable energy in poultry

As noted above, ME is the primary energy value used in poultry feed formulation and because of the economic importance of accurately assessing diet energy, research in this area has been extensive for approximately 60 years. Although a variety of techniques have been studied to estimate ME, two primary types of ME estimation have remained in use. Classic ME estimation measures energy excreted in the feces and urine of test animals and then subtracts this value from the GE consumed (Sibbald, 1982). This technique is more appropriately termed AME since it does not account for the metabolic portion of energy excreted in the feces and urine. Feces and urine contain energy from the feed and metabolism. The metabolic fraction contains bile, intestinal cells and secretions that may be found in feces. The failure to account for this loss is not critical when FI is high because the metabolic loss represents a small proportion of the total undigested component of the diet. However, if FI of test animals is low, this value becomes an increasing proportion of the energy found in feces and urine, and thereby reduces the accuracy of the ME estimation. This is shown in Figure 2.2.

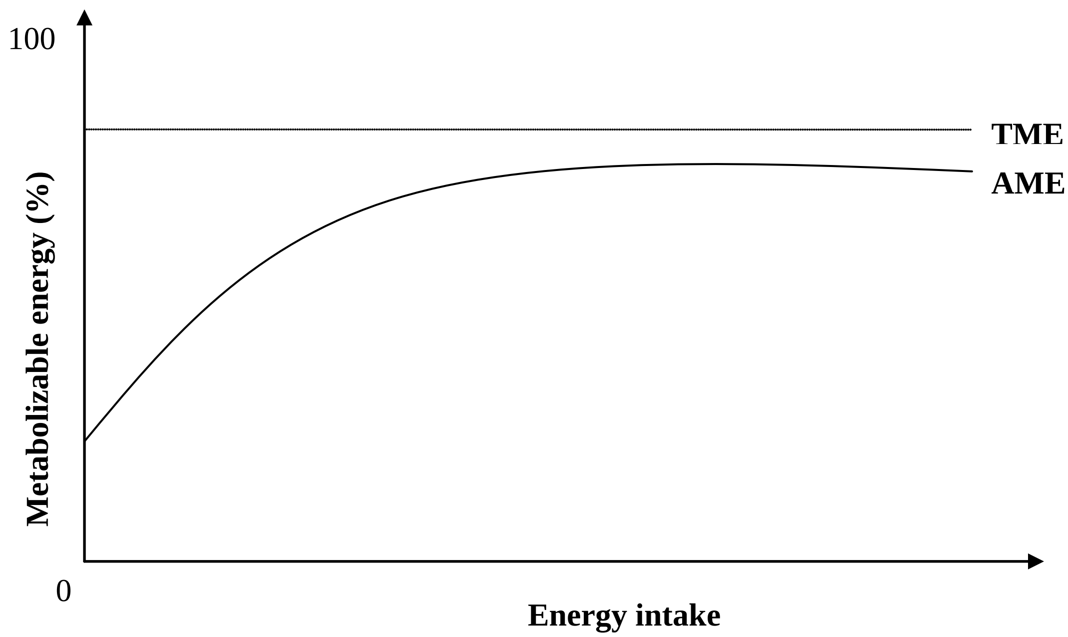

Figure 2.2. The theoretical AME and TME relationship with energy intake (Sibbald, 1982; Wolynetz and Sibbald, 1984).

Tests for AME either use a total collection procedure where all feces and urine are collected and related to FI, or an indigestible marker based approach, which uses changes in marker concentration to relate fecal energy to ingested energy. Due to potential feed spillage and other material such as feathers becoming incorporated into excreta samples, use of an indigestible marker such as chromic oxide (Driver et al., 2006) and acid insoluble ash (Lammers et al., 2008) has been recommended (Sibbald, 1982).

TME is an alternate method of measuring ME and as implied by the name, attempts to correct for the metabolic fraction of fecal and urine energy (Farrell, 1981; Sibbald, 1982). Although details of the procedure can vary, it usually involves precision feeding a limited amount of test material into the crop of a fasted bird (48 hours (hr)) and then collecting excreta for next 48 hr. Metabolic portions of energy in the feces and urine are measured by collecting excreta for 48 hr from fasted birds that have not been fed. The energy derived from this collection is then used to correct (lower) the ME values derived for test ingredients. Fundamental concerns about this procedure for estimating the metabolic fraction of energy in excreta are that it is not specific for ingredient and that the starvation period does not represent a normal physiological state.

Metabolizable energy is usually corrected for nitrogen retention and is then expressed as apparent metabolizable energy with nitrogen correction (AMEn) and true metabolizable energy with nitrogen correction (TMEn). Nitrogen correction is done to account for differences in protein synthesis and catabolism by test animals, which affects the energy derived from the protein. Nitrogen retention varies with age, strain and poultry species, and its impact is greater if high protein ingredients such as soybean meal are used in diets (Lopez and Leeson, 2008). Birds that retain more nitrogen in their body, such as in fast growing birds, are able to obtain more energy than slow growing birds. This is because birds with less protein deposition would only obtain 4.4 kcal/g of energy compared to 5.7 kcal/g of energy in birds with more protein deposition (Pesti et al., 2005). Hence, to improve accuracy and precision as well as to make the value more applicable to a wider range of ages and genotypes, nitrogen correction is important.

The debate on which method of ME estimation is superior has been extensive and ongoing for many years. A study concluded that TMEn is the most practical and effective method because the ME is not affected by FI of the bird while AMEn is affected (Wolynetz and Sibbald, 1984). AMEn values are affected by the bird's FI, but as mentioned earlier birds are more in a normal physiological condition than TMEn. Additionally, TMEn may over- or underestimate the value for energy when high amounts of fibre are used in the feed (Boldaji et al., 1986; Francesch et al., 2002). Therefore, AMEn was used in this study to measure digestibility of feed ingredients in birds under a more normal physiological condition.

Establishing the response of birds to dietary energy has important economic consequences and as result has been the focus of considerable research and this review will focus on more recent publications.

2.1.4 Effect of varying energy on broiler production

Dietary energy content in the diet can affect broiler performance including growth, FI and carcass characteristics. With increasing dietary energy level in relationship to the dietary AA, more fat is generally deposited in the carcass (Summers et al., 1992; Leeson et al., 1996). This is explained in greater detail in later sections. The growth of broiler chickens may be related to FI of the bird. When broiler chickens are able to adjust their FI based on the dietary energy level (within a moderate range) to maintain similar energy intake, the dietary energy has no effect on broiler growth (Leeson et al., 1996). However, when broiler chickens are not able to regulate their FI based on dietary energy, there can be reduced broiler growth (Plumstead et al., 2007).

Historically, it is known that as the energy content of feed decreases, there is an increased FI in chickens as they attempt to maintain energy intake. This supports the theory that birds consume feed to meet or maintain their energy requirement. For the most part, this has been found, even though the internal mechanism controlling FI in the bird may not be perfect and as a consequence birds may consume more energy when fed higher energy diets (Leeson and Summers, 2005).

Research on the ability of broiler chickens to adjust FI to match diet energy has been contradictory. Some research is supportive of the classic theory described above (Leeson et al., 1996; Dozier III et al., 2006), while other research has suggested that broiler chickens are no longer able to adjust their FI according their energy requirement (Plumstead et al., 2007). The latter study suggests that broilers eat to physical capacity rather than an energy control point. This study found constant FI despite ME levels ranging from 3000 to 3100 kcal/kg in the diet of broiler chickens fed from 0 to 21 d of age. However, this lack of change in FI may be due to the physical limitation of the young bird or failure of the experiment to identify differences because of the small range of energy levels in the research.

2.1.4.1 Impact of age on the broiler's response to dietary energy level

There may be an age effect on the bird's ability to adjust FI based on the different energy levels of the diet. Young birds may not be able to eat to meet their energy requirement. When birds are young, there may be a limit to the amount of feed that can be consumed due to their undeveloped organs such as the crop, which with distension reduces FI (Ferket and Gernat, 2006). Reduced feed consumption occurs because pressure sensitive receptors in distended organ transmit signals to the brain. The brain then perceives satiety resulting in a drop in FI. Research has indicated that broiler chickens are not able to adjust their FI in proportion to diet energy before two weeks of age, but are more able to do so at an older age (Jones and Wiseman, 1985; Brickett et al., 2007; Kamran et al., 2008). It has been suggested that FI is determined by the energy requirement of broiler chickens only if it is not limited by physical limitation of crop fullness or various other factors (Ferket and Gernat, 2006).

2.1.4.2 Mechanism of feed intake

The historical concept of birds adjusting their FI based on dietary energy levels may be explained by one or both of the glucostatic and lipostatic feed regulation theories (Ferket and Gernat, 2006). The glucostatic theory is related to the blood glucose level. Birds attempt to maintain glucose level by suppressing their appetite when blood glucose is high, and increasing their appetite when there is low glucose in the blood. According to the lipostatic theory, birds increase their FI when body fat is low and decrease their feed consumption with high body fat. This is an internal mechanism to maintain a specific amount of body fat. However, these theories have not been completely confirmed by other scientific studies and their impacts on the bird's ability to regulate energy intake are not clear. Furthermore, these theories may not apply to the modern broiler chickens that have been genetically selected for growth for many years. Intense selection of this nature may have affected bird physiology and in particular the satiety mechanism(s) that regulates FI. Selected broiler chickens may eat to physical capacity instead of nutrient requirement due to changes in the hypothalamic control of FI (Burkhart et al., 1983). A study found that broiler chickens have different satiety and hunger system than layer chickens. Broiler chickens may be constantly hungry and eat to physical capacity, which is in agreement with the previous statement (Bokkers and Koene, 2003). The exact reason(s) why selected broilers may have lost capacity to control FI has not been determined, but it may be associated with the neuronal cells in the medio-basal hypothalamus and the production of chemicals such as neuropeptide Y (NPY), agouti-related peptide (AGRP) and pro-opiomelanocortin (POMC) that are related to FI regulation (Boswell, 2005). The hypothalamic control of FI is complex in birds and although mammalian controlling agents are also found in chickens, there are also significant differences in their effects. If the hypothalamus and the satiety mechanism have changed, the glucostatic and lipostatic theories may no longer explain the FI regulation in modern broiler chickens. Hence, further study on dietary energy and FI regulation in broiler chicken is needed.

2.2 Protein and amino acids

Protein and AA are vital nutrients for broiler growth and meat yield. This is because AA are required for protein synthesis, which in turn serves many bodily functions such as hormones, enzymes and muscle; the latter is of importance in the broiler industry where it is harvested for human food. Because of the cost of protein and its importance in growth and meat yield, formulating diets that match the AA requirements of the bird avoids costly losses due to deficiency and avoids excessive costs due to over formulation (Emmert and Baker, 1997; Khaksar and Golian, 2009). The ideal protein concept of formulating diets ensures that AA levels not only meet the bird’s minimum requirements but are also balanced to avoid catabolism of excessive AA.

2.2.1 Indispensable amino acids

Indispensable AA are required in animal feed and are defined as “AA which cannot be synthesized by animal” (Coon, 2002a). These AA include methionine, arginine, tryptophan, threonine, histidine, isoleucine, leucine, lysine, valine, and phenylalanine (Munks et al., 1945). Conditionally, indispensable AA such as glycine, serine, and proline can be synthesized by the bird, but rapidly growing chickens may not produce enough of these AA to meet the requirement for optimal growth. Limiting AA refers to the lowest indispensable AA that is found in an animal’s diet because it is the limiting AA in protein synthesis. The most limiting indispensable AA in practical poultry diets is usually methionine. Methionine is first limiting in poultry because of the importance of sulphur AA in feather growth as well as its other functions of serving as a methyl donor, being used for taurine synthesis and being an indispensible AA in protein synthesis (Patrick and Schaible, 1980). Generally the second limiting AA in poultry diets is lysine while the third limiting AA is variable and dependent on the nature of the diet (Kidd et al., 1999). Tryptophan and threonine are commonly third limiting. If sufficient indispensable AA is not in the diet, it negatively affects broiler performance and meat yield (Han et al., 1991; Kidd et al., 1999; Kidd et al., 2000; Sklan and Plavnik, 2002). Growth and carcass yield (CY) increases with sulphur amino acid supplementation in the basal diet (Huyghebaert and Pack, 1996), which demonstrates the first limiting nature of methione and the importance of cysteine and methionine in broiler growth and meat yield. Other indispensable amino acids such as lysine, isoleucine, threonine, histidine and threonine are similarly required in appropriate amounts to reach to the genetic potential of broilers for growth and performance (Han et al., 1991; Kidd et al., 1999; Kidd et al., 2000; Sklan and Plavnik, 2002).

2.2.2 Dispensable amino acids

Dispensable AA such as alanine and glutamine are AA that birds synthesize in enough quantity to meet their requirements. Including dispensable AA as part of diet formulation is important since it can have an impact on broiler performance especially if diets are low in protein (Corzo et al., 2005). This may be because dispensable AA is associated with protein synthesis as well as many metabolic functions (Wu, 2009). For instance, alanine is involved in gluconeogenesis and transamination and glutamine is important for NAD(P) synthesis and protein turn over regulation. Formulating diets to have optimum balance between indispensable and dispensable AA is essential to obtain maximum broiler performance. If an indispensable or dispensable AA is deficient, broiler performance including FE and body weight (BW) gain will decrease (Sklan and Plavnik, 2002). Hence, formulating a diet with certain amount of dispensable AA as well as creating a diet with appropriate ratio between indispensable and dispensable AA is important for broiler growth and performance.

2.2.3 Amino acid digestibility

Amino acids provided in the diet are not all digested in the small intestine and therefore, determining the digestibility of AA in ingredients is considered important to formulating diets appropriately and accurately (Leeson and Summers, 2001). Considerable research has been conducted comparing diets formulated based on DAA and total AA (Rostagno et al., 1995; Farrell et al., 1999; Ghaffari et al., 2007a; Ghaffari et al., 2007b; Khaksar and Golian, 2009). In some cases no differences in broiler performance were found between diets formulated on a digestible (DAA) or total AA (Farrell et al., 1999; Ghaffari et al., 2007a), while others found improved performance by using digestible values (Ghaffari et al., 2007b; Khaksar and Golian, 2009). The variation in response is undoubtedly ingredient specific with less benefit to be derived when feeding diets that are high in DAA (Farrell et al., 1999). Feed ingredients that have low digestibility benefit from using DAA in diet formulation and therefore this method is recommended. Using DAA in feed formulation also allows creation of feeds that are closer to the bird's AA requirement by avoiding under and over formulation of the diet (Rostagno et al., 1995). In turn this increases profitability in broiler production (Dari et al., 2005).

"Digestibility of a nutrient" is the portion of the nutrient in the feed that is absorbed in the bird's small intestine (Hoehler et al., 2005). It can be calculated by using the equation that includes AA intake from diet and AA excreted from the bird. While there are digestibility coefficients available, the value may vary depending on the methods used to estimate them. Two commonly used methods to determine AA digestibility are apparent ileal digestibility (AID) and true ileal digestibility (TID). The general concepts of these methods are similar to AME and TME which was mentioned in previous section. Apparent and true ileal digestibility values primarily differ because of the correction for endogenous losses but can also be impacted by the type of experimental birds used (Huang et al., 2007).

Several methods are currently being used to determine AID and TID and they include slaughter, cannulated, and cecectomized methods (Hoehler et al., 2005). The slaughter method involves surgically removing the bird's ileum after the birds are euthanized. The sample of digesta is collected from the ileum to be analyzed. Although this is a common method, it requires the use of many animals as well as an indigestible marker to permit digestibility calculation. The cannulated method involves the surgical insertion of a cannula at the end of the bird's ileum to obtain digesta samples. Highly trained individuals are required to surgically insert and remove the cannula, and again an indigestible marker is needed in this method. Both methods collect the digesta at the ileum to avoid any fermentation and modification of AA content that might occur in the large intestine and cecum. In the cecectamized method, the ceca are surgically removed and excreta is directly collected for digestibility analysis. This method does not require bird termination to collect samples. Apparent ileal digestibility is determined with the methods mentioned above. However, TID must be determined using different methods because an estimation of endogenous losses is required for this technique.

TID is obtained by measuring basal endogenous losses produced by the small intestine such as from sloughed cells, enzymes and hormones (Ravindran and Bryden, 1999; Hoehler et al., 2005). Total endogenous AA losses include basal endogenous losses, ingredient specific endogenous losses and undigested dietary AA (Figure 2.3). Basal endogenous losses are associated with dry matter intake and do not change with increased AA intake. Ingredient specific endogenous losses are influenced by the composition of the feed ingredient such as presence of anti-nutritional factors and they change with protein intake. The precision fed method is similar to the collection of endogenous losses in the TME technique and involves removing feed from birds for 48 hr and then collecting the excreta (Ravindran and Bryden, 1999) for an additional 48 hr. Although it may be a more easily performed method, the estimation of endogenous loss may be inaccurate due to fasting, an unnatural physical condition of the bird. Hence, feeding a protein free diet to birds using the precision fed assay for measuring endogenous losses may be a better method. However, providing a protein free diet has a disadvantage as well. It has been criticized for not providing sufficient protein to allow for the production of enzymes and other proteins that are normally part of the endogenous loss. Highly digestible protein such as casein in the diet stimulates protein synthesis and digestive tract secretions, and thereby can overcome the limitations of the protein free diet.

Standardized ileal amino acid digestibility (SIAAD) is a recently developed method, which estimates the endogenous losses in growing birds in a more physiologically normal condition similar to AID. It corrects and takes into account the basal endogenous losses and uses the slaughter method. Birds are fed a standard diet until 14 d of age (Golian et al., 2008). Following this, the birds are provided with test diets, which include a nitrogen free diet or a hydrolyzed casein test diet to determine the endogenous losses. Ileal digesta are collected when the birds are approximately 21 d of age. This procedure has the advantage of estimating basal endogenous ileal losses in a more physiologically normal condition compared to TID due to unlimited feed and water provided throughout the digestibility trial. Birds fed with hydrolyzed casein may have higher amount of endogenous losses compared to nitrogen free diet fed birds (Golian et al., 2008). This is due to the synthesis and secretion of endogenous protein that is induced by hydrolyzed casein. However, others have found no difference in endogenous loss when a regression analysis is completed based on the feeding of graded levels of hydrolyzed casein or nitrogen free diets to experimental birds (Adedokun et al., 2007b; Golian et al., 2008). As an example, meat and bone meal SIAAD values observed for birds at 21 d of age were similar when a nitrogen free diet was fed or the regression method was used with highly digestible casein (Adedokun et al., 2007b).

The digestive capacity of young chicks is inferior to older birds and therefore AMEn values and AA digestibility may be different between young and old broiler chickens (Batal and Parsons, 2002; Garcia et al., 2007). The degree of difference between older birds is ingredient specific, which suggests a need to complete digestibility experiments in both age classifications to ensure accurate diet formulation. In addition it raises the question of whether digestibility assays completed with adult chickens reflect the digestibility values of broiler chickens.

2.2.4 Ideal protein

The ideal protein concept is based on formulating diets that have a balanced proportion and appropriate amount of indispensable and dispensable AA. Lysine serves as the reference AA and other indispensible AA are formulated to be proportional to the lysine level (Emmert and Baker, 1997; Baker, 2003). Despite mostly being the second limiting AA in poultry, lysine is chosen as the reference AA because of its importance in protein synthesis for meat production and the fact that it is easier to analyze than methionine (Emmert and Baker, 1997). Hence, in most cases, the ratios of other AA to lysine are used for diet formulation. This results in formulation of balanced diets that minimize AA catabolism associated with AA levels that are above the bird's requirement.

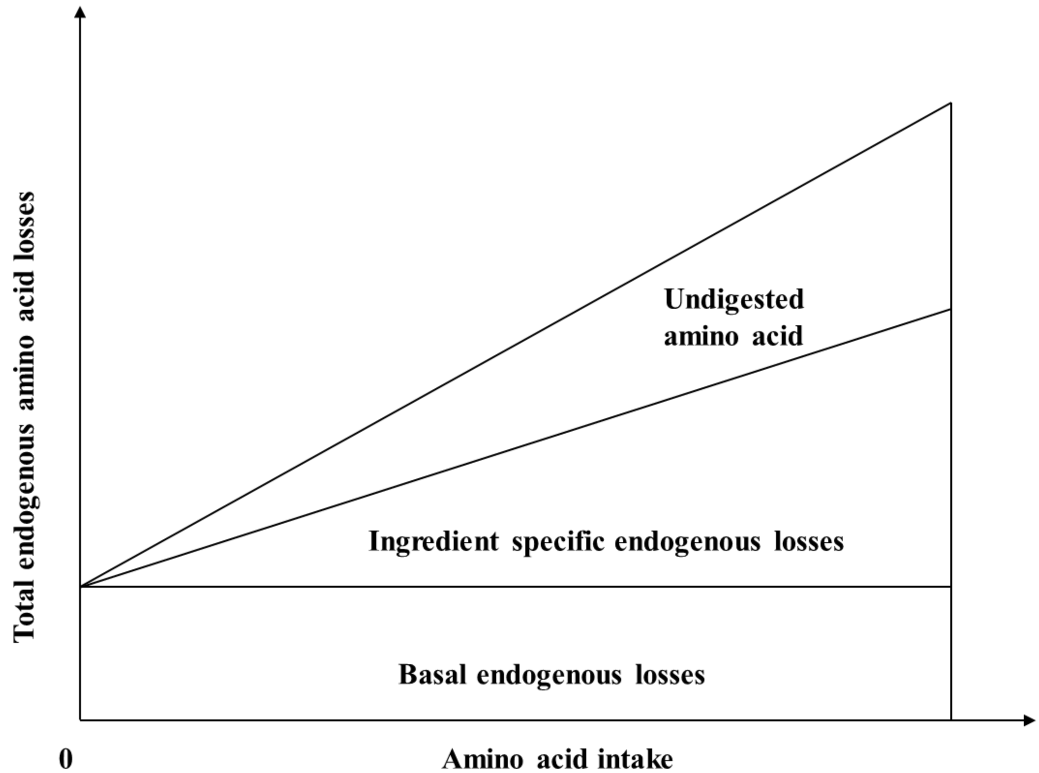

Figure 2.3. Change of proportion of various endogenous losses with different FI (Hoehler et al., 2005).

Research has been completed to determine the ideal AA profile, on a DAA basis, for broiler chickens (Baker and Han, 1994; Mack et al., 1999). The ideal AA ratio relative to digestible lysine (%) from 0 to 21 d of age is estimated to be: sulfur AA, 72%; threonine, 67%; valine, 77%; arginine, 105%; histidine, 32 %; isoleucine, 67%; tryptophan, 16%; leucine, 109%; and phenylalanine and tyrosine, 105% (Baker and Han, 1994). Furthermore, the ideal AA profile relative to digestible lysine (%) for 20 to 40 d of age is estimated to be: sulfur AA, 75%; threonine, 63%; valine, 81%; arginine, 112%; isoleucine, 71%; tryptophan, 19% (Mack et al., 1999).

2.2.5 Amino acid and feed intake regulation

The level and balance of AA can influence FI in chickens (Forbes, 2005). If a diet is slightly deficient in an AA there may be an increase in FI to compensate for the limiting AA. However, if the AA deficiency or imbalance is severe, there will be a decrease in FI. Because of the decrease in feed consumption and nutrient intake associated with severe AA deficiency or imbalance, there is also growth depression in the animal. The mechanism for this effect is not clear, but an AA theory suggests that the balance and amount of AA circulating in the blood regulate FI (Ferket and Gernat, 2006). The brain is able to detect the decrease in specific AA from the blood and it signals a reduction in FI (Tobin and Boorman, 1979).

2.3 Relationship between dietary energy and amino acid level

Dietary energy and AA constitute a large portion of the diet and are also expensive nutrients. Hence, to have optimal growth and a cost efficient diet, feed should be formulated to meet the bird's requirement while not providing excessive nutrients. To create a diet that is cost efficient, understanding FI of the bird and the relationship between dietary energy and amino acid is essential.

2.3.1 Impact of feed intake on diet formulation

Because of the economic and production importance of energy and AA in animal diets, it is essential to understand how their levels relate to each other. This is specifically relevant to FI, which plays a vital role in determining nutrient intake. If birds are able to adjust their FI according to the energy content of the diet, it would be possible to reduce the AA content of low energy diets. This is because birds would consume more of the low energy diet and therefore the amino acid content could be reduced in proportion to maintain the same level of intake. It would be logical to adjust the AA content of the diet according to the FI of the bird. Protein and AA are known to be expensive and hence adjusting the AA content in the diet based on the bird's FI would prevent providing an excess amount of AA to the birds and would be cost effective. A few studies have implemented that concept to their research (Skinner et al., 1992; Hildalgo et al., 2004; Brickett et al., 2007). However, if birds are not able to adjust their FI according the energy content of the diet, this may not be an appropriate strategy. In this case, dietary AA would be considered independent from the dietary energy content, and energy and AA would be considered separately when formulating diets. If broilers no longer respond to dietary energy the relationship between the energy and AA would more appropriately be based on providing sufficient energy in the diet for maintenance and to allow the protein synthesis of the diet amino acid content to be maximized.

2.3.2 Requirement for energy and protein for bird maintenance and productivity

Energy and protein are essential for growth and meat yield in birds and optimal levels of both nutrients should be included in the diet to maximize production. When a diet has high energy in relationship to its AA content, body fat increases (Sibbald and Wolynetz, 1987; Summer et al., 1992). This is due to the low protein content compared to the energy level of the diet. The energy that could not be used for protein synthesis because of the low dietary protein content would be deposited as fat. If the diet has high AA in relationship to its energy content, there would be increase in meat yield and less body fat (Summer et al., 1992). Hence, it is logical to think that there is a relationship between dietary energy and AA. If there is, diets should be formulated based on this relationship while maintaining a balance between the two nutrients. However, if birds respond independently to dietary energy and AA, the diets can be formulated based specifically on dietary energy and DAA content.

2.5 Economic implications of energy and protein in animal feeding

Feed comprises 55-60% of the input cost in broiler production (Sibbald, 1982). Thus, energy and AA, which are the major nutrients included in the diet are expensive and are key factors determining the cost of broiler production. Feed cost can be reduced by decreasing the energy and/or AA content in the diet, but this must be counterbalanced by potential losses in broiler performance such as BW gain, FE and meat yield (Corzo et al., 2005; Kidd et al., 2005). On the other hand, if high dietary energy and AA are provided to the birds, it may not affect broiler performance but will increase the feed cost. It may also waste dietary energy and protein by depositing the extra energy as fat or excreting nitrogen in the environment because of the excess protein in the diet. Hence, it is important to consider feed cost and broiler's performance to AA and energy in the diet to maximize margin. To maximize profit and margin, it is also important to understand feed cost and broiler performance when various energy and AA contents are provided to the birds.

2.6 Conclusion

Energy and AA are nutrients that are contained in large portion of the diet. These are also important nutrients for adequate growth and meat yield in broiler chickens. Hence, optimal levels of energy and AA in the diet are essential for maximizing broiler production and profitability.

It is assumed that that broiler chickens adjust their FI according to the dietary energy content and the degree of changes approximately matches what would be expected based on dietary energy. A few studies have found the same effect and agree with this concept (Leeson et al., 1996; Dozier III et al., 2006). However, a study has found that broiler chickens do not change their FI based on different energy level of the diet and disagrees with this concept (Plumstead et al., 2007). This study speculates that broiler chickens may not change their FI with different dietary energy content due to the intense genetic selection for growth and will eat to physical capacity. Other studies suggest an age effect on the chicken's ability to regulate FI (Brickett et al., 2007; Kamran et al., 2008). Young chickens may not regulate their FI due to limited gut capacity but are able to change their FI according to the dietary energy level when the birds are older. Additionally, the relationship between dietary energy and AA on broiler performance is currently not clear. Further examining FI in broiler chickens, and confirming and understanding the interaction between dietary energy and AA would improve broiler production and profitability. Therefore, research was completed to provide additional clarity to the understanding of dietary energy effects in broiler chickens and the relationship of dietary energy to AA levels. This study used wide range of energy and AA contents, diets were formulated based on digestible nutrients and there was consistent relationship between energy and fat. The digestibility of various feed ingredients was determined first to be used for diet formulation in later experiments. This research has two main objectives: 1) to investigate the effect of broiler age and dietary energy levels on FI, and 2) to further understand the response of broiler chickens to different energy and AA levels of the diet.

3.0 Apparent Ileal Amino Acid Digestibility and Apparent Metabolizable Energy of Feed Ingredients Determined In 5 or 6 and 21 Day Old Broiler Chickens

3.1 Abstract

Formulating diets based on digestibility of nutrients is important to create diets that deliver required nutrients to broiler chickens. However, most digestibility values are determined in older birds and since the digestive capacity of young chicks is limited, these digestibility values may not be accurate for this age of broiler. Hence, the objective of this research was to determine the AID and AMEn of five ingredients in 5 (AID) or 6 (AMEn) and 21 d (AID and AMEn) old broiler chickens. The feed ingredients were barley, canola meal, corn, soybean meal and wheat. AMEn was not different between the two ages for corn, canola meal and wheat, but was for barley and soybean meal. Amino acid digestibility generally increased with increasing age and it was significantly different between the two ages for all ingredients except corn and soybean meal. In conclusion, this research confirms that there are differences in nutrient digestibility in younger and older broiler chickens with a larger age effect on AID than AME. It also suggests that these differences should be accounted for when formulating diets for young and older birds.

Keywords: AME, amino acid, digestibility, broiler, age

3.2 Introduction

Accurate delivery of essential nutrients to broiler chickens requires an understanding of the digestible nutrient content of feed ingredients. In particular, formulating diets using AMEn and AA digestibility values enhances the probability that diets deliver these important nutrients at levels that match the bird's requirement.

It is common to use digestibility values from older birds (>21 d of age) to formulate diets. However, research has shown that nutrient digestibility in broiler chickens is age dependent and that the digestive capacity of the young chick is limited (Batal and Parsons, 2002; Huang et al., 2005; Thomas et al., 2008; Rynsburger, 2009). The reason for the limited digestive capacity of young birds is not established, but could include limited enzyme secretion, the presence of yolk sac nutrients and incomplete development of the gastrointestinal tract (Batal and Parsons, 2002; Thomas et al., 2008). The need for accuracy in feed formulation is also very important in nutrition research because it is essential that interpretation of collected data is not confounded by unexpected differences in ingredient digestibility.

The hypothesis of this research was that young chicks have limited ability to digest nutrients, and that the AID and AMEn digestibility values are lower in young than older broilers. The objective of this research was to determine the AID and AMEn of feed ingredients in 5 or 6 and 21 d old chicks so that the determined values could be used in later research on the impact of diet energy on broiler chickens.

3.3 Materials and methods

Protocols for these experiments were approved by the Animal Care Committee of University of Saskatchewan, and birds were reared and cared for according to the Canadian Council of Animal Care (1993).

3.3.1 Experimental diets

The five feed ingredients assessed for AID and AMEn were barley, canola meal, corn, soybean meal and wheat and test diets are shown in Tables 3.1 and 3.2. Barley, corn and wheat were ground in a hammer mill (model 160-D)[1] using a 4.0 mm screen hole size. For AID testing, canola meal and soybean meal were used as sole sources of protein, while 5% hydrolyzed casein was included in the test diets for barley, corn and wheat to increase the protein content, particularly for the testing in young birds. The hydrolyzed casein was assumed to be 100% digestible and corrected for when determining the digestibility of ingredients. The AID diets were cold pelleted. Water was added to canola meal, soybean meal, wheat, barley (4.18 L to 23 kg of diet) and corn (8.14 L of water to 23 kg of diet) diets before pelleting. After pelleting, the pellets were dried in a drying oven at 55 ºC. The reference diet for the AMEn trial, which was mostly composed of corn and soybean meal, was replaced with 40% of feed ingredient to create each test diet. A mathematical correction for inclusion level was used to determine AMEn of each feed ingredient. The AMEn experimental diets were fed in mash form. Celite[2] was used as an indigestible marker and 1.5% was added to the diets for AID and AMEn determination.

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[1] Jacobson Machine Works, Minneapolis, Minn.
[2] Celite Corporation, Quincy, WA, USA.

Table 3.1. Composition of the test diets for AID digestibility.

Ingredient (%)	Corn	Wheat	Soybean meal	Canola meal	Barley
Hydrolyzed casein	5.00	5.00	---	---	5.00
Corn	86.13	---	---	---	---
Wheat	---	87.06	---	---	---
Soybean meal	---	---	37.78	---	---
Canola meal	---	---	---	47.37	---
Barley	---	---	---	---	87.24
Corn oil	2.00	2.00	2.00	2.00	2.00
Dextrose	---	---	54.36	45.54	---
Sodium chloride	0.40	0.40	0.40	0.40	0.40
Dicalcium phosphate	2.00	1.73	1.88	1.59	1.64
Limestone	1.5	1.23	1.10	0.63	1.24
Celite	1.50	1.50	1.50	1.50	1.50
Vitamin - mineral premix[1]	0.50	0.50	0.50	0.50	0.50
Choline chloride	0.10	0.10	0.10	0.10	0.10
Avizyme 1302[2]	0.050	0.050	0.050	0.050	0.050
Endofeed[4]	0.025	0.025	0.025	0.025	0.025
Pellet binder[5]	0.30	0.30	0.30	0.30	0.30
Formulated nutrient composition (%)					
Crude protein	12.39	18.29	18.00	18.00	15.05
M.E. (kcal/kg)	3284	3141	2684	2481	2886
Lysine	0.58	0.73	1.10	0.83	0.74
Methionine	0.28	0.33	0.24	0.33	0.31
Calcium	1.12	1.00	1.00	1.00	1.00
Non-phytate P	0.49	0.48	0.48	0.48	0.48

[1] Supplied per kilogram of diet: vitamin A (retinyl acetate + retinyl palmitate), 11000 IU; vitamin D, 2200 IU; vitamin E (dl-α-topheryl acetate), 300 IU; menadione, 2.0 mg; thiamine, 1.5 mg; riboflavin, 6.0 mg; niacin, 60 mg; pyridoxine, 4 mg; vitamin B_{12}, 0.02 mg; pantothenic acid, 10.0 mg; folic acid, 0.6 mg; biotin, 0.15 mg; Iron, 80 mg; zinc, 80 mg; manganese, 80 mg; copper, 10 mg; iodine, 0.8 mg; selenium, 0.3 mg; and $CaCO_3$, 500 mg.
[2] Barley Endofeed (GNC Bioferm Inc., Bradwell, SK).
[3] Avizyme 1302 (Danisco Animal Nutrition, Marlborough, Wiltshire).
[4] Maxibond (Agresearch Inc., Joliet, IL).

Table 3.2. Composition of the test diets for AMEn determination.

Ingredients (%)	Reference	Corn	Wheat	Soybean meal	Canola meal	Barley
Corn	60.00	74.50	34.50	34.50	34.50	34.50
Wheat	---	---	40.00	---	---	---
Soybean meal	31.09	17.88	17.88	57.88	17.88	17.88
Canola meal	---	---	---	---	40.00	---
Barley	---	---	---	---	---	40.00
Canola oil	3.00	1.73	1.73	1.73	1.73	1.73
Dextrose						
Sodium chloride	0.49	0.49	0.49	0.49	0.49	0.49
Dicalcium phosphate	1.80	1.80	1.80	1.80	1.80	1.80
Limestone	1.15	1.15	1.15	1.15	1.15	1.15
Celite	1.50	1.50	1.50	1.50	1.50	1.50
Vitamin - minineral premix[1]	0.50	0.50	0.50	0.50	0.50	0.50
Choline chloride	0.10	0.10	0.10	0.10	0.10	0.10
Avizyme 1302[2]	0.05	0.05	0.05	0.05	0.05	0.05
Endofeed[3]	0.025	0.025	0.025	0.025	0.025	0.025
Pellet binder[5]	0.30	0.30	0.30	0.30	0.30	0.30
Formulated nutrient composition (%)						
Crude protein	20.40	15.46	18.13	30.79	26.93	16.63
AMEn (kcal/kg)	3058	3098	3018	2768	2602	2898
Lysine	1.07	0.72	0.79	1.78	1.32	0.79
Methionine	0.31	0.25	0.27	0.43	0.46	0.26
Calcium	1.00	0.97	0.98	1.07	1.23	0.99
Non-phytate P	0.49	0.48	0.50	0.53	0.56	0.50

[1] Supplied per kilogram of diet: vitamin A (retinyl acetate + retinyl palmitate), 11000 IU; vitamin D, 2200 IU; vitamin E (dl-α-topheryl acetate), 300 IU; menadione, 2.0 mg; thiamine, 1.5 mg; riboflavin, 6.0 mg; niacin, 60 mg; pyridoxine, 4 mg; vitamin B_{12}, 0.02 mg; pantothenic acid, 10.0 mg; folic acid, 0.6 mg; biotin, 0.15 mg; Iron, 80 mg; zinc, 80 mg; manganese, 80 mg; copper, 10 mg; iodine, 0.8 mg; selenium, 0.3 mg; and $CaCO_3$, 500 mg.
[2] Barley Endofeed (GNC Bioferm Inc., Bradwell, SK).
[3] Avizyme 1302 (Danisco Animal Nutrition, Marlborough, Wiltshire).
[4] Maxibond (Agresearch Inc., Joliet, IL).

3.3.2 Animals and housing

For AID, a total of 1008 male Ross x Ross 308 broiler chickens were used with 792 and 216 chicks reared until 5 and 21 d, respectively. For AMEn, the same numbers and type of birds were used as AID, but 792 and 216 chicks were raised until 6 and 21 d, respectively. Chicks were obtained from a commercial hatchery (Lilydale, Wynyard) at 0 d of age and were randomly allocated to 72 cages. The chicks were housed in Jamesway brooder battery cages (44 W, 85 L and 25 H cm) under a light regimen of 23 hr of light and1 hr of dark, with a light intensity of 30 lux. The temperature was initially set to approximately 32ºC and then gradually decreased 1ºC every 3 d. For AID and AMEn, there were 6 replications for each test diet with 22 chicks per replication for younger birds and 6 chicks per replication for older birds. A commercial broiler starter with nutrient levels meeting or exceeding the recommended values from Aviagen (2007) was fed initially and then replaced with test diets at 1 and 17 d for younger and older birds, respectively. Water and feed were available for chicks on an ad libitum basis.

3.3.3 Ileal digesta collection and chemical analysis

Chicks were euthanized by cervical dislocation for ileal digesta collection at 5 and 21 d of age. The middle two-thirds of the ileum was gently squeezed using a roller vial to collect contents and digesta were pooled for each replication. Samples were immediately frozen at -20°C and then freeze-dried. After the samples were freeze-dried, they were finely ground using a mortar and pestle, and mixed thoroughly before analysis. Dry matter and crude protein (N x 6.25) were analyzed according to AOAC (1990). A

Leco analyzer[3] was used to measure the nitrogen content in the feed and ileal digesta. AA analysis of the diets and ileal digesta were performed by Evonik (Hanau-Wolfang, Germany) using methods and procedures from Association of Official Analytical Chemists Official Method 994.12 (Llames and Fontaine, 1994). Celite was determined by a modified method from Vogtmann et al., (1975). This procedure involves weighing approximately 1-2 g of sample and putting it into 16 x 125 mm disposable tube. The tube is then ashed at 500°C for 24 hr or until the sample turns to white ash. After ashing, 5 mL of 4 N HCl is added and mixed, and then heated in the oven at 120°C for 1 hr. It is then centrifuged at 2500 x g for 10 minutes and dried overnight at 80°C. Following this, the dried sample is ashed again at 500°C overnight. All analyses were performed in duplicate.

3.3.4 Faecal collection and chemical analysis

Faeces were collected 4 times over 3 d using plastic sheets starting at 4 and 19 d of age for 6 and 21 d old birds, respectively. Immediately after collection, faeces were frozen at -20°C and then dried using a 55°C forced air oven. After the samples were dried, they were pooled within a replication and ground (1.0 mm screen) using a Retsch grinder[4]. All diet and faecal analysis were completed in duplicate and dry matter, crude protein (N x 6.25) and GE were done according to AOAC (1990). Nitrogen content in the faeces and feed was determined using Leco. Celite was analyzed by using a modified procedure from Vogtmann et al. (1975) as indicated above.

[3] Model FP-528L, Leco Corp., St. Joseph MI, USA.
[4] Hann, Germany.

3.3.5 Calculations and statistical analyses

Data for AID were statistically analyzed to compare the AA digestibility at 5 and 21 d of age. The statistical design was a one-way analysis with age at AMEn determination as main effect. For AID and AMEn, statistical analyses were performed using Proc GLM (General Linear Models Procedures) for least square of means of SAS version 9.2 (SAS Institute, 2001). Differences were considered significant when $P \leq 0.05$. The apparent digestibility coefficient of AA in the diet ($ADC_{amino\ acid}$) was calculated using the equation below (Ten Doeschate et al., 1993):

$$ADC_{amino\ acid}\ (\%) = 1 - \left[\left(\frac{\text{Acid insoluble ash in diet (\%)}}{\text{Acid insoluble ash in digesta (\%)}}\right) \times \left(\frac{\text{nutrient in digesta (\%)}}{\text{nutrient in diet (\%)}}\right)\right]$$

AMEn was calculated by using the equation shown below (Hill and Anderson, 1958; Scott et al., 1998):

$$\text{AME/g feed} = \text{Gross energy/g feed} - \left[\left(\text{Gross energy/g excreta} \times \frac{\text{\% Acid insoluble ash in diet}}{\text{\% Acid insoluble ash in excreta}}\right]\right.$$

$$\text{AMEn/g diet} = \text{Gross energy/g diet} - \text{Gross energy excreta/g diet} - \left[8.22\ \text{kcal/g} \times \text{g Nitrogen/g diet} - \left(\text{g Nitrogen/g excreta} \times \frac{\text{\% Acid insoluble ash in diet}}{\text{\% Acid insoluble ash in excreta}}\right)\right]$$

3.4 Results and discussion

3.4.1 Apparent ileal amino acid digestibility

Overall, digestibility increased with increasing age for most AA and most ingredients (Tables 3.3, 3.4, 3.5, 3.6 and 3.7). This is in agreement with previous research (Batal and

Parsons, 2002; Huang et al., 2005; Adedokun et al., 2007a; Garcia et al., 2007; Rynsburger, 2009) that found that AA digestibility is age dependent and lower in younger birds. This could be due to reduced digestive enzyme secretion in the small intestine and/or incomplete development of gastrointestinal tract in young birds (Uni et al., 1996; Sklan and Noy, 2003). Trypsin activity, length and diameter of the small intestine, as well as villus length significantly increase from 5 to 11 d of age.

Cystine digestibility was not affected by age in barley and wheat, but there was an age effect for all other AA. Digestibility of all AA in canola meal increased with age except for cystine and lysine. There were differences in digestibility between ages, with digestibility values increasing with increasing age for methionine, leucine and histidine in corn, and differences for cystine, threonine, phenylalanine and valine approached significance ($P < 0.10$). Only methionine digestibility increased with age in soybean meal. The smaller effect of age on soybean meal and to a lesser extent corn, does not appear to agree with studies evaluating the apparent AA digestibility of a corn-soybean meal diet, where differences were found in digestibility between 3 to 4 d old and 21 d old broilers (Batal and Persons, 2002). In contrast, the use of the standardized ileal digestibility test resulted in no differences in digestibility for corn and soybean meal in 7 and 21 d old broilers (Garcia et al., 2007). These differences may relate to the age of birds used for testing and/or the correction for endogenous losses that is used in the standardized ileal digestibility test. The AA digestibility values were relatively close to the reference values for all ingredients (Degussa, 2005).

Table 3.3. Effect of age on AID of barley (%).

	Days of age				
Amino acid	5	21	Mean	Pooled SEM	*P-value*
Arginine	73.7	80.8	77.3	1.52	0.0094
Cystine	68.5	72.5	70.5	1.44	NS
Histidine	73.0	79.0	76.0	1.33	0.015
Isoleucine	77.5	82.0	79.8	1.18	0.049
Leucine	79.8	85.0	82.4	1.17	0.018
Lysine	76.5	83.5	80.0	1.49	0.010
Methionine	78.8	85.7	82.3	1.38	0.0054
Phenylalanine	77.5	83.7	80.6	1.33	0.012
Threonine	64.8	72.8	68.8	1.79	0.016
Valine	77.3	82.2	79.8	1.10	0.019

Table 3.4. Effect of age on AID of canola meal (%).

	Days of age				
Amino acid	5	21	Mean	Pooled SEM	*P-value*
Arginine	78.0	85.5	81.8	1.68	0.016
Cystine	67.8	69.3	68.6	1.44	NS
Histidine	75.2	84.0	79.6	1.67	0.0019
Isoleucine	65.0	77.2	71.1	2.41	0.004
Leucine	70.8	81.3	76.1	2.13	0.0057
Lysine	62.2	69.3	65.8	2.01	0.072
Methionine	76.2	87.0	81.6	2.08	0.0025
Phenylalanine	67.3	78.0	72.7	2.29	0.011
Threonine	58.3	68.2	63.3	2.22	0.017
Valine	65.3	76.5	70.9	2.19	0.0035

Table 3.5. Effect of age on AID of corn (%).

	Days of age				
Amino acid	5	21	Mean	Pooled SEM	*P-value*
Arginine	75.0	82.7	78.9	1.90	0.036
Cystine	59.2	65.8	62.5	1.76	0.052
Histidine	67.3	76.5	71.9	1.99	0.012
Isoleucine	73.3	78.2	75.8	1.64	NS
Leucine	82.2	86.3	84.3	1.07	0.046
Lysine	73.5	80.2	76.9	2.26	NS
Methionine	79.0	85.3	82.2	1.54	0.032
Phenylalanine	74.8	80.5	77.7	1.53	0.060
Threonine	57.7	66.2	62.0	2.24	0.052
Valine	73.2	78.8	76.0	1.50	0.054

Table 3.6. Effect of age on AID of soybean meal (%).

	Days of age				
Amino acid	5	21	Mean	Pooled SEM	*P-value*
Arginine	85.7	86.3	71.7	0.89	NS
Cystine	65.7	68.2	67.0	1.25	NS
Histidine	81.8	85.2	83.5	1.05	NS
Isoleucine	80.0	81.7	80.9	1.05	NS
Leucine	81.3	82.8	82.1	1.05	NS
Lysine	75.8	78.8	77.3	1.09	NS
Methionine	79.0	86.5	82.8	1.88	0.039
Phenylalanine	80.3	80.5	80.4	1.00	NS
Threonine	72.7	76.7	74.7	1.36	NS
Valine	77.7	81.7	79.7	1.25	NS

Table 3.7. Effect of age on AID of wheat (%).

	Days of age				
Amino acid	5	21	Mean	Pooled SEM	*P-value*
Arginine	83.2	87.0	85.1	0.93	0.0317
Cystine	78.3	80.8	79.6	0.80	NS
Histidine	79.3	84.3	81.8	0.97	0.0028
Isoleucine	82.8	86.8	84.8	0.88	0.014
Leucine	85.8	90.2	88.0	0.89	0.0064
Lysine	80.3	87.7	84.0	1.41	0.0027
Methionine	84.8	90.2	87.5	1.00	0.0015
Phenylalanine	84.0	89.0	86.5	0.91	0.0008
Threonine	71.5	78.2	74.9	1.35	0.0056
Valine	82.1	86.0	84.1	0.82	0.012

3.4.2 Apparent metabolizable energy with nitrogen correction

There was no age effect on AMEn of feed ingredients except for barley and soybean meal (Table 3.8). The effect of age on AMEn has been inconsistent in the scientific literature. AMEn values for corn-soybean meal and corn-canola meal diets were lower in 7 d compared to 21 d old chicks (Batal and Parsons, 2002). Similarly, AMEn values for wheat and corn increased after 10 d of age (Thomas et al., 2008). On the other hand, other research found no age effect on AMEn values for corn and the results for soybean meal were variable (Lopez and Leeson, 2008). Differences in age and also sample being tested may account for the different research results.

The AMEn values for ingredients were generally similar to the literature value except canola meal and soybean meal (NRC, 1994). This could be due to processing in canola and soybean meal, which may have created variability in AMEn (Aburto et al., 1998; Newkirk et al., 2003). The AMEn value is affected by the amount of oil extracted from or added back to the canola meal (Newkirk et al., 2003). Soybean meal could also vary in AMEn depending on the solvent extraction and degree of heat treatment. During processing, the oil is removed from the soybean by mostly solvent extraction. However, depending on the degree of extraction, oil content in the soybean meal could be variable and result in inconsistent AMEn values. Extreme over heating of soybean meal could also decrease AMEn in soybean meal (Aburto et al., 1998).

Table 3.8. Effect of age on AMEn (kcal/kg) values of feed ingredients.

Ingredient	Days of age 6	Days of age 21	Mean	Pooled SEM	*P-value*
Barley	2523	2725	2624	43.9	0.012
Canola meal	1406	1380	1393	37.5	NS
Corn	3291	3270	3280	17.5	NS
Soybean meal	2499	2344	2421	31.3	0.0049
Wheat	3240	3193	3216	26.5	NS

3.5 Summary

In summary, AA digestibility increased with age for most ingredients but had less effect on ingredient AMEn. Where age affected digestibility, age appropriate values were used in diet formulation for later experiments while averages of the two ages were used when no differences were found.

4.0 The Effect of Age and Dietary Energy Levels on Feed Intake of Broiler Chickens

4.1 Abstract

An experiment was conducted to clarify the relationship between dietary energy level and FI in broiler chickens and how it is affected by bird age. Broilers were fed starter (S; 0-10 d), grower (G; 11-25 d) and finisher (F; 26-35 d) diets containing a range of dietary energy (2700, 2833, 2966 and 3100 kcal/kg). Diets in this energy range were fed starting at the beginning of the S, G or F periods; for the latter two treatments diets containing 3100 kcal/kg AMEn were fed until switching to the variable energy diets. Digestible dietary AA levels met or exceeded the primary breeder recommended values in all diets. Overall, broilers did not adjust their FI based on the energy level of the diet regardless of age. Similarly, only minor differences in FI were noted as a result of the age that variable energy diets were introduced. However, there was some indication that older birds may be less adaptive to changes in dietary energy. Growth was generally increased and feed to gain ratio decreased in response to increasing energy, either in a linear or quadratic fashion. Diet energy or program of feeding had little effect on mortality. This study suggests that broilers do not change their FI in response to dietary energy level to maintain energy intake. If confirmed this finding has important implications in diet formulation.

Keywords: Nutrient density, AME, broiler, feed intake

4.2 Introduction

Energy is an important nutrient that constitutes the largest component of the diet and thus affects feed cost and profitability (Sibbald, 1982). It is historically accepted that chickens are able to adjust their FI according to the dietary energy content (Leeson and Summers, 2005) and this important role in FI regulation has implications in feed formulation because of the need to ensure adequate consumption of other essential nutrients. However, the role of energy in regulating FI in broiler chickens is not clear and research has produced contradictory results. In research comparing dietary energy contents ranging from 2700 to 3300 kcal/kg in broiler chickens from 0 to 49 d of age (Leeson et al., 1996), birds increased their intake of lower energy diets to maintain a similar ME intake. Older broiler chickens (30 to 59 d of age) responded in a similar fashion to dietary energy contents ranging from 3175 to 3310 kcal/kg (Dozier III et al., 2006). In contrast, Plumstead et al. (2007) found no difference in FI for broilers fed dietary energy levels ranging from 3000 to 3200 kcal/kg. The authors suggested that the lack of regulation in FI may be due to the intense genetic selection for growth over the years in broiler chickens affecting satiety mechanisms. Some reports also suggest that FI regulation, and hence response to different dietary energy, is age dependent (Jones and Wiseman, 1985; Brickett et al., 2007; Kamran et al., 2008). Broiler chickens that were younger than 24 d of age did not adjust their FI in response to dietary energy ranging from 2577 to 3533 kcal/kg, but changed their FI according to the dietary energy levels from 25 to 49 d of age (Jones and Wiseman, 1985). More recent research provided evidence that broiler chickens under 14 d of age were not able to regulate FI (Brickett et al., 2007; Kamran et al., 2008). In these cases, a limited capacity of young birds to increase FI may be the reason. Brickett et al. (2007) also found that after 14 d of age, broiler chickens fed low energy diets adjusted their FI, but not to the extent expected based on dietary energy level.

The variable response of broilers to dietary energy supports the need for further research on the broiler's ability to alter FI according to dietary energy in order to maintain energy intake. Having a clear understanding of this area is important to broiler nutrition as it is important for predicting production performance and creating a cost efficient diet. In the current study, it was hypothesized that FI regulation is age dependent and broiler chickens would have an increased ability to change FI based on the energy level of the diet with increasing age. To confirm this hypothesis, the primary objective of this experiment was to investigate the relationship between dietary energy levels and FI in broiler chickens at various ages.

4.3 Materials and methods

Protocols for these experiments were approved by the Animal Care Committee of University of Saskatchewan, and birds were reared and cared for according to the Canadian Council of Animal Care (1993).

4.3.1 Animal and housing

A total of 5580 male and female Ross x Ross 308 broiler chickens were fed various levels of diet energy until 35 d of age. Chicks were obtained from a commercial hatchery (Lilydale Hatchery, Wynyard, SK) at d of hatch and were randomly allocated to one of the 9 independent rooms each containing 10 pens (pen dimension: 2.3 x 2.0 m). Each pen contained 62 birds (31 female and 31 male). The stocking density was estimated to be

30.0 kg per m^2 at trial end based on placement numbers and expected final weight. Straw litter (7.5 to 10 cm depth), a hanging feeder (0 to 21 d, 36 cm in diameter; 22 to 35 d, 43 cm in diameter) and a Lubing nipple drinker (6 nipples/drinker) were provided in each pen. The chickens had unlimited access to water and feed. Room temperatures were initially set to 34ºC and gradually reduced 2.8ºC every week until 22ºC was reached. The chicks were provided with supplemental feeders and drinkers until 5 d of age. Light intensity was set at 30 lux with 23 hr of light and 1 hr of darkness from 0 to 7 d of age. From 8 to 35 d of age, the light intensity was set at 10 lux with 18 hr of light and 6 hr of darkness. Additionally, light intensity increased and decreased in a dawn and dusk fashion with a period of 50 minutes to change intensity for each period.

4.3.2 Experimental diets

In a previous experiment, the AMEn of feed ingredients was determined based on testing from 6 and 21 d of age (Chapter 3.0). The diets in this research were formulated based on these results with age appropriate AMEn values used if there was a significant difference between ages for an ingredient, and a mean of the two ages if the difference was not significant. Overall, there were 10 treatments, with varying diet energy introduced at the S (0 d of age), G (10 d of age) or the F (25 d of age) phases (Figure 4.1). The four dietary energy levels were 2700, 2833, 2966 and 3100 kcal/kg (Tables 4.1, 4.2, 4.3, 4.4, 4.5 and 4.6). The control treatment consisted of birds being fed the high energy diet (3100 kcal/kg) from 0 to 35 d of age. The S program energy treatments (2700, 2833, 2966 kcal/kg) were fed from 0 to 35 d. At 10 d of age, the same energy levels were introduced to the G program and fed for the remainder of the trial (11 to 35 d). The same dietary energy levels were introduced to the F program at 25 d of age and they were fed from 26 to 35 d of age. Birds on the G and F programs were fed S and/or G diets containing 3100 kcal/kg diet until they were switched to the experimental energy levels.

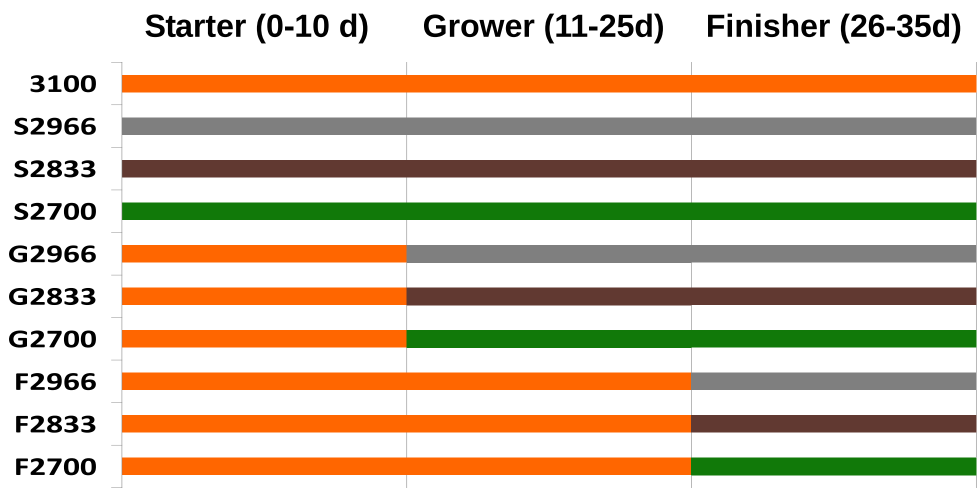

Figure 4.1. Outline of treatment application during the experiment. S, G and F on the Y axis represent starter, grower and finisher application of variable energy diets, respectively. Numbers in the Y-axis indicate the diet energy (kcal/kg) of the treatment at the start, grow and finisher phases. Diet energy levels are indicated by different colours; orange, 3100 kcal/kg; grey, 2966 kcal/kg; brown, 2833 kcal/kg; green, 2700kcal/kg.

Low (2700 kcal/kg) and high (3100 kcal/kg) diets were all formulated on an apparent ileal DAA basis with digestibility values determined in the previous experiment (Chapter 3.0). Diets were formulated to maintain a minimum ratio between digestible essential AA and lysine content (Emmert and Baker, 1997), and DAA levels in the diet met or exceeded recommended values (Aviagen, 2007). The intermediate energy diets were calculated based on appropriate portions of the high and the low energy diets. The ratio between crude fat (ether extract) and energy levels were held constant in all the diets.

Table 4.1. Composition of the experimental starter diets (%) fed from 0 to 10 d of age.

	Energy levels (kcal/kg)			
Ingredient (%)	2700	2833	2966	3100
Corn	0.00	15.00	30.00	45.00
Barley	36.92	24.61	12.31	0.00
Soybean meal	28.92	31.14	33.36	35.58
Wheat	16.02	13.99	11.95	9.92
Canola meal	9.14	6.09	3.05	0.00
Canola oil	4.11	4.14	4.17	4.20
Limestone	1.52	1.54	1.56	1.58
Dicalcium phosphate	1.31	1.39	1.47	1.55
Vitamin - mineral premix[1]	0.50	0.50	0.50	0.50
Sodium chloride	0.42	0.42	0.41	0.41
Choline chloride	0.10	0.10	0.10	0.10
L-Lysine HCl	0.25	0.27	0.30	0.32
DL-Methionine	0.35	0.37	0.38	0.40
L-Threonine	0.09	0.09	0.09	0.09
Barley Endofeed[2]	0.03	0.03	0.02	0.02
Avizyme 1302[3]	0.05	0.05	0.05	0.05
Salinomycin sodium[4]	0.05	0.05	0.05	0.05
Virginiamycin[5]	0.03	0.03	0.02	0.02
Pellet binder[6]	0.20	0.20	0.20	0.20

[1] Supplied per kilogram of diet: vitamin A (retinyl acetate + retinyl palmitate), 11000 IU; vitamin D, 2200 IU; vitamin E (dl-α-topheryl acetate), 300 IU; menadione, 2.0 mg; thiamine, 1.5 mg; riboflavin, 6.0 mg; niacin, 60 mg; pyridoxine, 4 mg; vitamin B_{12}, 0.02 mg; pantothenic acid, 10.0 mg; folic acid, 0.6 mg; biotin, 0.15 mg; iron, 80 mg; zinc, 80 mg; manganese, 80 mg; copper, 10 mg; iodine, 0.8 mg; selenium, 0.3 mg; and $CaCO_3$, 500 mg.
[2] Barley Endofeed (GNC Bioferm Inc., Bradwell, SK).
[3] Avizyme 1302 (Danisco Animal Nutrition, Marlborough, Wiltshire).
[4] Coccistac (Phibro Animal Health, Ridgefield Park, NJ).
[5] Stafac-44 (Phibro Animal Health, Ridgefield Park, NJ).
[6] Maxibond (Agresearch Inc., Joliet, IL).

Table 4.2. Nutrient composition of the experimental starter diets (%) fed from 0 to 10 d of age.

	Energy levels (kcal/kg)			
Formulated nutrient composition (%)	2700	2833	2966	3100
Crude protein	23.50	23.15	22.81	22.46
AMEn (kcal/kg)	2700	2833	2966	3100
Ether extract	5.44	5.70	5.97	6.24
Lysine	1.43	1.42	1.41	1.39
Digestible lysine	1.27	1.27	1.27	1.27
Arginine	1.46	1.46	1.45	1.44
Digestible arginine	1.31	1.31	1.31	1.31
Methionine	0.70	0.71	0.72	0.73
Digestible methionine	0.66	0.67	0.68	0.70
Sulfur AA	1.06	1.05	1.05	1.04
Digestible sulfur AA	0.94	0.94	0.94	0.94
Threonine	0.98	0.97	0.96	0.94
Digestible threonine	0.83	0.83	0.83	0.83
Tryptophan	0.33	0.32	0.30	0.29
Digestible tryptophan	0.27	0.26	0.25	0.24
Calcium	1.05	1.05	1.05	1.05
Non-phytate P	0.50	0.50	0.50	0.50

Table 4.3. Composition of the experimental grower diets (%) fed from 11 to 25 d of age.

	Energy levels (kcal/kg)			
Ingredient (%)	2700	2833	2966	3100
Corn	0.00	15.00	30.00	45.00
Barley	53.83	35.89	17.94	0.00
Soybean meal	23.16	24.98	26.79	28.61
Wheat	6.06	9.97	13.87	17.78
Canola meal	8.8	5.87	2.93	0.00
Canola oil	3.82	3.84	3.85	3.87
Limestone	1.27	1.30	1.32	1.35
Dicalcium phosphate	1.09	1.17	1.26	1.34
Vitamin - mineral premix[1]	0.50	0.50	0.50	0.50
Sodium chloride	0.44	0.43	0.41	0.40
Choline chloride	0.10	0.10	0.10	0.10
L-Lysine HCl	0.21	0.24	0.26	0.29
DL-Methionine	0.30	0.32	0.33	0.35
L-Threonine	0.07	0.07	0.07	0.07
Barley Endofeed[2]	0.03	0.03	0.03	0.03
Avizyme 1302[3]	0.05	0.05	0.05	0.05
Salinomycin sodium[4]	0.05	0.05	0.05	0.05
Virginiamycin[5]	0.03	0.03	0.03	0.03
Pellet binder[6]	0.20	0.20	0.20	0.20

[1] Supplied per kilogram of diet: vitamin A (retinyl acetate + retinyl palmitate), 11000 IU; vitamin D, 2200 IU; vitamin E (dl-α-topheryl acetate), 300 IU; menadione, 2.0 mg; thiamine, 1.5 mg; riboflavin, 6.0 mg; niacin, 60 mg; pyridoxine, 4 mg; vitamin B_{12}, 0.02 mg; pantothenic acid, 10.0 mg; folic acid, 0.6 mg; biotin, 0.15 mg; iron, 80 mg; zinc, 80 mg; manganese, 80 mg; copper, 10 mg; iodine, 0.8 mg; selenium, 0.3 mg; and $CaCO_3$, 500 mg.
[2] Barley Endofeed (GNC Bioferm Inc., Bradwell, SK).
[3] Avizyme 1302 (Danisco Animal Nutrition, Marlborough, Wiltshire).
[4] Coccistac (Phibro Animal Health, Ridgefield Park, NJ).
[5] Stafac-44 (Phibro Animal Health, Ridgefield Park, NJ
[6] Maxibond (Agresearch Inc., Joliet, IL).

Table 4.4. Nutrient composition of the experimental grower diets (%) fed from 11 to 25 d of age.

	Energy levels (kcal/kg)			
Formulated nutrient composition (%)	2700	2833	2966	3100
Crude protein	21.00	20.71	20.43	20.15
AMEn (kcal/kg)	2700	2833	2966	3100
Ether extract	5.26	5.52	5.78	6.04
Lysine	1.25	1.24	1.22	1.21
Digestible lysine	1.10	1.10	1.10	1.10
Arginine	1.28	1.27	1.27	1.26
Digestible arginine	1.14	1.14	1.14	1.14
Methionine	0.62	0.63	0.64	0.65
Digestible methionine	0.58	0.59	0.61	0.62
Sulfur AA	0.95	0.95	0.94	0.93
Digestible sulfur AA	0.84	0.84	0.84	0.84
Threonine	0.87	0.86	0.85	0.84
Digestible threonine	0.73	0.73	0.73	0.73
Tryptophan	0.31	0.29	0.27	0.26
Digestible tryptophan	0.25	0.24	0.23	0.21
Calcium	0.90	0.90	0.90	0.90
Non-phytate P	0.45	0.45	0.45	0.45

Table 4.5. Composition of the experimental finisher diets (%) fed from 26 to 35 d of age.

	Energy levels (kcal/kg)			
Ingredient (%)	2700	2833	2966	3100
Corn	0.00	15.00	30.00	45.00
Barley	56.49	37.66	18.83	0.00
Soybean meal	18.71	20.34	21.96	23.59
Wheat	9.49	14.28	19.08	23.87
Canola meal	8.12	5.41	2.71	0.00
Canola oil	3.11	3.09	3.07	3.05
Limestone	1.24	1.27	1.29	1.32
Dicalcium phosphate	0.97	1.05	1.13	1.21
Vitamin - mineral premix[1]	0.50	0.50	0.50	0.50
Sodium chloride	0.44	0.42	0.41	0.39
Choline chloride	0.10	0.10	0.10	0.10
L-Lysine HCl	0.17	0.20	0.22	0.25
DL-Methionine	0.25	0.27	0.28	0.30
L-Threonine	0.05	0.05	0.05	0.05
Barley Endofeed[2]	0.03	0.03	0.03	0.03
Avizyme 1302[3]	0.05	0.05	0.05	0.05
Salinomycin sodium[4]	0.05	0.05	0.05	0.05
Virginiamycin[5]	0.03	0.03	0.03	0.03
Pellet binder[6]	0.20	0.20	0.20	0.20

[1] Supplied per kilogram of diet: vitamin A (retinyl acetate + retinyl palmitate), 11000 IU; vitamin D, 2200 IU; vitamin E (dl-α-topheryl acetate), 300 IU; menadione, 2.0 mg; thiamine, 1.5 mg; riboflavin, 6.0 mg; niacin, 60 mg; pyridoxine, 4 mg; vitamin B_{12}, 0.02 mg; pantothenic acid, 10.0 mg; folic acid, 0.6 mg; biotin, 0.15 mg; iron, 80 mg; zinc, 80 mg; manganese, 80 mg; copper, 10 mg; iodine, 0.8 mg; selenium, 0.3 mg; and $CaCO_3$, 500 mg.
[2] Barley Endofeed (GNC Bioferm Inc., Bradwell, SK).
[3] Avizyme 1302 (Danisco Animal Nutrition, Marlborough, Wiltshire).
[4] Coccistac (Phibro Animal Health, Ridgefield Park, NJ).
[5] Stafac-44 (Phibro Animal Health, Ridgefield Park, NJ).
[6] Maxibond (Agresearch Inc., Joliet, IL).

Table 4.6. Nutrient composition of the experimental finisher diets (%) fed from 26 to 35 d of age.

	Energy levels (kcal/kg)			
Formulated nutrient composition (%)	2700	2833	2966	3100
Crude protein	19.30	19.04	18.77	18.51
AMEn (kcal/kg)	2700	2833	2966	3100
Ether extract	4.64	4.87	5.10	5.33
Lysine	1.11	1.10	1.09	1.07
Digestible lysine	0.97	0.97	0.97	0.97
Arginine	1.15	1.15	1.14	1.14
Digestible arginine	1.02	1.02	1.02	1.02
Methionine	0.56	0.57	0.58	0.59
Digestible methionine	0.52	0.53	0.54	0.56
Sulfur AA	0.87	0.86	0.85	0.84
Digestible sulfur AA	0.76	0.76	0.76	0.76
Threonine	0.79	0.77	0.76	0.75
Digestible threonine	0.65	0.65	0.65	0.65
Tryptophan	0.29	0.27	0.26	0.24
Digestible tryptophan	0.24	0.22	0.21	0.20
Calcium	0.85	0.85	0.85	0.85
Non-phytate P	0.42	0.42	0.42	0.42

4.3.3 Crumble size and pellet quality index

Crumble size and pellet durability index (PDI) (ASAE Standard, 1987) were determined for the S and G diets. Crumble size was determined by using sieve analysis. Crumbled feed was placed on the top sieve of a mechanical sieve shaker which had six different sieves (3.36 mm, 2.38 mm, 2.00 mm, 1.41 mm, 1.00 mm, and 0.84 mm hole size). After shaking for 30 seconds, the feed remaining at each sieve level was weighed. Crumble size, expressed as a percentage, was then calculated by using the equation below.

$$\text{Retained crumbled feed in screen (\%)} = \frac{\text{Weight of feed in sieve after shake}}{\text{Weight of total feed}}$$

PDI was measured by weighing 500 grams of the F diet pellets and then placing it in a rolling drum (300 x 300 x 125 mm) (ASAE Standards, 1987). The rolling drum was rotated 50 revolutions per minute. After 10 minutes, the pellets and fines were removed from the drum and sieved in a 3.57 x 19.05 mm screen. The PDI, expressed as a percentage, was then calculated by using the equation below.

$$\text{PDI (\%)} = \frac{\text{Mass of pellets after rotation}}{\text{Mass of pellets before rotation}}$$

4.3.4 Data collection

Feed consumption and BW (pen basis) were measured when birds were 0, 5, 10, 15, 20, 25, 30 and 35 d of age. Feed to gain ratios were calculated using these data with correction for mortality (feed consumption/ (final weight + mortality weight – beginning weight)).

4.3.5 Statistical analysis

Data were tested for normality using Proc Univariate of SAS version 9.2 (SAS Institute, 2001). There were 9 replications per treatment with 62 birds per replication. Within a program, linear and quadratic regression analyses using Proc Reg of SAS version 9.2 (SAS Institute, 2001) were used to establish relationships between dietary energy treatments. Regression analysis was also used to examine the effect of dietary energy content on the crumble size and PDI. There were 2 replications for the crumble size and 1 replication for the PDI.

The linear [1] and quadratic [2] functions were:

$$Y = b0 + b1\ E \qquad [1]$$

$$Y = b0 + b1\,E + b2\,E^2 \qquad [2]$$

Where Y= predicted response, E = energy content of the diet, b0 = intercept, and b1 and b2 = regression coefficient. The different ages for initiation of treatment diets were compared using A Priori contrast of SAS version 9.2 (SAS Institute, 2001). Differences were considered significant when $P<0.05$ unless otherwise specified.

4.4 Results

4.4.1 Performance

Energy level in the diet had an impact on most broiler performance parameters including BW and BW gain and feed to gain ratio. However, diet energy had little or no effect on FI and mortality regardless of age of treatment energy introduction.

4.4.1.2 Feed consumption

Overall (0 to 35 d), there was no effect of dietary energy content on FI regardless of feeding program (Table 4.7 and 4.8), but effects were noted for other time periods. FI from 0 to 5 d of the S program was affected by diet energy, with a tendency of FI to increase ($P = 0.067$) with decreasing energy level. A quadratic response ($P = 0.041$) was shown from 11 to 15 d with the highest FI for the intermediate energy levels. For the G program a significant linear effect was shown for 16 to 20, 21 to 25 and 11 to 25 d of age with FI decreasing with increasing energy level. In all cases the effect is relatively small. A quadratic response was indicated for the 26 to 30 d period but the mean values do not support a strong trend. FI increased in a linear fashion with increasing energy for the 26 to 30 and 26 to 35 d time period for the F program.

Table 4.7. Effect of dietary energy level on feed consumption in broiler chickens.

	Feed consumption (kg)										
Energy content	0-5 d	6-10 d	0-10 d	11-15 d	16-20 d	21-25 d	11-25 d	26-30 d	31-35 d	26-35 d	0-35 d
Starter program											
2700 kcal/kg	0.086	0.190	0.277	0.341	0.518	0.646	1.514	0.836	1.012	1.862	3.711
2833 kcal/kg	0.092	0.188	0.281	0.347	0.522	0.642	1.519	0.837	1.006	1.848	3.674
2966 kcal/kg	0.087	0.187	0.275	0.350	0.530	0.653	1.539	0.833	1.002	1.840	3.681
3100 kcal/kg	0.085	0.186	0.273	0.346	0.519	0.629	1.503	0.849	1.006	1.872	3.710
Pooled SEM	0.00075	0.00094	0.0012	0.0015	0.0024	0.0044	0.0070	0.0036	0.0041	0.0076	0.015
Grower program											
2700 kcal/kg	---	---	0.278	0.344	0.529	0.660	1.543	0.835	1.006	1.849	3.707
2833 kcal/kg	---	---	0.283	0.349	0.536	0.657	1.553	0.849	1.016	1.872	3.744
2966 kcal/kg	---	---	0.281	0.346	0.528	0.637	1.521	0.833	0.991	1.833	3.669
3100 kcal/kg	---	---	0.273	0.346	0.519	0.629	1.503	0.849	1.006	1.872	3.710
Pooled SEM	---	---	0.0013	0.0018	0.0028	0.0047	0.0076	0.0039	0.0050	0.0081	0.014
Finisher program											
2700 kcal/kg	---	---	0.281	---	---	---	1.535	0.821	1.000	1.837	3.698
2833 kcal/kg	---	---	0.276	---	---	---	1.505	0.820	0.982	1.809	3.615
2966 kcal/kg	---	---	0.279	---	---	---	1.552	0.832	1.000	1.843	3.724
3100 kcal/kg	---	---	0.273	---	---	---	1.503	0.849	1.006	1.872	3.710
Pooled SEM	---	---	0.0014	---	---	---	0.0076	0.0038	0.0048	0.0082	0.015

Table 4.8. The relationship between dietary energy levels on feed consumption in broiler chickens.

	Feed consumption (kg)										
	0-5 d	6-10 d	0-10 d	11-15 d	16-20 d	21-25 d	11-25 d	26-30 d	31-35 d	26-35 d	0-35 d
Starter program											
Coefficient											
Intercept	0.0891	---	---	0.336	0.511	0.650	---	---	---	---	---
E	-0.00029	---	---	0.0058	0.0077	-0.0015	---	---	---	---	---
E^2	---	---	---	-0.00039	-0.00054	---	---	---	---	---	---
R^2	0.097	----	----	0.123	0.090	0.078	----	----	----	----	----
P-value											
Linear	0.067	NS	NS	NS	NS	0.10	NS	NS	NS	NS	NS
Quadratic	NS[1]	NS	NS	0.041	0.092	NS	NS	NS	NS	NS	NS
Grower program											
Coefficient											
Intercept	---	---	0.286	---	0.541	0.674	1.572	---	---	---	---
E	---	---	-0.00094	---	-0.0016	-0.0036	-0.0054	---	---	---	---
E^2	---	---	---	---	---	---	---	---	---	---	---
R^2	---	---	0.140	----	0.091	0.160	0.141	----	----	----	----
P-value											
Linear	---	---	0.023	NS	0.078	0.015	0.026	NS	NS	NS	NS
Quadratic	---	---	NS	NS	NS	NS	NS	NS	NS	NS	NS
Finisher program											
Coefficient											
Intercept	---	---	0.294	---	---	---	---	0.749	---	1.715	---
E	---	---	-0.0016	---	---	---	---	0.0076	---	0.012	---
E^2	---	---	---	---	---	---	---	---	---	---	---
R^2	---	---	0.083	---	---	---	----	0.252	----	0.127	----
P-value											
Linear	---	---	0.094	---	---	---	NS	0.0020	NS	0.032	NS
Quadratic	---	---	NS	---	---	---	NS	NS	NS	NS	NS

[1]NS = P> 0.10.

4.4.1.3 Body weight and body weight gain

Dietary energy level affected BW with BW decreasing with lower energy. For the S program significant effects were noted at 10, 15, 20, 30 and 35 d of age with the response quadratic in nature for all but the 10 d BW (Table 4.9 and 4.10). For the G program, significance was noted at 15, 20, 25 and 30 d of age and again the response was quadratic for all times except for 30 d when it was linear. Although the 35 d BW values were not significantly different, the 2700 kcal/kg treatment was numerically the lowest. Diet energy did not affect BW for bird given the F program.

When examining growth using BW gain on a 5 d basis, the results demonstrate a larger effect on weight gain in younger than older birds. For the S program, the 6 to 10, 11 to 15 and 16 to 20 d periods were affected with the lowest gain for the lowest energy diet. Statistically, the response is linear for the 6 to 10 d time frame and quadratic for the two other periods of time. As a consequence, overall gain is affected in a quadratic manner. Weight gain in birds fed the G program was affected for 11 to 15 (quadratic), 16 to 20 (linear) and 11 to 25 (linear) d periods with growth rate increasing with increasing dietary energy. Similarly, bird weight gain increased linearly with increasing energy from 26 to 30 and 26 to 35 d for the F program (Table 4.11 and 4.12).

Table 4.9. Effect of dietary energy level on BW in broiler chickens.

	Body weight (kg)							
Energy content	0 d	5 d	10 d	15 d	20 d	25 d	30 d	35 d
Starter program								
2700 kcal/kg	0.047	0.131	0.273	0.499	0.833	1.239	1.685	2.195
2833 kcal/kg	0.046	0.133	0.278	0.513	0.856	1.253	1.718	2.226
2966 kcal/kg	0.046	0.132	0.275	0.515	0.864	1.262	1.731	2.249
3100 kcal/kg	0.046	0.129	0.278	0.516	0.865	1.265	1.744	2.250
Pooled SEM	0.00012	0.00087	0.00082	0.0018	0.0029	0.0043	0.0062	0.0072
Grower program								
2700 kcal/kg	0.046	---	0.281	0.504	0.843	1.232	1.690	2.202
2833 kcal/kg	0.046	---	0.284	0.517	0.861	1.262	1.729	2.251
2966 kcal/kg	0.047	---	0.284	0.518	0.864	1.263	1.730	2.232
3100 kcal/kg	0.046	---	0.278	0.516	0.865	1.265	1.744	2.250
Pooled SEM	0.00015	---	0.00098	0.0015	0.0024	0.0037	0.0061	0.0084
Finisher program								
2700 kcal/kg	0.046	---	0.282	---	---	1.274	1.727	2.217
2833 kcal/kg	0.046	---	0.280	---	---	1.262	1.718	2.211
2966 kcal/kg	0.047	---	0.283	---	---	1.280	1.740	2.247
3100 kcal/kg	0.046	---	0.278	---	---	1.265	1.744	2.250
Pooled SEM	0.000068	---	0.0011	---	---	0.0044	0.0063	0.0088

[1]NS = P> 0.10.

Table 4.10. The relationship between dietary energy levels on BW in broiler chickens.

	Body weight (kg)							
	0 d	5 d	10 d	15 d	20 d	25 d	30 d	35 d
Starter program								
Coefficient								
Intercept	---	---	---	0.490	0.815	1.225	1.659	2.163
E	---	---	---	0.011	0.021	0.015	0.031	0.036
E^2	---	---	---	-0.00072	-0.0014	-0.00095	-0.0019	-0.0022
R^2	---	---	---	0.395	0.542	0.154	0.342	0.267
P-value								
Linear	NS[1]	NS	NS	0.019	0.0008	0.098	0.0039	0.035
Quadratic	NS	NS	NS	0.00004	<0.0001	0.087	0.0099	0.012
Grower program								
Coefficient								
Intercept	---	---	0.286	0.434	0.741	1.081	1.505	---
E	---	---	-0.00063	0.019	0.028	0.041	0.0503	---
E^2	---	---	---	-0.0010	-0.0014	-0.0021	-0.00246	---
R^2	----	---	0.114	0.357	0.370	0.330	0.270	----
P-value								
Linear	NS	---	0.040	0.081	0.0097	0.019	0.010	NS
Quadratic	NS	---	NS	0.0005	0.0016	0.0032	0.036	NS
Finisher program								
Coefficient								
Intercept	---	---	---	---	---	---	---	---
E	---	---	---	---	---	---	---	---
E^2	---	---	---	---	---	---	---	---
R^2	----	---	----	---	---	----	----	----
P-value								
Linear	NS	---	NS	---	---	NS	NS	NS
Quadratic	NS	---	NS	---	---	NS	NS	NS

[1]NS = P> 0.10.

Table 4.11. Effect of dietary energy level on BW gain in broiler chickens.

	Body weight gain (kg)										
Energy content	0-5 d	6-10 d	0-10 d	11-15 d	16-20 d	21-25 d	11-25 d	26-30 d	31-35 d	26-35 d	0-35 d
Starter program											
2700 kcal/kg	0.084	0.142	0.226	0.226	0.334	0.406	0.966	0.447	0.510	0.957	2.149
2833 kcal/kg	0.087	0.145	0.232	0.236	0.342	0.397	0.975	0.465	0.508	0.974	2.180
2966 kcal/kg	0.086	0.143	0.228	0.241	0.349	0.398	0.987	0.470	0.517	0.987	2.202
3100 kcal/kg	0.083	0.148	0.231	0.238	0.349	0.400	0.987	0.479	0.506	0.985	2.203
Pooled SEM	0.00088	0.0010	0.00084	0.0012	0.0015	0.0033	0.0039	0.0052	0.0042	0.0062	0.0072
Grower program											
2700 kcal/kg	---	---	0.235	0.223	0.339	0.389	0.951	0.459	0.512	0.971	2.156
2833 kcal/kg	---	---	0.237	0.233	0.344	0.402	0.979	0.467	0.521	0.988	2.204
2966 kcal/kg	---	---	0.237	0.234	0.346	0.399	0.979	0.468	0.502	0.969	2.185
3100 kcal/kg	---	---	0.231	0.238	0.349	0.400	0.987	0.479	0.506	0.985	2.203
Pooled SEM	---	---	0.00099	0.0013	0.0014	0.0019	0.0035	0.0039	0.0046	0.0069	0.0084
Finisher program											
2700 kcal/kg	---	---	0.236	---	---	---	0.992	0.453	0.490	0.943	2.171
2833 kcal/kg	---	---	0.234	---	---	---	0.982	0.456	0.493	0.949	2.165
2966 kcal/kg	---	---	0.236	---	---	---	0.998	0.460	0.507	0.967	2.201
3100 kcal/kg	---	---	0.231	---	---	---	0.987	0.479	0.506	0.985	2.203
Pooled SEM	---	---	0.0011	---	---	---	0.0037	0.0035	0.0061	0.0073	0.0088

[1]NS = P> 0.10.

Table 4.12. The relationship between dietary energy levels on BW gain in broiler chickens.

	Body weight gain (kg)										
	0-5 d	6-10 d	0-10 d	11-15 d	16-20 d	21-25 d	11-25 d	26-30 d	31-35 d	26-35 d	0-35 d
Starter program											
Coefficient											
Intercept	---	0.142	---	0.218	0.324	---	0.952	0.456	---	---	2.116
E	---	0.00046	---	0.0099	0.010	---	0.014	0.0019	---	---	0.036
E^2	---	---	---	-0.00064	-0.00063	---	-0.00087	---	---	---	-0.0022
R^2	----	0.132	----	0.539	0.483	----	0.146	0.089	----	----	0.268
P-value											
Linear	NS[1]	0.032	NS	0.012	0.0012	NS	NS	0.073	NS	NS	0.035
Quadratic	NS	NS	NS	<0.0001	0.0002	NS	0.083	NS	NS	NS	0.011
Grower program											
Coefficient											
Intercept	---	---	0.240	0.170	0.337	0.340	0.817	0.451	---	---	---
E	---	---	-0.00063	0.014	0.0010	0.014	0.037	0.0022	---	---	---
E^2	---	---	---	-0.00070	---	-0.00069	-0.0018	---	---	---	---
R^2	---	---	0.112	0.494	0.142	0.128	0.383	0.090	----	----	----
P-value											
Linear	---	---	0.044	<0.0001	0.022	NS	0.0018	0.079	NS	NS	NS
Quadratic	---	---	NS	0.0012	NS	0.084	0.0052	NS	NS	NS	NS
Finisher program											
Coefficient											
Intercept	---	---	---	---	---	---	---	0.390	---	0.843	---
E	---	---	---	---	---	---	---	0.0067	---	0.011	---
E^2	---	---	---	---	---	---	---	---	---	---	---
R^2	---	---	----	---	---	---	----	0.230	----	0.141	----
P-value											
Linear	---	---	NS	---	---	---	NS	0.0033	NS	0.026	NS
Quadratic	---	---	NS	---	---	---	NS	NS	NS	NS	NS

[1]NS = P> 0.10.

4.4.1.4 Feed to gain ratio

Feed to gain ration was affected by dietary energy for time periods in the S, G and F programs (Table 4.13 and 4.14). In all cases feed to gain ratio decreased with increasing dietary energy. In the S program feed to gain ratio decreased with increasing dietary energy for the 6-10 (linear), 0-10 (linear), 11-15 (quadratic), 16-20 (linear), 11-25 (linear), 26-30 (quadratic), 26-35 (quadratic) and 0-35 d (quadratic) periods. For the G program, a decrease in feed to gain ratio with increasing energy was seen for 11-15 (quadratic), 16-20 (linear), 21-25 (quadratic), 11-25 (quadratic) and 0-35 d (quadratic) periods. The effect of diet energy on feed to gain ratio for the F program was restricted to a negative linear relationship for the 0 to 35 d period.

Table 4.13. Effect of dietary energy level on feed to gain (with mortality correction) in broiler chickens.

	Feed to gain										
Energy content	0-5 d	6-10 d	0-10 d	11-15 d	16-20 d	21-25 d	11-25 d	26-30 d	31-35 d	26-35 d	0-35 d
Starter program											
2700 kcal/kg	1.028	1.337	1.221	1.508	1.553	1.598	1.559	1.900	1.992	1.941	1.687
2833 kcal/kg	1.060	1.299	1.209	1.476	1.521	1.618	1.549	1.800	1.979	1.892	1.663
2966 kcal/kg	1.016	1.314	1.200	1.449	1.519	1.639	1.550	1.776	1.945	1.862	1.651
3100 kcal/kg	1.033	1.267	1.180	1.449	1.484	1.577	1.512	1.780	1.992	1.885	1.640
Pooled SEM	0.0085	0.0077	0.0041	0.0069	0.0076	0.016	0.0088	0.023	0.015	0.011	0.0049
Grower program											
2700 kcal/kg	---	---	1.178	1.537	1.561	1.695	1.610	1.826	1.982	1.907	1.692
2833 kcal/kg	---	---	1.190	1.497	1.548	1.639	1.572	1.818	1.953	1.888	1.669
2966 kcal/kg	---	---	1.182	1.474	1.518	1.599	1.540	1.783	1.984	1.885	1.651
3100 kcal/kg	---	---	1.180	1.449	1.484	1.577	1.512	1.780	1.992	1.885	1.640
Pooled SEM	---	---	0.0046	0.0080	0.0076	0.013	0.0078	0.011	0.015	0.0092	0.0054
Finisher program											
2700 kcal/kg	---	---	1.185	---	---	---	1.535	1.813	2.083	1.946	1.670
2833 kcal/kg	---	---	1.174	---	---	---	1.530	1.796	2.006	1.902	1.653
2966 kcal/kg	---	---	1.177	---	---	---	1.546	1.821	2.002	1.912	1.663
3100 kcal/kg	---	---	1.180	---	---	---	1.512	1.780	1.992	1.885	1.640
Pooled SEM	---	---	0.0048	---	---	---	0.0053	0.0092	0.024	0.012	0.0045

[1]NS = P> 0.10.

Table 4.14. The relationship between dietary energy levels on feed to gain (with mortality correction) in broiler chickens.

	Feed to gain										
	0-5 d	6-10 d	0-10 d	11-15 d	16-20 d	21-25 d	11-25 d	26-30 d	31-35 d	26-35 d	0-35 d
Starter program											
Coefficient											
Intercept	---	1.326	1.216	1.544	1.541	---	1.560	1.970	---	1.989	1.708
E	---	-0.0047	-0.0029	-0.039	-0.0046	---	-0.0037	-0.085	---	-0.054	-0.024
E^2	---	---	---	0.003	---	---	---	0.0054	---	0.0035	0.0014
R^2	----	0.243	0.328	0.352	0.240	----	0.116	0.132	----	0.196	0.359
P-value											
Linear	NS[1]	0.0024	0.0002	0.012	0.0022	NS	0.045	NS	NS	NS	0.0021
Quadratic	NS	NS	0.098	0.0024	NS	NS	NS	0.065	NS	0.012	0.010
Grower program											
Coefficient											
Intercept	---	---	---	1.815	1.598	2.131	1.914	---	---	---	1.877
E	---	---	---	-0.073	-0.0091	-0.115	-0.079	---	---	---	-0.049
E^2	---	---	---	0.0035	---	0.0056	0.0037	---	---	---	0.0023
R^2	---	---	----	0.470	0.397	0.347	0.625	----	----	----	0.394
P-value											
Linear	---	---	NS	<0.0001	<0.0001	0.0019	<0.0001	NS	NS	NS	0.0006
Quadratic	---	---	NS	0.0090	NS	0.018	0.0009	NS	NS	NS	0.014
Finisher program											
Coefficient											
Intercept	---	---	---	---	---	---	---	---	---	---	1.725
E	---	---	---	---	---	---	---	---	---	---	-0.0064
E^2	---	---	---	---	---	---	---	---	---	---	---
R^2	---	---	----	---	---	---	----	----	----	----	0.125
P-value											
Linear	---	---	NS	---	---	---	NS	NS	NS	NS	0.037
Quadratic	---	---	NS	---	---	---	NS	NS	NS	NS	NS

[1]NS = P> 0.10.

4.4.1.5 Mortality

Mortality was relatively unaffected by dietary energy (Table 4.15 and 4.16). Exceptions in the S program were linear increases in mortality with increasing energy for the 6-10 and 31-35 d periods and a quadratic response from 26-35 d, where highest mortality was found in the 2700 and 3100 kcal/kg treatments. In the G program, mortality increased in a linear fashion with increasing dietary energy for the 31-35 and 26-35 d periods. The effect of dietary energy on mortality for the 0 to 35 d period approached significance (P=0.058) with a quadratic response, and again highest mortality in the lowest and highest energy levels. A similar significant quadratic response was found for the 0 to 35 d period in the F program despite a lack of significance for mortality during the period of time when the energy treatments were applied.

Table 4.15. Effect of dietary energy level on mortality in broiler chickens.

	Mortality (%)										
Energy content	0-5 d	6-10 d	0-10 d	11-15 d	16-20 d	21-25 d	11-25 d	26-30 d	31-35 d	26-35 d	0-35 d
Starter program											
2700 kcal/kg	0.358	0.358	0.717	0.179	1.075	0.538	1.792	1.255	1.434	2.688	5.197
2833 kcal/kg	0.358	0.343	0.701	0.358	0.880	0.538	1.776	0.358	0.717	1.075	3.553
2966 kcal/kg	0.538	0.538	1.08	0.538	1.075	0.358	1.971	0.538	0.538	1.075	4.122
3100 kcal/kg	0.179	1.26	1.43	0.717	0.896	0.538	2.151	0.896	1.971	2.867	6.452
Pooled SEM	0.13	0.16	0.20	0.15	0.19	0.14	0.28	0.20	0.22	0.31	0.54
Grower program											
2700 kcal/kg	---	---	1.255	1.255	1.255	0.538	3.047	0.538	0.896	1.434	5.735
2833 kcal/kg	---	---	1.072	0.00	1.252	0.717	1.969	0.896	0.717	1.613	4.654
2966 kcal/kg	---	---	0.736	0.538	0.896	0.736	2.170	0.358	1.075	1.434	4.340
3100 kcal/kg	---	---	1.434	0.717	0.896	0.538	2.151	0.896	1.971	2.867	6.452
Pooled SEM	---	---	0.18	0.17	0.16	0.13	0.26	0.19	0.19	0.24	0.35
Finisher program											
2700 kcal/kg	---	---	1.613	---	---	---	2.151	0.179	1.792	1.971	5.735
2833 kcal/kg	---	---	0.896	---	---	---	0.896	0.538	0.717	1.255	3.047
2966 kcal/kg	---	---	0.179	---	---	---	1.792	0.896	1.434	2.330	4.301
3100 kcal/kg	---	---	1.434	---	---	---	2.151	0.896	1.971	2.867	6.452
Pooled SEM	---	---	0.22	---	---	---	0.25	0.19	0.22	0.26	0.433

Table 4.16. The relationship between dietary energy levels on mortality in broiler chickens.

	Mortality (%)										
	0-5 d	6-10 d	0-10 d	11-15 d	16-20 d	21-25 d	11-25 d	26-30 d	31-35 d	26-35 d	0-35 d
Starter program											
Coefficient											
Intercept	---	0.259	---	---	---	---	---	---	0.757	3.556	3.973
E	---	0.077	---	---	---	---	---	---	0.086	-1.173	0.181
E^2	---	---	---	---	---	---	---	---	---	0.086	---
R^2	----	0.152	----	----	----	----	----	----	0.102	0.187	0.076
P-value											
Linear	NS[1]	0.021	NS	NS	NS	NS	NS	NS	0.049	NS	0.10
Quadratic	NS	NS	NS	NS	NS	NS	NS	NS	0.065	0.030	NS
Grower program											
Coefficient											
Intercept	---	---	---		---	---	---	---	-0.00000099	0.394	13.928
E	---	---	---		---	---	---	---	0.150	0.186	-2.327
E^2	---	---	---		---	---	---	---	---	---	0.135
R^2	---	---	----	0.079	----	----	----	----	0.176	0.164	0.166
P-value											
Linear	---	---	NS	NS	NS	NS	NS	NS	0.012	0.015	NS
Quadratic	---	---	NS	0.10	NS	NS	NS	NS	NS	NS	0.058
Finisher program											
Coefficient											
Intercept	---	---	38.050	---	---	---	---	---	---	-1.142	71.414
E	---	---	-6.790	---	---	---	---	---	---	0.302	-12.613
E^2	---	---	0.305	---	---	---	---	---	---	---	0.587
R^2	---	---	0.183	---	---	---	----	----	----	0.082	0.211
P-value											
Linear	---	---	NS	---	---	---	NS	NS	NS	0.093	NS
Quadratic	---	---	0.011	---	---	---	NS	NS	NS	NS	0.013

[1]NS = P> 0.10.

4.4.1.6 Metabolizable energy intake per kg of gain

The ME intake per kg of gain increased linearly with increasing dietary energy content for all programs (data not shown). This is due to the similar FI in birds fed different dietary energy levels.

4.4.2 Programs

Some significant differences were seen between programs, but the responses were small and were not of biological significance (data not shown).

4.4.3 Crumble size and pellet quality index

There was a linear increase in crumble size with increasing energy content of the starter diet (Table 4.17). Increasing energy content of the diet increased the percentage of crumble size over 3.36 mm and decreased the percentage crumble size from 1.99 to 1.00 mm. The opposite effect was seen in the low energy diet. There was no relationship seen between the low and the high energy diets for the fine crumble size (less than 0.99 mm). There was a quadratic response in the PDI between the different energy content of the diet in the F phase with the highest value for the 3100 kcal/kg diet.

Table 4.17. The effect of different dietary energy content and pellet quality in the diet (%).

Energy (kcal/kg)	Crumble size (starter diet)				PDI (finisher diet)
	>3.36 mm	3.35 to 2.00 mm	1.99 to 1.00 mm	<0.99 mm	
2700	9.80	27.01	32.43	30.77	82.28
2833	12.83	30.21	29.65	27.31	81.72
2966	10.82	29.74	30.24	29.21	80.03
3100	16.71	28.52	26.22	28.55	86.04
Pooled SEM	1.014	0.485	0.847	0.497	0.830
Coefficient					
Intercept	7.855	22.323	34.150	---	88.332
E	1.874	5.934	-1.806	---	-7.254
E^2	---	-1.105	---	---	1.643
R^2	0.610	0.869	0.812	---	0.798
P-value					
Linear	0.0271	0.080	0.0045	NS	0.060
Quadratic	NS	0.0032	NS	NS	0.014

[1]NS = P> 0.10.

4.5 Discussion

It was hypothesized that FI regulation was age dependent and the birds would adjust their FI according to the energy content of the diet at an older age. However, the results of this research do not support this hypothesis. FI was generally not altered with the different phases and programs under investigation and the birds did not adjust their FI based on diet energy for the whole production period. This is in disagreement with other studies (Griffiths et al., 1977; Jones and Wiseman, 1985; Brickett et al., 2007; Kamran et al., 2008). In these studies, FI regulation was limited at an early age and the birds were only able to regulate their FI at an older age. Suggested reasons for an age dependent response included limited physical gastrointestinal tract capacity of young chicks and/or the influence of energy derived from the yolk (Griffiths et al., 1977; Kamran et al., 2008). Again, the findings of the present research fail to support this concept.

Broilers generally did not alter their FI in response to the different dietary energy content and even where statistical significance was found, the response was not as large as expected. In other words, the theoretical percent difference in FI between the low and high energy diet did not match the actual percent difference in FI. The difference between the lowest and highest energy was 400 kcal or 14.8% in this experiment. If chickens are able to adjust their FI based on dietary energy level, the percent difference in the FI between low and high energy should also be 14.8%. However, the actual percent difference was very small and in most cases, non-significant. Therefore, our research suggests that broiler chickens do not adjust their FI to diets containing energy ranging from 2700 to 3100 kcal/kg. Similar results were seen in a research where dietary energy ranged from 3000 to 3200 kcal/kg with broiler chickens raised to 21 d of age (Plumstead et al., 2007). In this study, the theoretical difference in FI between the low and the high energy for this study was 6.7%, while the actual FI difference was small in relation to the dietary energy (0.34%). Furthermore, the results of the present study are also in contrast with other studies that found the actual value of change in FI approximately matched what would be expected based on dietary energy (Leeson et al., 1996; Dozier III et al., 2006; Kamran et al., 2008). These studies demonstrated that chickens ate to maintain energy intake when fed diets containing 2700 to 3300 kcal/kg ME (Leeson et al., 1996), and when diets ranging in energy between 3175 to 3310 kcal/kg were fed to broilers from 30 to 59 d of age (Dozier III et al., 2006).

Providing diets of varying energy level at different ages had minor effects on FI and production traits in this research. Differences that were found indicated that young birds may more readily adapt to changes in energy content. In the F program from 25 to 30 d, birds linearly increased their FI with increasing dietary energy levels. This was not seen in the other two programs and the sudden change in energy content of the feed from G to F diets in the F program may have caused the decrease in FI for the lower energy diets.

The variation in FI response in relationship to dietary energy in the scientific literature is large and may be due to a number of factors including dietary fat content, feed form and pellet quality, AA content of the diet and genetic strain of broiler chickens. The approach taken in this study was to keep the balance between fat and the energy content in the diet constant based on the potential of dietary fat levels to impact FI. Broiler chickens decreased their FI with increasing energy and fat content of the diet when dietary carbohydrate were held constant (Leeson et al., 1996). A similar response was seen when dietary energy and sunflower oil content increased from 2985 to 3200 kcal/kg and 3 to 7%, respectively, with varying carbohydrate content in the diet (Sanz et al., 2000). Furthermore, the high fat content that is often found in high energy diets can decrease pellet quality (Briggs et al., 1999), which may in turn affect FI.

Feed form and pellet quality of the diet could affect FI in broiler chickens. Pelleted diets are well known to increase FI and improve the performance of boiler chickens compared to mash diets (Svihus et al., 2004; Amerah et al., 2007a; Brickett et al., 2007; Mirghelenj and Golian, 2009; Zang et al., 2009). This could be due to the increased nutrient density of the diet promoting more rapid and efficient eating. In addition, pelleted diets have been shown to decrease feed wastage, which could be interpreted as reduced FI (Hamilton and Proudfoot, 1995; Amerah et al., 2007b). Furthermore, pellet quality can affect FI in broiler chickens with poor pellet quality reducing FI in broiler chickens (Lemme et al., 2006). Although there were statistically significant differences in crumble and pellet quality in the present study, the actual differences were relatively small and therefore unlikely to have a major effect on FI.

Some studies could have different results from the present research because of different strategies used in relationship to formulating the essential AA content in the diet. Brickett et al., (2007) chose to maintain the same ratio of total essential AA content to dietary energy in anticipation that FI would change appropriately to maintain energy intake. In this study, the effect of dietary energy changes is confounded by the level of AA in the diet because diets with excessive or deficient AA content can affect FI (Summers et al., 1992). Studies that use total AA instead of DAA content as a basis for feed formulation may have performance effects (including FI) that are related to the nature of feed ingredients instead of the energy content of the diet. This is particularly true if ingredients vary in AA composition and digestibility (Farrell et al., 1999). In the present research, dietary AA content was held relatively constant and the measured DAA content of ingredients was used to formulate diets.

Modern broiler chickens may not adjust their FI according to the dietary energy level of the diet due to the intense genetic selection for growth over the years and instead may consume feed to their maximum physical capacity regardless of the energy content of the feed. The change in broiler growth through genetic selection is well documented (Havenstein et al., 2003) and industry records confirm that the increase in growth potential has continued to the time of the writing this document. Selection for heavier BW in broiler chickens also results in indirect selection for higher FI since there is a high positive correlation between the two responses (Siegel and Wiseman, 1966; Pym and Nicholls, 1979). Thus, selection for heavier BW in broilers may also unconsciously select for birds with less hypothalamic response to satiety signals (Burkhart et al., 1983). This may have resulted in birds that attempt to eat to maximum physical capacity regardless of the energy content of the diet.

In the present experiment, dietary energy affected feed to gain ratio in either a quadratic or linear fashion over the respective program feeding periods. The highest ratios (poorest FE) were found for birds fed lower energy diets. Although, FI effects were small to non-existent, changes in BW resulted in the changes in FE. It can be speculated that lower energy diets contained insufficient energy for the protein synthesis potential of the diets and that as a consequence catabolism of AA occurred to make up this deficiency. This would in turn result in reduced growth and poorer FE.

Research has indicated that mortality increases with increasing energy content of diet (Dale and Villacres, 1988). However, this was not seen in our study and this is in agreement with a few other studies (Hidalgo et al., 2004; Brickett et al., 2007) even when growth rates are quite different.

In summary, broiler chickens did not adjust their FI according to the energy content of the diet and this effect was similar regardless of bird age. If this finding is confirmed, it has important implications for diet formulation such as the need to relate diet amino content to energy content, and the specific energy levels chosen for broiler diets. The age at which lower energy diets were introduced to broilers had a relatively minor effect in this study, but there is some indication that older broilers may be less adaptive to a larger change in diet energy content. Growth and FE were slightly poorer in broilers fed lower energy diets despite the same FI and it is speculated that this may be due to AA catabolism to overcome a deficiency in diet energy. Mortality was not affected in a major way by the energy content of the diet.

5.0 The Effect of Dietary Energy and Digestible Amino Acid Content on Broiler Performance

5.1 Abstract

Broilers may not adjust FI according to dietary AME levels. It was of interest to study the FI response to diet AME and determine if this response is affected by dietary AA content. Diets were formulated based on the determined energy and AA digestibility of key ingredients (at 5 and 21 d of age) to contain four levels of AME (2700, 2833, 2966 and 3100 kcal/kg) and three levels of digestible lysine (0 to 10 d of age – 1.14, 1.02 and 0.89%; 11 to 25 d of age – 0.99, 0.88 and 0.77%; 26 to 35 d of age – 0.87, 0.78 and 0.68%) balanced with other indispensible AA. Each AME by digestible lysine subclass was replicated 9 times with 62 mixed sex chicks per replication. With the exception of mortality, which was unaffected by treatment, there were significant interactions between AME and digestible lysine content for all parameters including CY and breast meat yield (BY) (% of live weight). For the high lysine level, BW, and CY and BY (P = 0.076) increased with AME, but FI was unaffected. At the intermediate level, production and meat yield parameters including FI were unaffected by AME. At the low lysine level, BW, FI, CY and BY decreased with increasing AME. Data from the high lysine treatment suggest that low levels of AME are insufficient to maximize protein synthesis and growth possibly because broilers catabolize DAA to meet their energy requirements. In contrast, all AME levels are adequate to match the energy requirements of the limited growth potential in the intermediate lysine treatment. Excess energy in combination with

low lysine may result in an imbalance in these nutrients that is large enough to decrease FI at higher energy levels. The results confirm that FI is not affected by AME when diets contain moderate to high levels of lysine content. The interaction between AME and DAA demonstrate the need to meet both energy and protein requirements of the broiler while also maintaining balance between them.

Keywords

Digestible amino acid, broiler, AME, lysine, nutrient density

5.2 Introduction

Chickens adjust their FI according to the energy content in the diet in an effort to maintain a constant energy intake (Leeson et al., 1996). This has been a basis for diet formulation and if birds can modify FI accurately, other dietary nutrients can be altered to match FI levels. As a consequence, broiler performance, other than FI and FE, are relatively unaffected with a range of ME because of the chicken's ability to maintain nutrient intake levels (Leeson et al., 1996). However, a previous experiment in this thesis (Chapter 4.0) and other research (Plumstead et al., 2007) has found that broilers chickens do not change their FI in response to different energy levels in the diet. There is no obvious reason for this discrepancy, but it has been hypothesized that intense genetic selection in broilers has modified broiler FI control mechanisms (Burkhart et al., 1983). In addition, differences between experiments in dietary AA content, ratios of energy contributing components in the diet such as fat, and the range of ME examined may influence the ability of research to accurately detect the response to dietary energy. Dietary AA content is related to growth and CY in broiler chickens and deficiencies in indispensable dietary AA can reduce broiler performance and flock uniformity as well as carcass and meat yield (Tesseraud, 1996; Kidd et al., 2000). To ensure that deficiencies are avoided, the use of DAA content in feed formulation is widespread, and furthermore, balance in AA content has been improved with the introduction of the ideal protein concept (Dari et al., 2005).

If broilers have changed in their ability to respond to ME, it may also affect the relationship of ME to AA content in the diet. Dozier III et al. (2006) compared the performance of broilers fed variable AME (3175 to 3310 kcal/kg) and total lysine contents (0.89 or 0.93%) from 30 to 59 d of age. Feed consumption, BW and BY increased when crude protein and AA were increased by 4% in a 3310 kcal/kg energy diet compared to the diet with no additional supplement of AA, demonstrating that the dietary AA content limited the growth of broiler chickens in the latter diet. In an experiment conducted to 21 d of age, broilers were provided with different ME (3000 to 3200 kcal/kg) and digestible lysine (1.05 to 1.29%) levels (Plumstead et al., 2007). No interactions were found between dietary AA and energy content, and production parameters responded independently to energy and AA content in the diet. Of significance, FI was similar regardless of the ME or AA content.

Based on the above research, the interaction between ME and DAA content, and the fact that the biological response associated with this interaction in broiler chickens is not clear, the present research was completed. Because of the lack of response in FI to changes in ME in previous work (Chapter 4.0, Plumstead et al., 2007), and the independence of performance in response to ME and DAA, the hypothesis for this research was that the FI response to dietary AME will vary according to the DAA content in the diet. Therefore, two objectives in this research were 1) to investigate the effect of dietary energy on broiler FI and 2) to examine the relationship between dietary energy and DAA levels in broiler chickens.

5.3 Materials and methods

Protocols for these experiments were approved by the Animal Care Committee of University of Saskatchewan, and birds were reared and cared according to the Canadian Council of Animal Care (1993).

5.3.1 Animal and housing

Ross x Ross 308 mixed sexed broiler chickens were obtained from a commercial hatchery (Lilydale Hatchery, Wynyard, SK) at 0 d of age. These were randomly placed in one of the nine rooms with 12 floor pens (pen dimension: 2.3 x 2.0 m) in each room. Each pen contained 62 birds (31 female and 31 male broiler chickens) and the stocking density was 30.0 kg per m^2 at expected final BW. Every pen had straw litter, a hanging feeder (0 to 21 d, 36 cm in diameter; 22 to 35 d, 43 cm in diameter) and a Lubing nipple drinker (6 nipples per pen), and feed and water were available on an ad libitum basis. The chicks had supplementary feed and water from 0 to 5 d of age to ensure that the chicks had adequate access. The temperature was set to 34 ºC at 0 d of age and was reduced 2.8 ºC every week until 22 ºC was reached. The light intensity was set to 30 lux (23 hr of light and 1 hr of dark) until 7 d of age and then set to 10 lux (18 hr of light and 6 hr of dark) for the remaining production period. A dawn and dusk system gradually increased and decreased light intensity over a 50 minute period.

5.3.2 Experimental diets

The diets were formulated based on a previous experiment (Chapter 3.0), which evaluated key ingredients for AA and energy digestibility at 4 to 6 and 19 to 21 d of age. If AME or AID values were significantly different from 5 and 21 d old chicks, they were used in diet formulation on an age appropriate basis. If there were no significant differences between ages, the average of the digestibility values for the two ages was used in feed formulation. There were 12 different dietary treatments each varying in energy and/or AA content. There were four dietary energy levels, which were 2700, 2833, 2966 and 3100 kcal/kg AME, and three digestible lysine contents that varied according to the production phase (Table 5.1, 5.2, 5.3, 5.4, 5.5 and 5.6). Apparent ileal digestible lysine levels were 1.14, 1.02 and 0.89 (S; 0 to 10 d of age), 0.99, 0.88 and 0.77 (G; 11 to 25 d of age), and 0.87, 0.78 and 0.68% (F; 26 to 35 d of age) for the starter grower and finisher phases, respectively. Diets were formulated based on the ideal protein concept (Emmert and Baker, 1997). Hence, diets were formulated to maintain a similar ratio between digestible essential AA and lysine content. High and low energy diets were formulated and intermediate diets were calculated based on these values to reduce variability in ingredient use. Diet crude fat (ether extract) was held constant in relation to energy levels for all diets.

5.3.3 Crumble size and pellet quality index

Sieve analysis was done to measure crumble size in the S and G diets. A mechanical shaker with six different sieves was used to shake the crumbled feed. The crumbled feed was placed on top of the sieve of the mechanical shaker and was shaken for 30 seconds. Feed from each sieve was weighed individually. Crumble size was calculated using the equation below.

$$\text{Retained crumbled feed in screen (\%)} = \frac{\text{Weight of feed on sieve after shake}}{\text{Weight of total feed}}$$

Pelleted feed of the F diets were weighed (500 g; ASAE Standards, 1987) and then placed in a rolling drum (300 x 300 x 125 mm) that was rotated 50 revolutions per minute for 10 minutes. It was sieved using a 3.57 x 19.05 mm screen and the PDI was calculated using the equation below.

$$\text{PDI (\%)} = \frac{\text{Mass of pellets after rotation}}{\text{Mass of pellets before rotation}}$$

5.3.4 Data collection

FI and BW were measured at 0, 10, 25 and 35 d of age on a pen basis. Feed conversion ratios were calculated and corrected for mortality. Meat yield was determined at 35 d of age and a total of 648 birds (3 female and 3 male from each replication) were randomly selected. After birds were processed at a commercial poultry processor (Lilydale, Wynyard, SK), breast (pectoral major and minor, and skin), left drum (meat, skin, bone), left thigh (meat, thigh, bone), right drum, right thigh, wings, abdominal fat and remaining carcass were separated and weighed.

5.3.5 Statistical analysis

Proc Univariate of SAS version 9.2 (SAS Institute, 2001) was used to test for normality and then data were analyzed using Proc GLM (General Linear Models Procedures) as a 4 (energy) x 3 (lysine) factorial arrangement ($P \leq 0.05$). In this study, there were 9 replications per treatment with 62 birds per replication. Proc GLM was used to examine the gender effect in meat yield while other treatment responses used the linear and quadratic regression analyses of Proc Reg of SAS version 9.2 (SAS Institute, 2001). The linear [1] and quadratic [2] functions were:

$$Y = b0 + b1\ E \qquad [1]$$

$$Y = b0 + b1\ E + b2\ E^2 \qquad [2]$$

Where Y= predicted response, E = energy content of the diet, b0 = intercept, and b1 and b2 = regression coefficient.

Table 5.1. Composition of the high digestible lysine diets (%).

	Starter				Grower				Finisher			
	Energy levels (kcal/kg)											
Ingredient (%)	2700	2833	2966	3100	2700	2833	2966	3100	2700	2833	2966	3100
Corn	0.00	3.80	7.60	11.40	0.00	1.67	3.33	5.00	0.00	1.67	3.33	5.00
Barley	40.67	27.11	13.56	0.00	44.61	29.74	14.87	0.00	51.81	34.54	17.27	0.00
Soybean meal	35.29	36.19	37.09	37.99	23.83	23.98	24.13	24.28	19.28	18.25	17.23	16.20
Wheat	9.99	20.31	30.63	40.95	14.96	28.61	42.27	55.92	13.58	29.48	45.38	61.28
Canola meal	5.21	3.47	1.74	0.00	8.47	7.59	6.70	5.82	7.50	7.98	8.45	8.93
Canola oil	4.15	4.36	4.58	4.79	3.97	4.21	4.46	4.70	3.89	4.12	4.35	4.58
Limestone	1.54	1.57	1.59	1.62	1.28	1.30	1.33	1.35	1.25	1.27	1.28	1.30
Dicalcium phosphate	1.30	1.33	1.37	1.40	1.08	1.10	1.13	1.15	0.98	0.99	1.00	1.01
Vitamin- mineral premix[1]	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Sodium chloride	0.43	0.41	0.40	0.38	0.43	0.40	0.38	0.35	0.44	0.41	0.38	0.35
Choline chloride	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
L-Lysine HCl	0.11	0.12	0.14	0.15	0.14	0.16	0.17	0.19	0.12	0.15	0.17	0.20
DL-Methionine	0.26	0.27	0.27	0.28	0.20	0.20	0.19	0.19	0.16	0.15	0.14	0.13
L-Threonine	0.08	0.08	0.08	0.08	0.06	0.07	0.07	0.08	0.05	0.06	0.06	0.07
Barley Endofeed[2]	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Avizyme 1302[3]	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Salinomycin sodium[4]	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Virginiamycin[5]	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Pellet binder[6]	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20

[1] Supplied per kilogram of diet: vitamin A (retinyl acetate + retinyl palmitate), 11000 IU; vitamin D, 2200 IU; vitamin E (dl-α-topheryl acetate), 300 IU; menadione, 2.0 mg; thiamine, 1.5 mg; riboflavin, 6.0 mg; niacin, 60 mg; pyridoxine, 4 mg; vitamin B_{12}, 0.02 mg; pantothenic acid, 10.0 mg; folic acid, 0.6 mg; biotin, 0.15 mg; iron, 80 mg; zinc, 80 mg; manganese, 80 mg; copper, 10 mg; iodine, 0.8 mg; selenium, 0.3 mg; and $CaCO_3$, 500 mg.
[2] Barley Endofeed (GNC Bioferm Inc., Bradwell, SK).
[3] Avizyme 1302 (Danisco Animal Nutrition, Marlborough, Wiltshire).
[4] Coccistac (Phibro Animal Health, Ridgefield Park, NJ).
[5] Stafac-44 (Phibro Animal Health, Ridgefield Park, NJ).
[6] Maxibond (Agresearch Inc., Joliet, IL).

Table 5.2. Nutrient composition of the high digestible lysine diets (%).

	Starter				Grower				Finisher			
	Energy levels (kcal/kg)											
Formulated nutrient composition (%)	2700	2833	2966	3100	2700	2833	2966	3100	2700	2833	2966	3100
Crude Protein	24.50	24.57	24.63	24.70	21.40	21.56	21.72	21.88	19.40	19.58	19.76	19.94
M.E. (kcal/kg)[1]	2700	2833	2966	3100	2700	2833	2966	3100	2700	2833	2966	3100
Ether extract	5.39	5.66	5.92	6.19	5.39	5.66	5.92	6.19	5.39	5.66	5.92	6.19
Lysine	1.47	1.46	1.45	1.44	1.25	1.25	1.24	1.23	1.10	1.09	1.09	1.08
Dig. Lysine[1]	1.14	1.14	1.14	1.14	0.99	0.99	0.99	0.99	0.87	0.87	0.87	0.87
Arginine	1.70	1.67	1.64	1.61	1.35	1.34	1.34	1.34	1.20	1.19	1.17	1.16
Dig. Arginine[1]	1.18	1.18	1.18	1.18	1.03	1.03	1.03	1.03	0.92	0.92	0.92	0.92
Methionine	0.62	0.62	0.62	0.62	0.53	0.52	0.52	0.51	0.46	0.45	0.44	0.43
Dig. Methionine[1]	0.55	0.55	0.55	0.55	0.48	0.48	0.48	0.47	0.42	0.41	0.40	0.40
Sulfur AA	1.05	1.04	1.03	1.03	0.93	0.92	0.92	0.91	0.83	0.83	0.83	0.82
Dig. Sulfur AA[1]	0.85	0.85	0.85	0.85	0.76	0.76	0.76	0.76	0.68	0.68	0.68	0.68
Threonine	1.02	1.01	1.00	0.99	0.88	0.87	0.86	0.86	0.78	0.78	0.78	0.77
Dig. Threonine[1]	0.75	0.75	0.75	0.75	0.66	0.66	0.66	0.66	0.59	0.59	0.59	0.59
Tryptophan	0.35	0.34	0.33	0.33	0.31	0.30	0.30	0.30	0.29	0.28	0.28	0.27
Dig. Tryptophan[1]	0.29	0.29	0.28	0.28	0.26	0.25	0.25	0.25	0.24	0.23	0.23	0.23
Calcium	1.05	1.05	1.05	1.05	0.90	0.90	0.90	0.90	0.85	0.85	0.85	0.85
Non-phytate P	0.50	0.50	0.50	0.50	0.45	0.45	0.45	0.45	0.42	0.42	0.42	0.42

[1] Digestibility values obtained from preliminary experiments.

Table 5.3. Composition of the intermediate digestible lysine diets (%).

	Starter				Grower				Finisher			
	Energy levels (kcal/kg)											
Ingredient (%)	2700	2833	2966	3100	2700	2833	2966	3100	2700	2833	2966	3100
Corn	0.00	3.33	6.67	10.00	0.00	1.67	3.33	5.00	0.00	1.67	3.33	5.00
Barley	41.71	27.81	13.90	0.00	56.69	37.79	18.90	0.00	57.86	38.57	19.29	0.00
Soybean meal	27.17	27.79	28.40	29.02	21.42	19.60	17.78	15.96	15.30	13.29	11.28	9.27
Wheat	14.88	26.05	37.21	48.38	9.30	26.72	44.15	61.57	12.62	30.41	48.19	65.98
Canola meal	7.57	6.08	4.60	3.11	4.46	5.86	7.26	8.66	6.44	8.06	9.68	11.30
Canola oil	4.03	4.25	4.47	4.69	3.92	4.14	4.36	4.58	3.83	4.04	4.26	4.47
Limestone	1.53	1.55	1.58	1.60	1.30	1.31	1.33	1.34	1.25	1.26	1.27	1.28
Dicalcium phosphate	1.34	1.37	1.40	1.43	1.16	1.17	1.17	1.18	1.03	1.03	1.04	1.04
Vitamin- mineral premix[1]	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Sodium chloride	0.43	0.41	0.39	0.37	0.45	0.42	0.38	0.35	0.44	0.41	0.37	0.34
Choline chloride	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
L-Lysine HCl	0.13	0.15	0.16	0.18	0.12	0.16	0.19	0.23	0.12	0.16	0.19	0.23
DL-Methionine	0.19	0.19	0.20	0.20	0.17	0.15	0.14	0.12	0.12	0.11	0.09	0.08
L-Threonine	0.06	0.06	0.07	0.07	0.05	0.06	0.07	0.07	0.04	0.05	0.05	0.06
Barley Endofeed[2]	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Avizyme 1302[3]	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Salinomycin sodium[4]	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Virginiamycin[5]	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Pellet binder[6]	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20

[1] Supplied per kilogram of diet: vitamin A (retinyl acetate + retinyl palmitate), 11000 IU; vitamin D, 2200 IU; vitamin E (dl-α-topheryl acetate), 300 IU; menadione, 2.0 mg; thiamine, 1.5 mg; riboflavin, 6.0 mg; niacin, 60 mg; pyridoxine, 4 mg; vitamin B_{12}, 0.02 mg; pantothenic acid, 10.0 mg; folic acid, 0.6 mg; biotin, 0.15 mg; iron, 80 mg; zinc, 80 mg; manganese, 80 mg; copper, 10 mg; iodine, 0.8 mg; selenium, 0.3 mg; and $CaCO_3$, 500 mg.
[2] Barley Endofeed (GNC Bioferm Inc., Bradwell, SK).
[3] Avizyme 1302 (Danisco Animal Nutrition, Marlborough, Wiltshire).
[4] Coccistac (Phibro Animal Health, Ridgefield Park, NJ).
[5] Stafac-44 (Phibro Animal Health, Ridgefield Park, NJ).
[6] Maxibond (Agresearch Inc., Joliet, IL).

Table 5.4. Nutrient composition of the intermediate digestible lysine diets (%).

	Starter				Grower				Finisher			
	Energy levels (kcal/kg)											
Formulated nutrient composition (%)	2700	2833	2966	3100	2700	2833	2966	3100	2700	2833	2966	3100
Crude Protein	22.30	22.37	22.43	22.50	19.20	19.39	19.58	19.78	17.60	17.80	17.99	18.19
M.E. (kcal/kg)[1]	2700	2833	2966	3100	2700	2833	2966	3100	2700	2833	2966	3100
Ether extract	5.39	5.66	5.92	6.19	5.39	5.66	5.92	6.19	5.39	5.66	5.92	6.19
Lysine	1.31	1.30	1.29	1.28	1.10	1.10	1.09	1.09	0.98	0.97	0.97	0.96
Dig. Lysine[1]	1.02	1.02	1.02	1.02	0.88	0.88	0.88	0.88	0.78	0.78	0.78	0.78
Arginine	1.43	1.42	1.42	1.41	1.20	1.18	1.17	1.15	1.06	1.04	1.02	1.00
Dig. Arginine[1]	1.05	1.05	1.05	1.05	0.91	0.91	0.91	0.91	0.82	0.82	0.82	0.82
Methionine	0.53	0.53	0.53	0.52	0.46	0.45	0.44	0.43	0.40	0.39	0.38	0.37
Dig. Methionine[1]	0.46	0.46	0.46	0.46	0.42	0.41	0.40	0.39	0.36	0.35	0.34	0.33
Sulfur AA	0.94	0.93	0.92	0.92	0.82	0.82	0.81	0.81	0.75	0.75	0.75	0.74
Dig. Sulfur AA[1]	0.75	0.75	0.75	0.75	0.67	0.67	0.67	0.67	0.61	0.61	0.61	0.61
Threonine	0.91	0.90	0.89	0.88	0.77	0.77	0.76	0.76	0.70	0.69	0.69	0.68
Dig. Threonine[1]	0.66	0.66	0.66	0.66	0.58	0.58	0.58	0.58	0.52	0.52	0.52	0.52
Tryptophan	0.32	0.31	0.31	0.30	0.29	0.28	0.28	0.27	0.27	0.26	0.26	0.25
Dig. Tryptophan[1]	0.26	0.26	0.26	0.25	0.24	0.23	0.23	0.23	0.22	0.22	0.21	0.21
Calcium	1.05	1.05	1.05	1.05	0.90	0.90	0.90	0.90	0.85	0.85	0.85	0.85
Non-phytate P	0.50	0.50	0.50	0.50	0.45	0.45	0.45	0.45	0.42	0.42	0.42	0.42

[1] Digestibility values obtained from preliminary experiments.

Table 5.5. Composition of the low digestible lysine diets (%).

	Starter				Grower				Finisher			
	Energy levels (kcal/kg)											
Ingredient (%)	2700	2833	2966	3100	2700	2833	2966	3100	2700	2833	2966	3100
Corn	0.00	3.33	6.67	10.00	0.00	2.81	5.62	8.43	0.00	1.89	3.79	5.68
Barley	47.60	31.73	15.87	0.00	51.81	34.54	17.27	0.00	68.28	48.04	27.79	7.55
Soybean meal	21.16	20.92	20.69	20.45	11.40	10.57	9.73	8.90	12.78	10.34	7.89	5.45
Wheat	15.40	28.33	41.26	54.19	19.05	33.73	48.41	63.09	8.02	26.46	44.91	63.35
Canola meal	7.26	6.85	6.44	6.03	9.83	10.20	10.58	10.95	3.13	5.27	7.42	9.56
Canola oil	3.93	4.14	4.35	4.56	3.78	3.99	4.20	4.41	3.78	3.99	4.19	4.40
Limestone	1.53	1.55	1.57	1.59	1.27	1.29	1.30	1.32	1.26	1.27	1.28	1.29
Dicalcium phosphate	1.40	1.42	1.45	1.47	1.18	1.19	1.21	1.22	1.10	1.10	1.10	1.10
Vitamin- mineral premix[1]	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Sodium chloride	0.43	0.41	0.38	0.36	0.43	0.40	0.37	0.34	0.46	0.42	0.39	0.35
Choline chloride	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
L-Lysine HCl	0.12	0.14	0.17	0.19	0.16	0.19	0.21	0.24	0.10	0.14	0.18	0.22
DL-Methionine	0.14	0.14	0.13	0.13	0.09	0.08	0.08	0.07	0.09	0.07	0.06	0.04
L-Threonine	0.06	0.06	0.07	0.07	0.04	0.05	0.05	0.06	0.04	0.05	0.05	0.06
Barley Endofeed[2]	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Avizyme 1302[3]	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Salinomycin sodium[4]	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Virginiamycin[5]	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Pellet binder[6]	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20

[1] Supplied per kilogram of diet: vitamin A (retinyl acetate + retinyl palmitate), 11000 IU; vitamin D, 2200 IU; vitamin E (dl-α-topheryl acetate), 300 IU; menadione, 2.0 mg; thiamine, 1.5 mg; riboflavin, 6.0 mg; niacin, 60 mg; pyridoxine, 4 mg; vitamin B_{12}, 0.02 mg; pantothenic acid, 10.0 mg; folic acid, 0.6 mg; biotin, 0.15 mg; iron, 80 mg; zinc, 80 mg; manganese, 80 mg; copper, 10 mg; iodine, 0.8 mg; selenium, 0.3 mg; and $CaCO_3$, 500 mg.
[2] Barley Endofeed (GNC Bioferm Inc., Bradwell, SK).
[3] Avizyme 1302 (Danisco Animal Nutrition, Marlborough, Wiltshire).
[4] Coccistac (Phibro Animal Health, Ridgefield Park, NJ).
[5] Stafac-44 (Phibro Animal Health, Ridgefield Park, NJ).
[6] Maxibond (Agresearch Inc., Joliet, IL).

Table 5.6. Nutrient composition of the low digestible lysine diets (%).

	Starter				Grower				Finisher			
	Energy levels (kcal/kg)											
Formulated nutrient composition (%)	2700	2833	2966	3100	2700	2833	2966	3100	2700	2833	2966	3100
Crude Protein	20.00	20.11	20.21	20.32	17.30	17.47	17.63	17.80	15.60	15.80	16.00	16.20
M.E. (kcal/kg)[1]	2700	2833	2966	3100	2700	2833	2966	3100	2700	2833	2966	3100
Ether extract	5.39	5.66	5.92	6.19	5.39	5.66	5.92	6.19	5.39	5.66	5.92	6.19
Lysine	1.15	1.14	1.13	1.12	0.97	0.96	0.95	0.95	0.84	0.84	0.83	0.83
Dig. Lysine[1]	0.89	0.89	0.89	0.89	0.77	0.77	0.77	0.77	0.68	0.68	0.68	0.68
Arginine	1.25	1.24	1.23	1.22	1.01	1.00	0.99	0.98	0.92	0.90	0.88	0.86
Dig. Arginine[1]	0.92	0.92	0.92	0.92	0.80	0.80	0.80	0.80	0.71	0.71	0.71	0.71
Methionine	0.45	0.45	0.44	0.44	0.37	0.37	0.36	0.35	0.34	0.33	0.31	0.30
Dig. Methionine[1]	0.39	0.38	0.38	0.38	0.34	0.33	0.32	0.32	0.31	0.29	0.28	0.27
Sulfur AA	0.83	0.83	0.82	0.82	0.73	0.73	0.72	0.72	0.65	0.65	0.65	0.65
Dig. Sulfur AA[1]	0.66	0.66	0.66	0.66	0.59	0.59	0.59	0.59	0.53	0.53	0.53	0.53
Threonine	0.81	0.80	0.80	0.79	0.68	0.68	0.68	0.67	0.61	0.61	0.61	0.60
Dig. Threonine[1]	0.58	0.58	0.58	0.58	0.51	0.51	0.51	0.51	0.46	0.46	0.46	0.46
Tryptophan	0.29	0.29	0.28	0.28	0.26	0.26	0.25	0.24	0.25	0.24	0.24	0.23
Dig. Tryptophan[1]	0.24	0.24	0.23	0.23	0.21	0.21	0.21	0.20	0.20	0.20	0.19	0.19
Calcium	1.05	1.05	1.05	1.05	0.90	0.90	0.90	0.90	0.85	0.85	0.85	0.85
Non-phytate P	0.50	0.50	0.50	0.50	0.45	0.45	0.45	0.45	0.42	0.42	0.42	0.42

[1] Digestibility values obtained from preliminary experiments.

5.4 Results

5.4.1 Performance

Significant interactions between energy and AA were found on main effects for all response criteria except for mortality. Hence, the interaction between energy and AA will be emphasized rather than the main effects for these criteria.

5.4.2 Body weight and body weight gain

Interactions between diet energy and AA content were found for BW and BW gain for all ages except for BW when birds were 0 d of age. No treatment effects were found for 0 d weight (data not shown). As the AME increased, there was a linear increase in BW and BW gain for the high lysine diet (Table 5.7, 5.8 and Figure 5.1). For the intermediate lysine diet, BW and gain were unaffected by increasing energy content in the diet, except for BW at 25 d of age and BW gain from 11 to 25 d of age; a linear increase of BW and gain were seen during those periods. BW and gain decreased in a linear fashion with increasing dietary energy levels for the low lysine diet after 25 d and 11 d of age for BW and gain, respectively.

Table 5.7. The interaction between dietary AA and energy for broiler BW and BW gain.

	Body weight (kg)				Body weight gain (kg)			
Nutrient content	0 d	10 d	25 d	35 d	0-10 d	11-25 d	25-35 d	0-35 d
High lysine content								
2700 kcal/kg	0.0439	0.275	1.286	2.257	0.231	1.011	0.971	2.213
2833 kcal/kg	0.0442	0.280	1.303	2.332	0.236	1.022	1.029	2.287
2966 kcal/kg	0.0442	0.287	1.331	2.370	0.242	1.044	1.039	2.325
3100 kcal/kg	0.0440	0.288	1.343	2.371	0.245	1.055	1.028	2.327
Pooled SEM	0.000074	0.0013	0.0051	0.012	0.0013	0.0042	0.0084	0.012
Intermediate lysine content								
2700 kcal/kg	0.0441	0.271	1.268	2.267	0.227	0.997	0.999	2.223
2833 kcal/kg	0.0438	0.278	1.280	2.254	0.234	1.003	0.974	2.211
2966 kcal/kg	0.0441	0.279	1.299	2.279	0.235	1.020	0.980	2.235
3100 kcal/kg	0.0439	0.277	1.294	2.269	0.233	1.017	0.978	2.225
Pooled SEM	0.000076	0.0012	0.0047	0.0086	0.0013	0.0042	0.0064	0.0086
Low lysine content								
2700 kcal/kg	0.0443	0.255	1.145	2.036	0.211	0.890	0.891	1.991
2833 kcal/kg	0.0443	0.257	1.159	2.051	0.213	0.902	0.892	2.006
2966 kcal/kg	0.0442	0.248	1.080	1.884	0.204	0.832	0.804	1.840
3100 kcal/kg	0.0443	0.258	1.113	1.908	0.213	0.855	0.795	1.864
Pooled SEM	0.000096	0.0012	0.0066	0.015	0.0012	0.0059	0.0098	0.015

Table 5.8. The relationship between dietary AA and energy for broiler BW and BW gain.

	Body weight (kg)				Body weight gain (kg)			
Nutrient content	0 d	10 d	25 d	35 d	0-10 d	11-25 d	25-35 d	0-35 d
High lysine content								
Coefficient								
Intercept	-0.020	0.182	0.882	-7.195	0.139	0.700	-7.561	-7.176
E	0.000044	0.000035	0.00015	0.0063	0.000034	0.00012	0.0058	0.0063
E^2	-0.0000000075	---	---	-0.0000010	---	---	-0.00000098	-0.0000020
R^2	0.100	0.450	0.548	0.455	0.449	0.466	0.294	0.453
P-value								
Linear	NS[1]	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.012	<0.0001
Quadratic	0.072	NS	NS	0.045	NS	NS	0.022	0.047
Intermediate lysine content								
Coefficient								
Intercept	---	-0.776	1.079	---	-0.841	0.845	---	---
E	---	0.00071	0.000071	---	0.00073	0.000057	---	---
E^2	---	-0.00000012	---	---	-0.00000012	---	---	---
R^2	---	0.174	0.149	---	0.177	0.116	---	---
P-value								
Linear	NS	0.077	0.020	NS	0.076	0.042	NS	NS
Quadratic	NS	0.075	NS	NS	0.069	NS	NS	NS
Low lysine content								
Coefficient								
Intercept	---	---	1.504	3.165	---	1.247	1.662	3.121
E	---	---	-0.00013	-0.00041	---	-0.00013	-0.00028	-0.00041
E^2	---	---	---	---	---	---	---	---
R^2	---	---	0.251	0.473	---	0.306	0.527	0.474
P-value								
Linear	NS	NS	0.0019	<0.0001	NS	0.0005	<0.0001	<0.0001
Quadratic	NS	NS	NS	NS	NS	NS	NS	NS

[1]NS = P> 0.10.

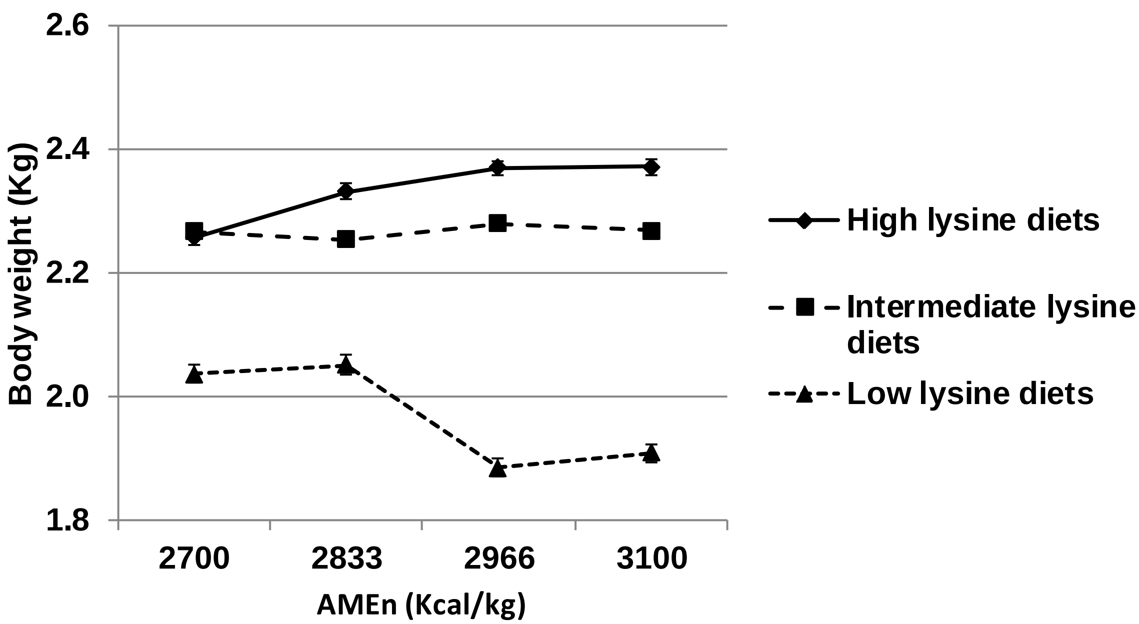

Figure 5.1. The relationship between dietary energy and AA on the response of broiler BW.

5.4.3 Feed intake

There were significant nutrient interactions in FI for all ages. Dietary energy did not affect broiler FI in the high lysine diet (Table 5.9, 5.10 and Figure 5.2). FI for broilers fed the intermediate lysine diets increased linearly from 0 to 10 d of age and decreased linearly from 25 to 35 d of age with increasing AME levels. However, the differences were small and as a result overall (0 to 35 d) FI was unaffected by diet AME content. On the other hand, broilers fed the low lysine diets reduced feed consumption with increasing diet energy levels after 11 d of age.

Table 5.9. The interaction between dietary AA and energy contents for broiler feed consumption and feed gain ratio (with mortality correction).

	Feed consumption (kg/bird)				Feed to gain ratio			
Nutrient content	0-10 d	11-25 d	25-35 d	0-35 d	0-10 d	11-25 d	25-35 d	0-35 d
High lysine content								
2700 kcal/kg	0.283	1.577	1.860	3.759	1.219	1.542	1.904	1.664
2833 kcal/kg	0.280	1.598	1.871	3.772	1.181	1.538	1.820	1.624
2966 kcal/kg	0.283	1.599	1.903	3.823	1.167	1.514	1.836	1.617
3100 kcal/kg	0.287	1.591	1.855	3.763	1.168	1.492	1.804	1.592
Pooled SEM	0.0013	0.0056	0.0096	0.015	0.0048	0.0055	0.0089	0.0052
Intermediate lysine content								
2700 kcal/kg	0.277	1.580	1.876	3.753	1.217	1.571	1.880	1.671
2833 kcal/kg	0.283	1.577	1.853	3.731	1.204	1.562	1.901	1.670
2966 kcal/kg	0.288	1.600	1.851	3.776	1.219	1.551	1.887	1.659
3100 kcal/kg	0.288	1.589	1.823	3.714	1.230	1.553	1.867	1.655
Pooled SEM	0.0014	0.0066	0.0089	0.016	0.0042	0.0032	0.0061	0.0027
Low lysine content								
2700 kcal/kg	0.274	1.507	1.767	3.581	1.298	1.677	1.993	1.773
2833 kcal/kg	0.277	1.501	1.788	3.600	1.300	1.649	2.011	1.768
2966 kcal/kg	0.272	1.391	1.608	3.294	1.323	1.664	1.999	1.770
3100 kcal/kg	0.279	1.441	1.579	3.323	1.305	1.673	1.982	1.760
Pooled SEM	0.0010	0.0096	0.018	0.029	0.0043	0.0045	0.0060	0.0025

Table 5.10. The relationship between dietary AA and energy contents for broiler feed consumption and feed gain ratio (with mortality correction).

	Feed consumption (kg/bird)				Feed to gain ratio			
Nutrient content	0-10 d	11-25 d	25-35 d	0-35 d	0-10 d	11-25 d	25-35 d	0-35 d
High lysine content								
Coefficient								
Intercept	---	---	---	---	6.117	1.904	2.457	2.108
E	---	---	---	---	-0.0033	-0.00013	-0.00021	-0.00017
E^2	---	---	---	---	0.00000054	---	---	---
R^2	---	---	---	---	0.566	0.373	0.361	0.650
P-value								
Linear	NS[1]	NS	NS	NS	<0.0001	<0.0001	<0.0001	<0.0001
Quadratic	NS	NS	NS	NS	0.0051	NS	0.069	NS
Intermediate lysine content								
Coefficient								
Intercept	0.201	---	2.200	---	---	1.694	-2.869	1.791
E	0.000029	---	-0.00012	---	---	-0.000046	0.0033	-0.000044
E^2	---	---	---	---	---	---	-0.00000058	---
R^2	0.270	---	0.116	---	---	0.132	0.108	0.171
P-value								
Linear	0.0012	NS	0.042	NS	NS	0.030	NS	0.012
Quadratic	NS	NS	NS	NS	NS	NS	0.091	NS
Low lysine content								
Coefficient								
Intercept	---	2.134	3.301	5.798	---	6.066	---	1.853
E	---	-0.00023	-0.00056	-0.00081	---	-0.0031	---	-0.000029
E^2	---	---	---	---	---	0.00000053	---	---
R^2	---	0.372	0.581	0.509	---	0.122	---	0.087
P-value								
Linear	NS	<0.0001	<0.0001	<0.0001	NS	NS	NS	0.081
Quadratic	NS	0.070	NS	NS	NS	0.041	NS	NS

[1]NS = P> 0.10.

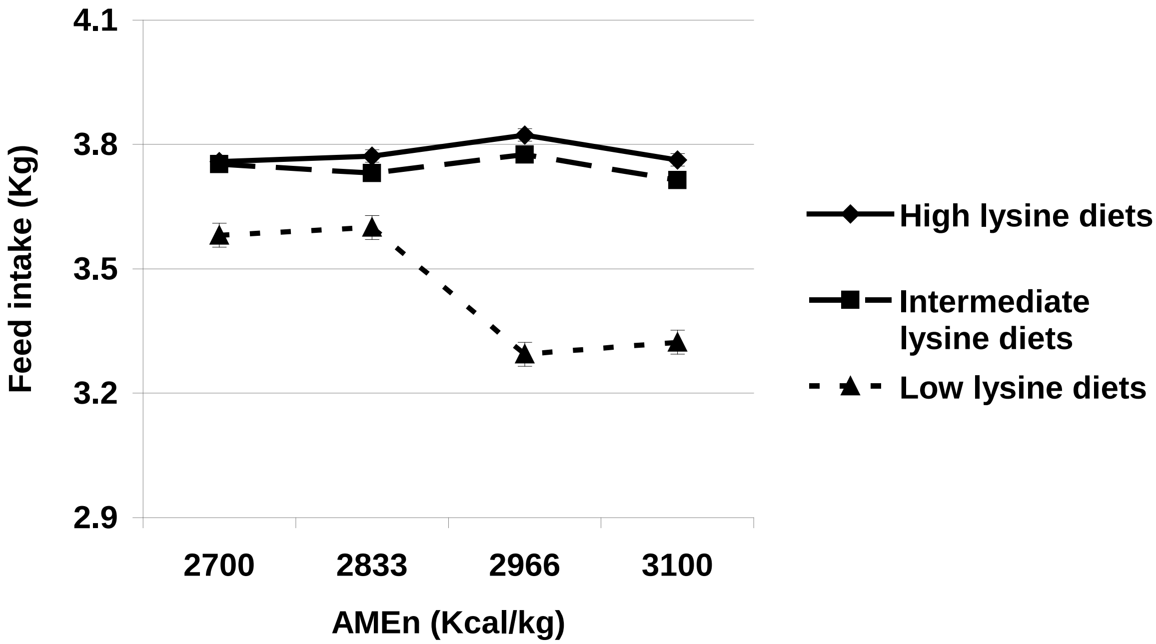

Figure 5.2. The relationship between dietary energy and AA on the response of broiler FI.

5.4.4 Feed to gain ratio

Significant interactions between main effects were seen for feed to gain ratio for the whole production period. For birds fed the high lysine diets, there was a significant linear decrease in feed to gain ratio with increasing AME content (Table 5.9, 5.10 and Figure 5.3). Feed to gain ratios for the 11 to 25 and 0 to 35 d periods were affected by AME levels when birds were fed the intermediate lysine level diets. In both these cases, a linear reduction in feed to gain ratio was found with increasing energy content in the diet. Dietary energy did not affect feed to gain ratio for birds fed the low AA diets, except for the 11 to 25 d period, where a quadratic response was found. There was an increase in feed to gain ratio with increasing energy content (2833 to 3100 kcal/kg) of the diet.

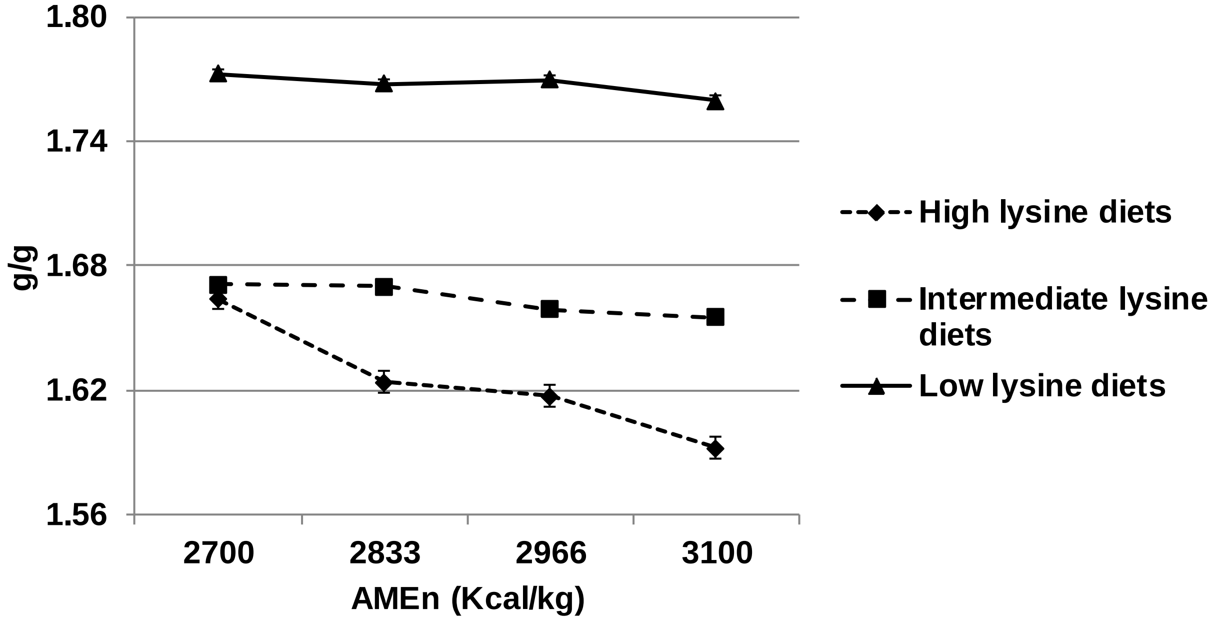

Figure 5.3. The relationship between dietary energy and AA on the response of feed to gain ratio (with mortality correction) in broiler chickens.

5.4.5 Mortality

There were no interactions between diet energy and AA content on the incidence of mortality (Table 5.11 and 5.12). There was no treatment effect on the total trial (0 to 35 d) incidence of mortality. The only significant treatment effect ($P \leq 0.05$) was a linear increase in mortality with increasing lysine contents in the diet from 11 to 25 d of age.

Table 5.11. Effects of dietary AA and energy contents on broiler mortality.

	Mortality (%)			
Nutrient content	0-10 d	11-25 d	25-35 d	0-35 d
Energy level				
2700 kcal/kg	1.255	3.106	1.075	5.793
2833 kcal/kg	2.210	3.823	0.597	6.631
2966 kcal/kg	2.270	3.465	1.075	6.810
3100 kcal/kg	2.210	2.866	0.717	5.793
Lysine level				
High lysine content	2.061	3.896	0.986	6.943
Intermediate lysine content	1.479	3.405	0.582	5.466
Low lysine content	2.419	2.643	1.031	6.093
Overall energy and amino acid				
Pooled SEM	0.20	0.24	0.12	0.34

Table 5.12. The impact of dietary AA levels and dietary energy contents on broiler mortality.

	Mortality (%)			
Nutrient content	0-10 d	11-25 d	25-35 d	0-35 d
Energy level				
Coefficient				
Intercept	---	---	---	---
E	---	---	---	---
E^2	---	---	---	---
R^2	---	---	---	---
P-value				
Linear	0.095	NS	NS	NS
Quadratic	NS[1]	NS	NS	NS
Lysine level				
Coefficient				
Intercept	---	-1.697	---	---
E	---	0.063	---	---
E^2	---	---	---	---
R^2	---	0.043	---	---
P-value				
Linear	NS	0.032	NS	NS
Quadratic	0.068	NS	0.088	NS
Overall energy and amino acid				
P-value				
Energy x amino acid	NS	NS	NS	NS

[1]NS = P> 0.10.

5.4.6 Meat yield

Data for meat yield were analyzed on both an absolute (g) (data not shown) and proportional basis (% of live weight). Because treatments affected BW, CY on an absolute basis was also affected, but these data are not presented. On a proportional basis, interactions between AME and AA levels were found for CY, BY and breast skin. These criteria will be presented in both main effect and interaction format. A three-way interaction was also found between AME, AA and bird gender. This interaction did not follow obvious and consistent trends and so is not presented. Abdominal fat values represent the amount of fat remaining after evisceration and previous research has shown this criteria to not be an accurate reflection of carcass fat, and therefore are only presented to provide a complete recovery of eviscerated carcass components.

5.4.6.1 Main effects

Level of dietary energy did not impact the proportion of abdominal fat, right thigh or right drum as a percent of live weight, but increasing dietary energy resulted in larger proportional wing and back values. There was a linear decrease in the proportion of abdominal fat, right thigh, wings and back with increasing dietary lysine levels (Table 5.13 and 5.14).

Gender differences were seen in the meat yield. Females had higher proportional CY, BY, breast skin, right thigh and wing weights, and lower abdominal fat and right drum weights than males (Table 5.13 and 5.14). The proportion of back was not affected by gender.

Table 5.13. The effects of dietary AA and energy levels, and bird gender on broiler meat yield (% of live weight at processing).

Nutrient content and gender	Carcass weight	Pectoralis major	Pectoralis minor	Total breast	Breast skin	Abdominal fat	Right thigh	Right drum	Wings	Back
Diet energy level										
2700 kcal/kg	67.83	15.46	3.28	18.74	2.14	0.86	5.96	4.70	7.42	16.68
2833 kcal/kg	67.87	15.37	3.25	18.62	2.13	0.85	6.06	4.74	7.49	16.71
2966 kcal/kg	67.86	14.99	3.21	18.19	2.13	0.85	6.06	4.77	7.48	16.93
3100 kcal/kg	67.83	15.06	3.11	18.17	2.14	0.92	6.05	4.74	7.52	17.09
Lysine level										
High lysine content	68.88	16.58	3.39	19.98	2.06	0.83	5.67	4.73	7.41	16.59
Intermediate lysine content	68.38	15.81	3.30	19.11	2.15	0.84	6.00	4.69	7.49	16.78
Low lysine content	66.28	13.27	2.94	16.21	2.20	0.95	6.13	4.78	7.54	17.21
Gender										
Female	68.05	15.42	3.33	18.75	2.20	0.81	6.09	4.65	7.53	16.79
Male	67.64	15.02	3.09	18.11	2.07	0.93	5.97	4.82	7.42	16.92
Overall										
Pooled SEM	0.095	0.080	0.020	0.089	0.020	0.016	0.021	0.012	0.015	0.056

Table 5.14. The impact of dietary AA and energy levels, and bird gender on broiler meat yield (% of live weight at processing).

Nutrient content and gender	Carcass weight	Pectoralis major	Pectoralis minor	Total breast	Breast skin	Abdominal fat	Right thigh	Right drum	Wings	Back
Diet energy level										
Coefficient										
Intercept	---	18.589	4.341	22.929	---	---	5.364	---	6.832	14.005
E	---	-0.0012	-0.00039	-0.0015	---	---	0.00023	---	0.00022	0.00098
E^2	---	---	---	---	---	---	---	---	---	---
R^2	---	0.0079	0.014	0.011	---	---	0.0046	---	0.0078	0.011
P-value										
Linear	NS[1]	0.033	0.0039	0.011	NS	NS	0.10	NS	0.034	0.011
Quadratic	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Lysine level										
Coefficient										
Intercept	7.332	-52.410	-6.816	-59.226	2.735	1.343	6.561	8.821	7.945	19.336
E	1.402	1.543	0.230	1.773	-0.0075	-0.0059	-0.0067	-0.101	-0.0059	-0.031
E^2	-0.0080	-0.0086	-0.0013	-0.0099	---	---	---	0.00062	---	---
R^2	0.230	0.513	0.164	0.529	0.016	0.016	0.012	0.015	0.016	0.0345
P-value										
Linear	<0.0001	<0.0001	<0.0001	<0.0001	0.0024	0.0025	0.0096	NS	0.0021	<0.0001
Quadratic	<0.0001	<0.0001	0.0012	<0.0001	NS	NS	NS	0.014	NS	NS
Gender										
P-value										
Gender	0.0046	<0.0001	<0.0001	<0.0001	0.0009	<0.0001	0.0054	<0.0001	<0.0001	NS
Overall										
P-value										
Energy x amino acid	0.0009	<0.0001	0.0024	<0.0001	NS	NS	NS	NS	NS	NS
Energy x amino acid x gender	NS	NS	NS	NS	NS	NS	NS	NS	0.0046	NS

[1]NS = P> 0.10.

5.4.6.2 Energy and amino acid interaction

There were interactions between dietary energy and AA for carcass weight, pectoralis major and minor, and total breast on percent live weight basis (Table 5.15 and 5.16). Overall, CY (% live weight basis) increased with increasing energy content in high lysine diets (Figure 5.4). In the intermediate lysine diets, live weight and CY were unaffected by AME level. There was a linear decrease in CY (% live weight basis) with increasing diet energy content in the low lysine diet. AME levels had no effect on pectoralis major and minor, and total breast (% live weight basis) when diets contained high and intermediate lysine content, but there was a reduction in these criteria with increasing AME content in the low lysine diet (Figure 5.5).

Table 5.15. The interaction between dietary AA and energy levels for meat yield (% age of live weight at processing) in broiler chickens.

Nutrient content	Carcass weight	Pectoralis major	Pectoralis minor	Total breast	Breast skin	Abdominal fat	Right thigh	Right drum	Wings	Back
High lysine content										
2700 kcal/kg	68.55	16.30	3.36	19.66	2.14	0.82	5.90	4.72	7.40	16.38
2833 kcal/kg	68.30	16.54	3.41	19.95	1.92	0.75	5.97	4.71	7.35	16.40
2966 kcal/kg	69.14	16.79	3.46	20.25	2.05	0.81	6.02	4.76	7.40	16.61
3100 kcal/kg	69.53	16.72	3.35	20.07	2.10	0.91	5.99	4.73	7.47	16.99
Pooled SEM	0.15	0.098	0.030	0.10	0.030	0.024	0.035	0.019	0.025	0.093
Intermediate lysine content										
2700 kcal/kg	68.22	15.84	3.37	19.22	2.09	0.81	5.91	4.64	7.42	16.79
2833 kcal/kg	68.54	15.90	3.27	19.17	2.20	0.88	6.05	4.73	7.58	16.64
2966 kcal/kg	68.52	15.68	3.37	19.06	2.14	0.81	6.04	4.71	7.44	16.81
3100 kcal/kg	68.23	15.84	3.18	18.98	2.16	0.85	5.99	4.69	7.52	16.81
Pooled SEM	0.13	0.086	0.033	0.096	0.033	0.025	0.036	0.021	0.027	0.10
Low lysine content										
2700 kcal/kg	66.76	14.30	3.11	17.41	2.19	0.94	6.06	4.72	7.44	16.90
2833 kcal/kg	66.70	13.59	3.07	16.65	2.28	0.92	6.16	4.78	7.55	17.12
2966 kcal/kg	65.92	12.46	2.79	15.25	2.21	0.92	6.12	4.83	7.59	17.37
3100 kcal/kg	65.72	12.67	2.80	15.47	2.15	1.00	6.17	4.80	7.57	17.47
Pooled SEM	0.15	0.10	0.031	0.12	0.039	0.033	0.038	0.020	0.026	0.092

Table 5.16. The relationship between dietary AA and energy levels for meat yield (% age of live weight at processing) in broiler chickens.

Nutrient content	Carcass weight	Pectoralis major	Pectoralis minor	Total breast	Breast skin	Abdominal fat	Right thigh	Right drum	Wings	Back
High lysine content										
Coefficient										
Intercept	67.946	16.154	---	19.550	2.404	0.956	---	---	---	16.082
E	0.370	0.167	---	0.166	-0.347	-0.181	---	---	---	0.203
E^2	---	---	---	---	0.0690	0.0429	---	---	---	---
R^2	0.037	0.018	---	0.016	0.026	0.027	---	---	---	0.029
P-value										
Linear	0.0066	0.058	NS	0.075	NS	NS	NS	NS	NS	0.017
Quadratic	NS[1]	NS	NS	NS	0.024	0.077	NS	NS	NS	NS
Intermediate lysine content										
Coefficient										
Intercept	---	---	---	---	---	---	3.217	---	---	---
E	---	---	---	---	---	---	0.849	---	---	---
E^2	---	---	---	---	---	---	-0.0628	---	---	---
R^2	---	---	---	---	---	---	0.021	---	---	---
P-value										
Linear	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Quadratic	NS	NS	NS	NS	NS	NS	0.084	NS	NS	NS
Low lysine content										
Coefficient										
Intercept	70.640	42.743	4.162	49.665	---	---	---	---	7.080	15.306
E	-0.408	-5.058	-0.117	-5.708	---	---	---	---	0.043	0.182
E^2	---	0.212	---	0.238	---	---	---	---	---	---
R^2	0.057	0.255	0.093	0.278	---	---	---	---	0.017	0.025
P-value										
Linear	0.0010	<0.0001	<0.0001	<0.0001	NS	NS	NS	NS	0.076	0.031
Quadratic	NS	0.020	NS	0.020	NS	NS	NS	NS	NS	NS

[1]NS = P> 0.10.

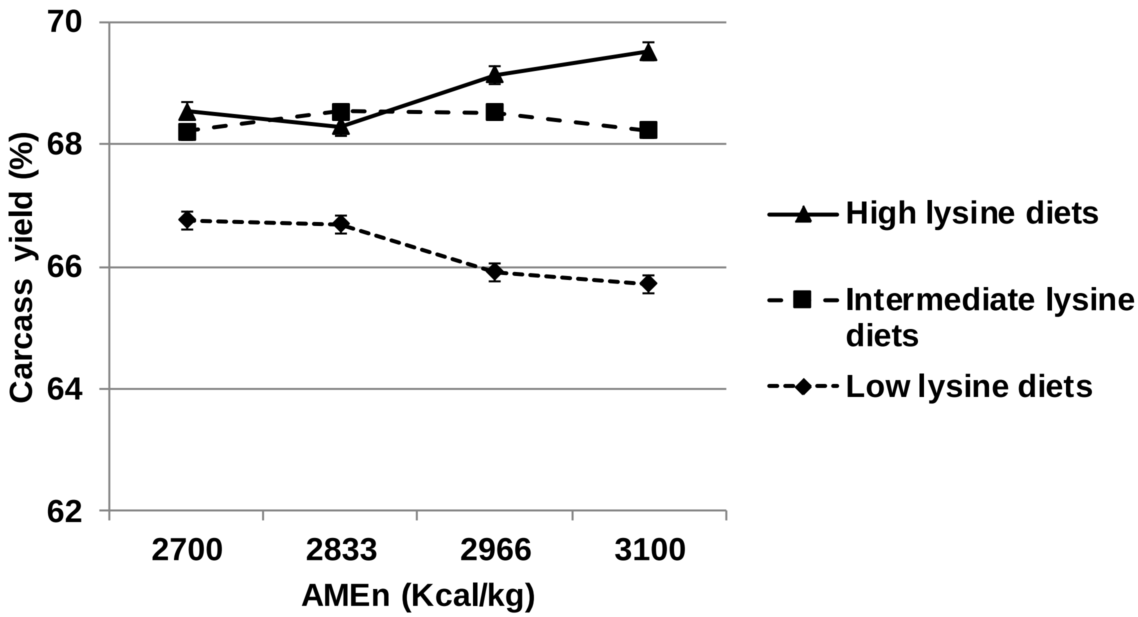

Figure 5.4. The relationship between dietary energy and AA on the response of CY (% live weight) in broiler chickens.

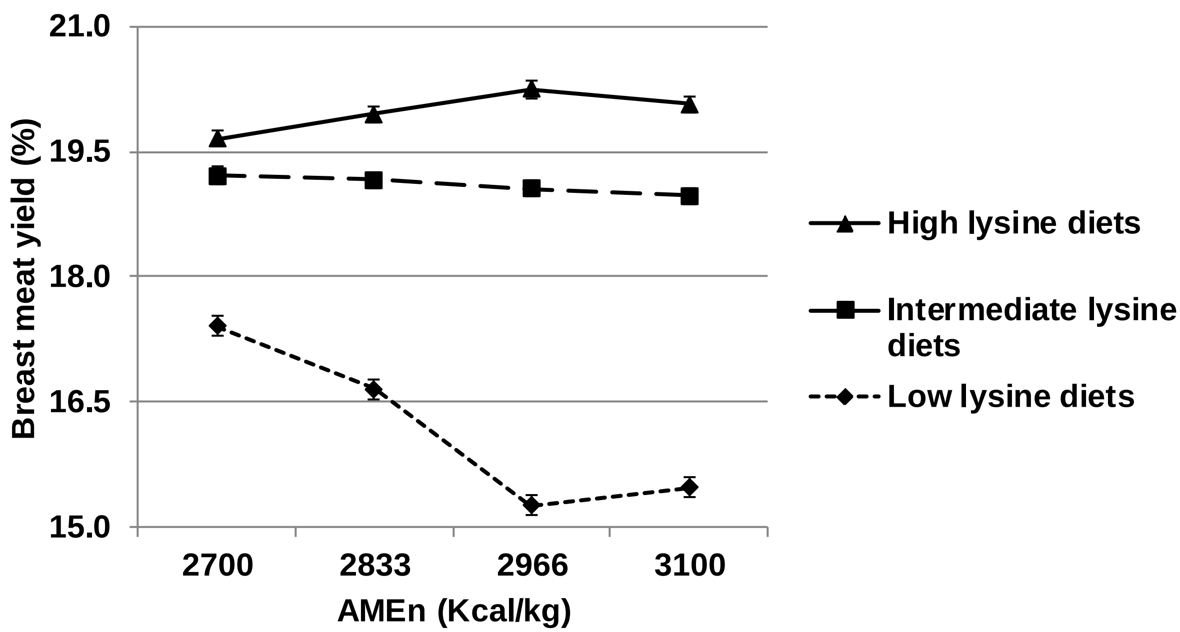

Figure 5.5. The relationship between dietary energy and AA on the response of BY (% live weight) in broiler chickens.

5.4.7 Crumble size and pellet quality index

Linear responses were seen in crumble size over 3.36 mm and between 2.00 to 3.35 mm, and quadratic responses were seen under 0.99 mm and PDI with various AME levels in the high lysine diet (Table 5.17 and 5.18). The intermediate lysine diet showed a linear increase with increasing AME levels in the PDI. At low lysine level, there was a quadratic response in the PDI with different AME content in the diet. Overall, PDI increased with increasing dietary AME levels for all lysine treatments.

Table 5.17. The effect of different dietary energy and AA content and pellet quality in the diet (%).

Nutrient content	Crumble size (starter diet)				
	>3.36 mm	3.35 to 2.00 mm	1.99 to 1.00 mm	<0.99 mm	Pellet durability index (finisher diet)
High lysine content					
2700 kcal/kg	11.96	32.06	31.01	24.98	58.66
2833 kcal/kg	12.89	34.44	29.95	22.72	70.36
2966 kcal/kg	11.41	33.76	30.18	24.65	71.28
3100 kcal/kg	10.72	33.63	29.50	26.15	73.60
Intermediate lysine content					
2700 kcal/kg	12.03	32.45	30.94	24.58	62.24
2833 kcal/kg	15.18	35.88	27.90	21.04	64.76
2966 kcal/kg	15.13	30.27	28.05	26.54	72.24
3100 kcal/kg	13.28	37.40	28.54	20.78	74.52
Low lysine content					
2700 kcal/kg	13.75	36.55	28.41	21.29	65.10
2833 kcal/kg	13.62	36.47	29.52	20.40	66.36
2966 kcal/kg	13.08	34.51	29.51	22.91	71.96
3100 kcal/kg	10.82	31.01	29.46	28.71	76.18
Pooled SEM	0.374	0.552	0.274	0.633	1.081

Table 5.18. The impact of different dietary energy and AA content and pellet quality in the diet (%).

Nutrient content	Crumble size (starter diet)				
	>3.36 mm	3.35 to 2.00 mm	1.99 to 1.00 mm	<0.99 mm	Pellet durability index (finisher diet)
High lysine content					
Coefficient					
Intercept	15.152	39.279	---	25.516	63.890
E	-0.934	-1.858	---	-5.904	0.184
E^2	---	---	---	1.676	0.740
R^2	0.557	0.627	---	0.834	0.979
P-value					
Linear	0.028	0.019	NS	0.0078	<0.0001
Quadratic	NS[1]	NS	NS	0.049	0.049
Intermediate lysine content					
Coefficient					
Intercept	---	---	---	---	39.632
E	---	---	---	---	4.43
E^2	---	---	---	---	---
R^2	---	---	---	---	0.950
P-value					
Linear	NS	NS	NS	NS	0.0002
Quadratic	NS	NS	NS	NS	NS
Low lysine content					
Coefficient					
Intercept	---	---	---	---	-235.157
E	---	---	---	---	53.819
E^2	---	---	---	---	-2.345
R^2	---	---	---	---	0.945
P-value					
Linear	0.062	NS	NS	NS	0.0004
Quadratic	NS	NS	NS	0.063	0.012

[1]NS = P> 0.10.

5.5 Discussion

It is historically accepted that broiler chickens modify their FI based on the energy level of the diet in an attempt to maintain constant energy intake. However, in recent studies, dietary AME level did not affect FI to a degree that would be expected if broiler chickens were able to regulate their FI based on the AME level of the diet (Chapter 4.0; Plumstead et al., 2007). A possible reason for this lack of response could be that intensively selected broiler chickens have lost the ability to regulate FI based on dietary AME. The intense genetic selection for growth in broiler chickens over the years has modified the physiology of the chicken and may have also influenced satiety mechanisms (Burkhart et al., 1983; Bokkers and Koene, 2003). Another possible reason for the lack of response could be an effect of the DAA content in the diet as DAA content can affect FI in broiler chickens (Ferket and Gernat, 2006). Hence, this research was completed to further examine the broiler FI response to dietary AME when fed a wide range of diet DAA content.

The hypothesis for this research is that broiler chickens will change their FI to dietary AME based on DAA levels in the diet and the results obtained in this study support this hypothesis. When diets had moderate to high levels of lysine, either no or minor changes in FI were found in response to energy, which is in agreement with previous research in this thesis. However, when lysine content was low, FI decreased with increasing dietary AME. Although this appears to support the historical concept of FI regulation in chickens, the difference in this experiment is that growth rate decreased proportionally with increasing dietary AME resulting in an equal overall (0 to 35 d) feed conversion ratio. The reason for this decrease in FI with increasing AME in the low lysine can’t be proven in this research, but it may relate to the use of

FI to maintain a balance between levels of energy and AA intake. It could also be an attempt by broilers to not exceed certain levels of body adipose tissue by modifying FI. Breast skin, which contains subcutaneous fat, was used to assess total body or carcass fat content in this research because abdominal fat is removed inconsistently at commercial processing. For the low lysine diet in our study, proportional breast skin was not affected by the dietary AME content, which supports the concept that broiler chickens can regulate their FI to maintain a constant body fat level.

The change in FI with the dietary AME level may have been only observed in the low lysine diet due to the high body fat content compared to other levels of dietary lysine. The excess energy that could not be used for body maintenance and growth in the low lysine or DAA diet would be stored as fat. The averages for percent breast skin for the high, intermediate and low lysine diets across dietary AME levels were 2.05, 2.14 and 2.21%, respectively. CY as a percent live weight basis in the low lysine diet was lower than the other lysine treatments. Although this is at least partially accounted for the lower BY in these birds, it could also indicate that the low lysine or DAA diet fed birds had more body fat than the high or intermediate lysine or DAA diet fed birds. Since abdominal fat is a major site of adipose tissue deposition in the chicken, this would be removed during the evisceration and as a result impact CY.

A lipostatic mechanism for FI control has long been suggested with early work in both rats and chickens. Rats were found to regulate and adjust their body fat through changes in FI (Kennedy, 1953). When there is excess fat in the body, this situation is detected by the brain, which in turn mediates a reduction in FI. A similar phenomenon was also seen in White Leghorn chickens (Lepkovsky, 1973). Cockerels were force fed above ad libitum consumption, which resulted in increased fat deposition. After force feeding was stopped, the birds ceased eating. FI only returned to normal when adipose tissue levels returned to their original level. A molecule similar to leptin, a hormone that is synthesized by adipose tissue and the liver in chickens, may be responsible for regulating body fat by sending signals to the brain to reduce FI (Brunner et al., 1997). This leptin like molecule in chickens has an effect on neuronal cells such as NPY, AGRP, POMC and cocaine- and amephetamine-regulated transcript (CART) that exist in the arcuate nucleus of the medio-basal hypothalamus of the bird (Boswell, 2005). NPY/AGRP neurons are known to increase or stimulate appetite while POMC/CART reduces appetite. The interaction between the leptin like molecule and neuronal cells may be responsible for reducing the FI in birds when fat is accumulated in the body over a specific set point. Though leptin is known to reduce FI in lean animals, it was not clear if it would alter the FI in modern broiler chickens that are genetically selected for rapid growth and heavy weight. However, a study used intracerebroventricular injection of human recombinant leptin in broiler chickens and White Leghorns at four and six weeks of age, respectively, and found that both types of chickens reduced their FI (Denbow et al., 2000). This may imply that broiler chickens still have the ability to respond and reduce their FI in response to leptin. However, broiler chickens may require more leptin than laying hens to respond and the response to leptin may also be age dependent (Cassy et al., 2004). Broiler chickens and laying hens may not respond to leptin at a younger age but may respond to leptin at an older age. A study found that intraperitoneal injection of leptin was effective at 56 d old laying hen but not for the nine d old laying hen (Cassy et al., 2004). This could be due to the presence of alternative pathway for leptin and/or different FI regulation in younger birds.

Dietary AME and DAA are important because they constitute the largest component of the diet and are also associated with growth and meat yield in broiler chickens. Therefore, understanding the relationship and/or the interaction between these two components is essential to predict broiler performance and to create cost efficient diets. Though some research has been done in this area, the results are variable and not clear. Therefore, the present research was also performed to clarify the relationship between dietary AME and DAA on the response of broiler chickens.

A second objective in this research was to examine the relationship between dietary energy and DAA levels. Interactions were found between the dietary AME and DAA for broiler performance and carcass quality characteristics. For the most part (exceptions are the results from low lysine diets discussed above) the interactions are not based on a change in FI due to feed energy level but appear to be related to the need to balance levels of energy and balanced protein to achieve efficient growth. If one or the other nutrients is lacking, broiler performance and meat yield will be adversely affected. At the highest dietary lysine level, BW, FE, CY and BY increased as dietary AME increased even though there was no difference in FI. This suggests that the broiler's growth and meat yield was dependent on dietary energy at this lysine level. Energy is required for basal body functioning as well as growth and protein synthesis. If there is insufficient energy available in relationship to the lysine or DAA content of the diet, broiler performance may decrease because protein is catabolized to provide additional energy. At the intermediate lysine level, it appears that all diets had sufficient energy to match the limited growth potential of this level of AA. Therefore, overall growth and carcass characteristics were unaffected by dietary AME. Finally, at low level of lysine, growth and proportional carcass weights decreased as well as the FI with increasing energy content. This could be to maintain a balance between the two nutrients or to regulate body fat in the broiler chicken. This is explained in greater detail in the previous section.

The results obtained in this study are different from other studies (Dozier III et al., 2006; Plumstead et al., 2007). Although it is not possible to identify the exact reason for differences in research results, a number of factors may be involved. First of all, it may be due to the pellet quality or PDI. Variable PDI may decrease FI in broiler chickens (Lemme et al., 2006). Hence, PDI was measured in this study and although significant differences were found, the PDI values were mostly consistent across dietary energy levels. Higher PDI values were seen with increasing energy level of the diet, which coincided with increased inclusion of wheat, with its good pellet binding capacity. Most of the diets had relatively high PDI values and would probably have minimal or no effect on FI. Another reason may be the DAA content of research diets. Diets that are not formulated based on DAA may alter the broiler FI response due to the nature of the ingredients. Hence, diets were created based on the measured DAA content of ingredients used in this study. Much previous research on dietary energy effects on broiler production utilized total AA content in feed formulation (Skinner et al., 1992; Hildalgo et al., 2004; Brickett et al., 2007). Dietary fat can have an important effect on dietary energy and feed palatability and therefore the strategy used in this research was to maintain the same ratio between dietary fat and energy levels. Finally, the ranges in dietary AME and DAA used in this experiment were purposely chosen to be broad so as to increase the probability of seeing significant responses. This approach also extends the value of the research to a wider set of dietary specifications.

In summary, the FI response of broiler chickens to dietary AME varies with the DAA content in the diet. Dietary AME did not affect FI for the intermediate and high lysine diets, further demonstrating the inability of broilers to maintain a constant dietary energy intake in response to changes in dietary energy. When markedly suboptimal levels of lysine level were provided to broiler chickens, FI decreased with increasing dietary AME but so did growth rate. This suggests that broilers were either attempting to maintain a balance between energy and AA in the diet and/or to maintain a set limit of body fat content. The FI response at higher levels of lysine, that are mostly used in feeding broilers, supports the concept that diet formulation should be based on an appropriate balance between energy and protein to optimize production and meat yield. To optimize performance, dietary energy must match or exceed the energy required to ensure utilization of the level of balanced protein in the diet. Because energy is an expensive component of the diet, formulating to a close balance between energy and protein is economically relevant.

6.0 General Discussion

Dietary energy is essential for growth and performance of the broiler chicken and it is known to have a role in FI in birds. Broiler chickens have previously been shown to adjust their FI according to the energy level of the diet (Leeson and Summers, 2005). However, due to the intense selection for rapid growth and larger BW in broiler chickens, this ability has been questioned. There may be an age effect on the broiler's ability to regulate FI with the limited physical gut capacity in young birds limiting this capacity, but older broilers maintaining their ability to adjust FI based on dietary energy (Jones and Wiseman, 1985; Brickett et al., 2007; Kamran et al., 2008). Other research suggests that highly selected chickens have lost their ability to regulate FI based on dietary energy content (Plumstead et al., 2007). Because of the contradictory research, the role of dietary energy in regulating broiler FI is not clear. Hence, an experiment was designed to investigate the relationship between dietary energy and FI in broiler chickens at various ages using diets with a wide range of energy and having a consistent energy to fat ratio.

Broiler chickens did not change their FI based on the different energy content in the diet and this effect was seen in all ages. FI did not match what would be expected based on the dietary energy level of the diet and remained essentially the same regardless of dietary energy level within a range of 2700 to 3100 kcal/kg AME. In other words, the broiler chickens did not eat or adjust their FI to meet their energy requirement but rather appeared to eat to maximum physical capacity. Hence, this study does not support the historical concept of broiler chickens being able to regulate their FI based on dietary energy content. Unlike some research, there also was no age effect associated with dietary energy and FI. The FI response to dietary energy remained the same regardless if examined in the S, G or F phases of production.

The different results seen in various studies could be associated with aspects of experimental design and implementation. One of these factors could be the dietary fat content of experimental rations. A study found that different level of sunflower oil (3 to 7%) changed the FI in birds (Sanz et al., 2000). Though the energy level was the same in research diets, they varied in dietary fat and carbohydrates and hence may have also been different in NE in the diet. The addition of fat in the diet would increase the NE since it has lower heat increment than carbohydrates. In other words, fat is an efficient source of energy and may change the FI of the birds even at the same dietary ME because of the change in NE. Hence, to prevent the effect of dietary fat content and change of NE that may have on FI, a consistent relationship between dietary energy and fat should be maintained or NE should be determined and used. Another factor could be the feed form and quality. Birds may consume more feed in pellet than mash form and this can improve broiler growth and performance (Svihus et al., 2004). Poor pellet quality of the diet can also decrease FI in broiler chickens (Lemme et al., 2006) and thereby limit the FI response to dietary energy. Since practical diets varying in dietary energy contain at least some different ingredients with variable pelleting characteristics, it is possible that pellet quality can vary and thereby affect research results. Another potential dietary factor affecting research results is the AA composition and digestibility of the experimental diets. If requirements for indispensable and/or dispensable AA in the diet are not met, it may alter the FI of the broiler chickens (Sklan and Plavnik, 2002). Again this is a possibility because most research has utilized practical diets and therefore ingredients vary according to dietary energy. Formulating diets based on a DAA content minimizes this potential and the corresponding impact on broiler performance.

The different results seen in research could also be related to strain of broiler chickens. Broiler chickens have been genetically selected for growth for many years and the changes in growth and performance over the years is well known (Havenstein et al., 2003). Hence, it is possible that modern broiler chickens respond differently to dietary energy levels. The modern broiler chicken may eat to physical capacity instead of nutrient requirement. Even within modern broilers, how they respond to dietary energy may be different due to a different genotype base and selection emphasis. In the current study, Ross x Ross 308 was the only strain used and would be interesting to know if this lack of FI change to dietary energy level is strain specific or if similar effects are seen in other commercially relevant broilers such as the Cobb 500 and Ross x Ross 708.

Additional information collected in Chapter 3.0 of this thesis may have provided a clearer understanding of dietary energy effects. In particular, assessing meat yield analysis and whole body composition would have provided evidence of nutrient utilization and partitioning. BY and whole body composition could have been done to determine and compare the level of meat yield and fat deposit between the different energy levels. If the genetic potential for growth is reached and the energy content exceeds what is required for maintenance and protein synthesis, then there would be increased fat deposit with moderate BY. If energy were limiting the growth of the bird, there would be reduced fat deposit and BY. Meat yield would indicate how much the bird synthesized protein and if protein was limiting the growth of the bird. Fat analysis or fat deposition would be measured using the whole body composition since abdominal fat is not a good indicator. It will determine if energy was limiting the growth potential of the bird or energy content exceeded the requirement of the bird.

Energy and AA are nutrients that are contained in large portions of the broiler's diet. Hence, these nutrients have a major impact on feed cost and are also essential for maintenance and growth of broiler chickens. There have been a few studies that has observed the performance of broiler chickens with different energy and AA content in the diet (Dozier III et al., 2006; Plumstead et al., 2007). Although the relationship between dietary energy and AA has been studied previously, a change in how broilers respond to dietary energy from a FI perspective suggests a need to re-examine this area of research. Understanding the relationship between the energy and protein is important for predicting broiler performance and creating a cost efficient diet. Therefore, an experiment was conducted to examine the relationship between different dietary energy and DAA levels using broiler diets with a large range of dietary energy and AA content based on the determined digestibility data determined in the earlier experiment (Chapter 3.0).

There was a relationship between dietary energy and AA content on broiler performance. BW, CY and BY increased with increasing energy content in the high lysine diet. At the low energy level, it was hypothesized that there was insufficient energy available to match the protein synthesis capacity of dietary protein and that as a consequence AA were catabolized to provide additional energy to the bird. The consequence of such a situation would be reduced growth and meat yield. In other words, broiler performance was dependent on dietary energy at high lysine content in the diet and as dietary energy increases, most or more of the protein is used for protein synthesis and growth. Based on this hypothesis, it would be expected that dietary energy would have less impact on the performance of broilers fed a lower level of balanced protein. This in fact was the case as dietary energy did not affect the performance of broilers fed the intermediate lysine diet. It appears that all levels of dietary energy provided enough energy for bird maintenance and maximum broiler performance (protein synthesis) determined by the lysine content. At low lysine levels, there was a decrease in FI and growth with increasing dietary energy levels.

The reduction in FI with increasing energy content of the diet in the low lysine diet could support the theory that birds are adapting to the higher energy diet to maintain equal energy intake. However, different from the classical theories of FI regulation, growth rate decreased at the same time as did CY. In general, CY on a percent of live weight basis was also lower for birds fed the low lysine diets, which is likely due to a reduction in meat yield as well as an increase in abdominal fat that is removed during evisceration. If birds fed low lysine diets are already fatter, it is possible that they reduce FI with dietary increasing level to regulate additional fat deposition. The lipogenic theory of FI control suggests that there is a maximum fat storage limit and FI is reduced to prevent exceeding that limit. When the body fat is above that set point, the hypothalamus detects that condition and in turn sends a signal from neuronal cells in medio-basal hypothalamus such as NPY, AGRP, POMC and CART to reduce the FI to maintain constant body fat (Lepkovsky, 1973; Boswell, 2005). In the low lysine and high energy diet, the broiler chicken may have reached its maximum body fat content and as a consequence ate less to limit body fat deposition. Completing total body composition analysis would have provided useful information in this study and may have explained the broiler performance results seen in this experiment.

In cattle, increased energy intake increases the AA requirement because energy intake and rate of protein deposition have a linear relationship (Schroeder and Titgemeyer, 2008). When energy intake increases, protein deposition increases if enough protein is supplied in the diet. A similar effect was seen for CY and BY in broiler chickens (Figure 6.1 and 6.2). CY and BY increased in the high energy diet with increasing dietary AA. However, at low energy level, BY decreased with increasing AA content of the diet. This indicates that energy was limiting at the 2700 kcal/kg and increased energy intake would have increased the carcass and BY as it was seen in the higher energy levels. Hence, from our findings, it implies that certain amount of energy would be required for protein synthesis and may have an important application on growth modeling.

Energy cost of protein synthesis is not well known in chickens. A study has measured the energy requirement for protein synthesis in vivo and concluded that 5.35 kJ per gram of energy is required for protein synthesis (Aoyagi et al., 1988). However, further study is needed to accurately determine the energy requirement for protein synthesis. Though it is not well understood in chickens, the energy requirement for protein synthesis is well known in pigs and is a component of growth models (Green and Whittemore, 2003). Hence, measuring and determining the energy requirement for protein synthesis and then incorporating it to a growth model may be useful and should be considered in future studies to accurately predict broiler performance.

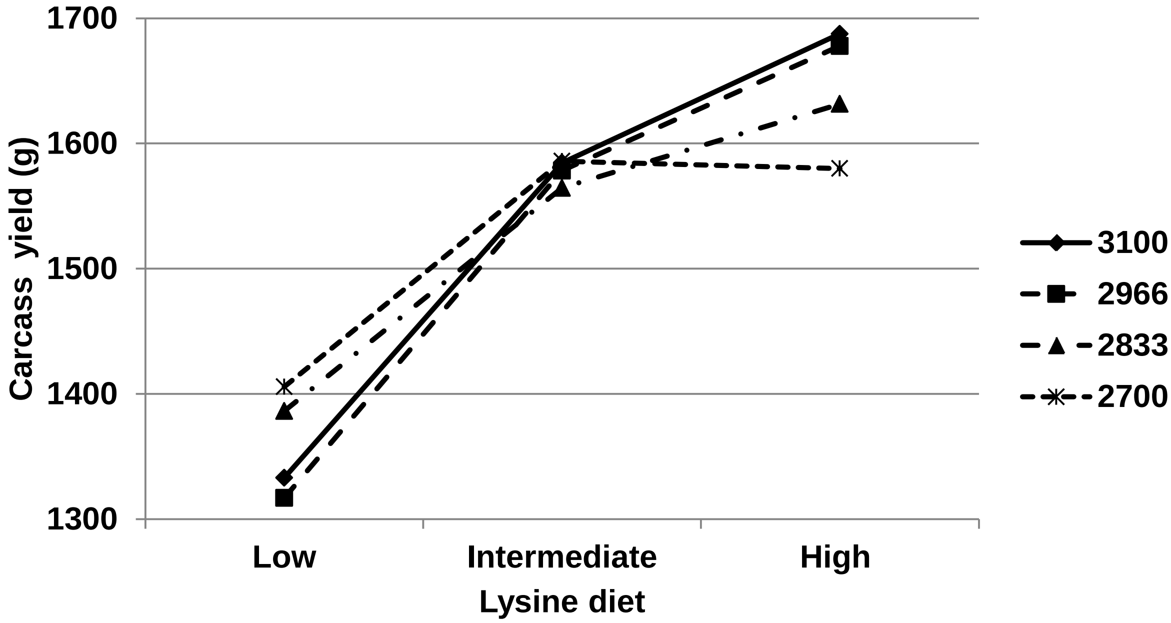

Figure 6.1. The relationship between dietary energy and lysine content and the effect on CY (g, as is basis).

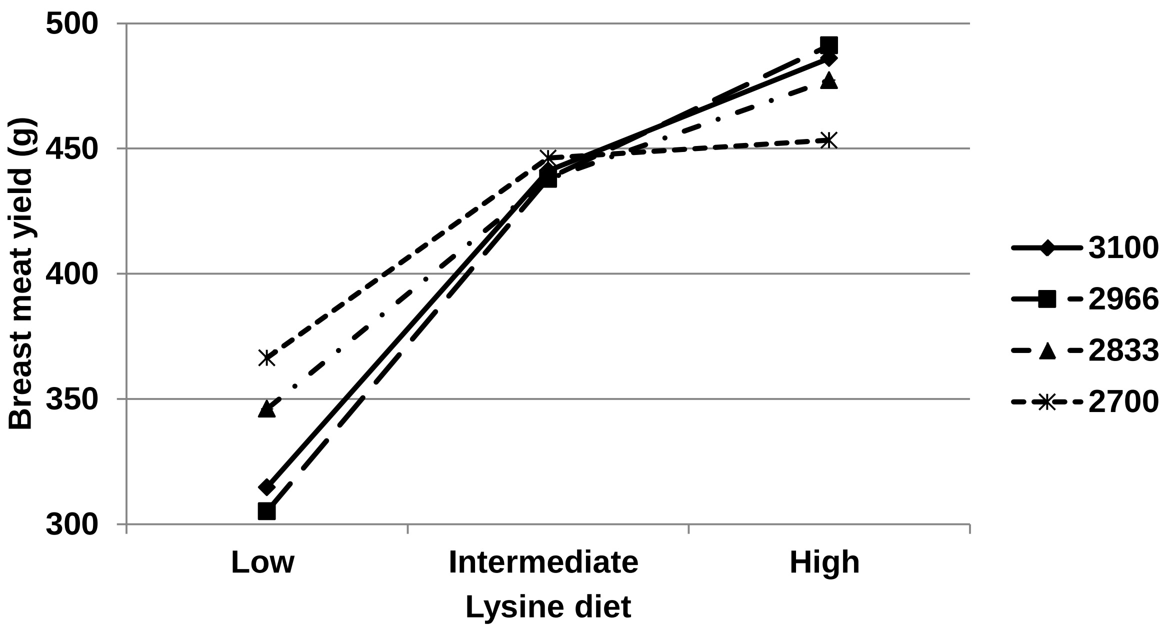

Figure 6.2. The relationship between dietary energy and lysine content and the effect on BY (g, as is basis).

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8.0 Appendices

8.1 Appendix A: Effect of age on dietary energy content

Table. Effect of age (S program vs. G program) on dietary energy content from 10 to 25 d on BW and BW gain.

	Body weight				Body weight gain			
S program vs. G program	10d	15d	20d	25d	10-15d	16-20d	21-25d	10-25d
Energy levels (kcal/kg)								
Contrast P-value								
2700 kcal/kg	0.001	NS[1]	0.055	NS	NS	NS	0.037	NS
2833 kcal/kg	0.030	NS	NS	NS	NS	NS	NS	NS
2966 kcal/kg	0.0004	NS	NS	NS	0.018	NS	NS	NS

[1]NS = P> 0.10.

Table. Effect of age (S program vs. G program) on dietary energy content from 10 to 25 d on feed consumption and feed to gain ratio (with mortality correction).

	Feed intake				Feed to gain ratio			
S program vs. G program	10-15d	16-20d	21-25d	10-25d	10-15d	16-20d	21-25d	10-25d
Energy levels (kcal/kg)								
Contrast P-value								
2700 kcal/kg	NS[1]	NS	NS	NS	NS	NS	0.007	0.018
2833 kcal/kg	NS	NS	NS	NS	NS	NS	NS	NS
2966 kcal/kg	NS	NS	NS	NS	NS	NS	NS	NS

[1]NS = P> 0.10.

Table. Effect of age (S program vs. G program) on dietary ener t from 10 to 25 d on mortality.

S program vs. G program	Mortality			
	10-15d	16-20d	21-25d	10-25d
Energy levels (kcal/kg)				
Contrast P-value				
2700 kcal/kg	0.012	NS	NS	NS
2833 kcal/kg	NS[1]	NS	NS	NS
2966 kcal/kg	NS	NS	NS	NS

[1]NS = P> 0.10.

Table. Effect of age (S and G program vs. F program) on dietary energy content from 26 to 35 d on BW and BW gain, and FI.

S and G program vs. F program	Body weight (kg)		Body weight gain (kg)		Feed intake (kg)	
	30 d	35 d	26-30d	31-35d	26-30d	31-35d
Energy levels (kcal/kg)						
Contrast P-value						
2700 kcal/kg	0.010	NS	NS	NS	NS	NS
2833 kcal/kg	NS[1]	NS	NS	NS	0.015	0.024
2966 kcal/kg	NS	NS	NS	NS	NS	NS

[1]NS = P> 0.10.

Table. Effect of age (S and G program vs. F program on dietary energy content from 26 to 35 d on feed to gain (with mortality correction) and mortality.

	Feed to gain ratio		Mortality (%)	
S and G program vs. F program	26-30d	31-35d	26-30d	31-35d
Energy levels (kcal/kg)				
Contrast P-value				
2700	NS[1]	0.036	NS	NS
2833	NS	NS	NS	NS
2966	NS	NS	NS	NS

[1]NS = P> 0.10.

8.2 Appendix B: Dietary amino acid and energy content and response on broiler performance

Table. Dietary AA and energy contents and response on broiler BW and BW gain.

	Body weight (kg)				Body weight gain (kg)			
Nutrient content	0 d	10 d	25 d	35 d	0-10 d	11-25 d	25-35 d	0-35 d
Energy level								
2700 kcal/kg	0.0441	0.267	1.233	2.187	0.227	0.966	0.954	2.142
2833 kcal/kg	0.0441	0.272	1.247	2.212	0.228	0.976	0.965	2.168
2966 kcal/kg	0.0442	0.271	1.237	2.177	0.227	0.965	0.941	2.133
3100 kcal/kg	0.0441	0.274	1.250	2.183	0.230	0.975	0.933	2.139
Coefficient								
Intercept	---	0.224	---	---	0.180	---	---	---
E	---	0.000016	---	---	0.000016	---	---	---
E^2	---	---	---	---	---	---	---	---
R^2	---	0.030	---	---	0.029	---	---	---
P-value								
Linear	NS[1]	0.076	NS	NS	0.077	NS	NS	NS
Quadratic	NS	NS	NS	NS	NS	NS	NS	NS
Lysine level								
High lysine content	0.0443	0.255	1.124	1.970	0.210	0.870	0.845	1.925
Intermediate lysine content	0.0440	0.276	1.285	2.267	0.232	1.009	0.982	2.223
Low lysine content	0.0441	0.283	1.316	2.332	0.239	1.033	1.017	2.288
Coefficient								
Intercept	0.0580	-0.326	-3.669	-6.635	-0.384	-3.343	-2.967	-6.693
E	-0.00034	0.014	0.114	0.204	0.014	0.101	0.090	0.205
E^2	0.0000021	-0.000077	-0.00066	-0.0012	-0.000079	-0.00058	-0.00051	-0.0012
R^2	0.062	0.725	0.869	0.830	0.730	0.863	0.696	0.830
P-value								
Linear	0.098	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Quadratic	0.044	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Overall energy and amino acid								
Pooled SEM	0.000049	0.0014	0.0087	0.017	0.0014	0.0075	0.0086	0.017
P-value								
Energy x amino acid	NS	0.0007	<0.0001	<0.0001	0.0009	<0.0001	<0.0001	<0.0001

[1]NS = P> 0.10.

Table. Dietary AA and energy contents and response on broiler feed consumption and feed gain ratio (with mortality correction).

	Feed consumption (kg/bird)				Feed to gain ratio			
Nutrient content	0-10 d	11-25 d	25-35 d	0-35 d	0-10 d	11-25 d	25-35 d	0-35 d
Energy level								
2700 kcal/kg	0.278	1.555	1.834	3.698	1.245	1.597	1.925	1.703
2833 kcal/kg	0.280	1.559	1.837	3.701	1.228	1.583	1.911	1.687
2966 kcal/kg	0.281	1.530	1.788	3.631	1.236	1.576	1.907	1.682
3100 kcal/kg	0.284	1.540	1.753	3.600	1.234	1.573	1.884	1.669
Coefficient								
Intercept	0.236	---	2.446	4.445	---	---	2.181	1.917
E	0.000015	---	-0.00022	-0.00027	---	---	-0.000095	-0.000080
E^2	---	---	---	---	---	---	---	---
R^2	0.077	---	0.085	0.044	---	---	0.033	0.034
P-value								
Linear	0.0037	NS	0.0023	0.030	NS	NS	0.062	0.057
Quadratic	NS[1]	NS	NS	NS	NS	NS	NS	NS
Lysine level								
High lysine content	0.275	1.460	1.686	3.450	1.307	1.666	1.996	1.768
Intermediate lysine content	0.284	1.587	1.851	3.744	1.218	1.559	1.884	1.664
Low lysine content	0.283	1.591	1.872	3.779	1.184	1.521	1.841	1.624
Coefficient								
Intercept	-0.024	-2.838	-3.492	-5.852	3.478	4.330	4.729	4.306
E	0.0073	0.104	0.124	0.223	-0.050	-0.062	-0.063	-0.059
E^2	-0.000043	-0.00061	-0.00072	-0.0013	0.00028	0.00034	0.00035	0.00032
R^2	0.208	0.654	0.538	0.586	0.798	0.841	0.706	0.886
P-value								
Linear	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Quadratic	0.0052	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0001	<0.0001
Overall energy and amino acid								
Pooled SEM	0.00080	0.0073	0.011	0.019	0.0056	0.0065	0.0075	0.0062
P-value								
Energy x amino acid	0.030	<0.0001	<0.0001	<0.0001	<0.0001	0.0028	0.0003	<0.0001

[1]NS = P> 0.10.

Table. The interaction between dietary AA and energy contents on broiler mortality.

	Mortality (%)			
Nutrient content	0-10 d	11-25 d	25-35 d	0-35 d
High lysine content				
2700 kcal/kg	1.971	2.867	1.434	6.272
2833 kcal/kg	2.330	5.197	0.358	7.885
2966 kcal/kg	1.434	3.763	1.255	6.452
3100 kcal/kg	2.509	3.758	0.896	7.163
Pooled SEM	0.34	0.37	0.18	0.62
Intermediate lysine content				
2700 kcal/kg	0.538	3.226	0.538	4.301
2833 kcal/kg	2.151	3.405	0.358	5.914
2966 kcal/kg	1.613	4.659	1.075	7.348
3100 kcal/kg	1.613	2.330	0.358	4.301
Pooled SEM	0.27	0.51	0.17	0.60
Low lysine content				
2700 kcal/kg	1.255	3.226	1.255	5.735
2833 kcal/kg	2.151	2.867	1.255	6.272
2966 kcal/kg	3.763	1.971	0.896	6.631
3100 kcal/kg	2.509	2.509	0.896	5.914
Pooled SEM	0.39	0.32	0.24	0.53

Table. The relationship between dietary AA and energy contents on broiler mortality.

	Mortality (%)			
Nutrient content	0-10 d	11-25 d	25-35 d	0-35 d
High lysine content				
Coefficient				
Intercept	---	---	---	---
E	---	---	---	---
E^2	---	---	---	---
R^2	---	---	---	---
P-value				
Linear	NS[1]	NS	NS	NS
Quadratic	NS	NS	NS	NS
Intermediate lysine content				
Coefficient				
Intercept	---	---	---	-547.582
E	---	---	---	0.381
E^2	---	---	---	-0.000066
R^2	---	---	---	0.111
P-value				
Linear	NS	NS	NS	NS
Quadratic	NS	NS	NS	0.052
Low lysine content				
Coefficient				
Intercept	---	---	---	---
E	---	---	---	---
E^2	---	---	---	---
R^2	---	---	---	---
P-value				
Linear	NS	NS	NS	NS
Quadratic	NS	NS	NS	NS

[1]NS = P> 0.10.

8.3 Appendix C: The effect of different dietary amino acid and energy levels, and gender on meat yield

Table. The effect of different dietary AA and energy levels, and sex on meat yield (g, as is basis) in broiler chickens.

Nutrient content and gender	Live weight	Carcass weight	Pectoralis major	Pectoralis minor	Total breast	Breast skin	Abdominal fat	Thigh	Drum	Wing	Back
Diet energy level											
2700 kcal/kg	2245.00	1520.99	347.74	73.31	421.05	47.96	19.43	133.43	105.35	165.98	373.91
2833 kcal/kg	2252.55	1529.80	348.27	73.33	421.61	47.88	19.37	136.27	106.83	168.42	375.59
2966 kcal/kg	2243.77	1525.03	339.66	72.17	411.83	47.75	19.31	135.69	106.86	167.38	379.24
3100 kcal/kg	2256.85	1535.07	343.35	70.64	413.98	48.29	21.03	136.37	107.19	169.52	385.67
Lysine level											
High lysine content	2052.37	1360.79	273.08	60.32	333.40	45.43	19.76	125.64	98.17	154.28	352.91
Intermediate lysine content	2306.25	1577.99	364.78	75.89	440.66	49.60	19.68	138.32	108.39	172.57	386.76
Low lysine content	2389.07	1643.59	396.04	80.85	476.90	48.90	19.92	142.30	113.05	176.51	395.96
Gender											
Female	2081.67	1416.12	322.76	69.55	392.31	45.84	16.97	126.48	96.53	156.19	348.53
Male	2417.93	1641.50	367.19	75.25	442.44	50.14	22.54	144.57	116.78	179.65	409.22
Overall											
Pooled SEM	11.61	8.91	3.00	0.61	3.46	0.50	0.39	0.80	0.64	0.86	2.29

Table. The impact of different dietary AA and energy levels, and sex on meat yield (g, as is basis) in broiler chickens.

Nutrient content and gender	Live weight	Carcass weight	Pectoralis major	Pectoralis minor	Total breast	Breast skin	Abdominal fat	Thigh	Drum	Wing	Back
Diet energy level											
Coefficient											
Intercept	---	---	---	---	---	---	---	---	---	---	292.934
E	---	---	---	---	---	---	---	---	---	---	0.030
E^2	---	---	---	---	---	---	---	---	---	---	---
R^2	---	---	---	---	---	---	---	---	---	---	0.0064
P-value											
Linear	NS[1]	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.055
Quadratic	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Lysine level											
Coefficient											
Intercept	-4260.878	-4103.180	-1981.025	-332.455	-2313.481	-104.393	---	-202.695	-109.938	-346.593	-440.386
E	148.139	128.407	52.646	9.193	61.839	3.690	---	7.712	4.741	11.901	18.619
E^2	-0.825	-0.718	-0.292	-0.051	-0.343	-0.022	---	-0.043	-0.025	-0.068	-0.104
R^2	0.220	0.292	0.492	0.337	0.504	0.018	---	0.126	0.149	0.201	0.097
P-value											
Linear	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.012	NS	<0.0001	<0.0001	<0.0001	<0.0001
Quadratic	0.0004	<0.0001	<0.0001	<0.0001	<0.0001	0.044	NS	0.0088	0.050	<0.0001	0.029
Gender											
P-value											
Gender	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Overall											
P-value											
Energy x amino acid	0.0007	<0.0001	<0.0001	<0.0001	<0.0001	NS	NS	0.038	0.059	0.0055	0.028
Energy x amino acid x gender	NS	0.052	NS	NS	0.087	NS	NS	0.074	0.071	NS	NS

[1]NS = P> 0.10.

Table. The relationship between dietary AA and energy levels, and sex on meat yield (g, as is basis) in broiler chickens.

Nutrient content	Live weight	Carcass weight	Pectoralis major	Pectoralis minor	Total breast	Breast skin	Abdominal fat	Thigh	Drum	Wing	Back
High lysine content											
2700 kcal/kg	2308.70	1580.00	376.38	77.45	453.33	49.36	19.18	135.85	108.91	170.05	377.66
2833 kcal/kg	2392.59	1631.57	396.16	81.17	477.33	46.03	18.17	142.30	112.67	175.31	391.14
2966 kcal/kg	2423.52	1677.88	407.50	83.68	491.18	49.66	19.82	145.91	115.54	179.71	403.11
3100 kcal/kg	2431.48	1687.60	404.85	81.20	486.05	50.56	22.46	145.38	115.23	181.26	412.86
Pooled SEM	18.67	13.79	4.12	0.91	4.65	0.77	0.63	1.35	1.09	1.45	3.97
Intermediate lysine content											
2700 kcal/kg	2325.74	1585.87	368.14	78.05	446.18	48.35	19.41	137.42	107.88	172.18	390.27
2833 kcal/kg	2283.70	1564.53	363.02	74.80	437.82	50.17	20.30	138.07	108.11	172.71	379.39
2966 kcal/kg	2307.41	1578.40	360.95	77.15	438.10	49.38	19.02	139.05	108.53	171.04	387.62
3100 kcal/kg	2308.15	1584.60	367.38	73.78	441.16	50.35	19.88	138.69	109.03	174.33	390.48
Pooled SEM	17.23	12.56	3.41	0.85	3.89	0.85	0.64	1.26	1.02	1.29	3.85
Low lysine content											
2700 kcal/kg	2100.56	1405.66	301.39	65.06	366.44	46.23	19.72	127.53	99.61	156.54	355.96
2833 kcal/kg	2078.11	1386.33	282.47	63.61	346.08	47.33	16.61	128.05	99.34	156.60	355.29
2966 kcal/kg	2000.37	1316.86	249.60	55.56	305.17	44.20	16.05	121.97	96.39	150.90	346.70
3100 kcal/kg	2030.93	1333.00	257.81	56.93	314.74	43.96	20.65	125.03	97.32	152.98	353.68
Pooled SEM	16.88	12.20	3.40	0.79	3.96	0.95	0.75	1.28	0.94	1.21	3.41

Table. The interaction between dietary AA and energy levels, and sex on meat yield (g, as is basis) in broiler chickens.

Nutrient content	Live weight	Carcass weight	Pectoralis major	Pectoralis minor	Total breast	Breast skin	Abdominal fat	Thigh	Drum	Wing	Back
High lysine content											
Coefficient											
Intercept	2282.059	1548.922	369.981	69.924	447.322	---	17.090	134.262	107.499	166.889	366.153
E	42.225	38.184	10.370	8.885	11.774	---	1.135	3.272	2.285	3.934	12.003
E^2	---	---	---	-1.501	---	---	---	---	---	---	---
R^2	0.029	0.047	0.039	0.028	0.040	---	0.021	0.036	0.027	0.045	0.055
P-value											
Linear	0.016	0.0021	0.0048	0.084	0.0045	NS	0.040	0.0072	0.021	0.0026	0.0008
Quadratic	NS[1]	NS	NS	0.10	0.10	NS	NS	NS	NS	NS	NS
Intermediate lysine content											
Coefficient											
Intercept	---	---	---	---	---	---	---	---	---	---	---
E	---	---	---	---	---	---	---	---	---	---	---
E^2	---	---	---	---	---	---	---	---	---	---	---
R^2	---	---	---	---	---	---	---	---	---	---	---
P-value											
Linear	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Quadratic	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Low lysine content											
Coefficient											
Intercept	2345.699	1641.840	442.355	92.270	534.624	---	---	---	---	---	---
E	-26.763	-25.844	-15.896	-3.025	-18.921	---	---	---	---	---	---
E^2	---	---	---	---	---	---	---	---	---	---	---
R^2	0.016	0.031	0.148	0.097	0.156	---	---	---	---	---	---
P-value											
Linear	0.082	0.015	<0.0001	<0.0001	<0.0001	NS	NS	NS	NS	NS	NS
Quadratic	NS	NS	0.064	NS	0.069	NS	NS	NS	NS	NS	NS

[1]NS = P> 0.10.