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Responsiveness of Cobb MV × 700 Broilers to Dietary Amino Acid and Energy Density

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Responsiveness of Cobb MV × 700 Broilers to Dietary Amino Acid and Energy Density

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ABSTRACT

As new broiler crosses are introduced to the industry, it is of paramount importance to understand their nutritional digressions from previous and other modern broilers. In particular, amino acids (**AA**) and dietary energy have been identified as key drivers of live performance and carcass composition. In addition, increased nutrient density in broiler diets have been linked to an increase in breast muscle myopathies such as white striping and woody breast. Therefore, a series of trials were conducted to determine the responsiveness of live performance, carcass characteristics, and breast muscle myopathies of Cobb MV × 700 broilers to dietary AA and energy density.

Experiment 1 served to identify the responsiveness to varying AA densities. Live performance responses were detected at 28 d of age, identifying a starting point for AA density modification in Cobb MV × 700 broiler diets. Experiment 2 attempted to identify key time points in the Cobb MV × 700 broiler growout where changes in AA density would be most beneficial for live performance and processing efficiency. It was determined that body weight gain (BWG) and feed intake (FI) responses to AA density were evident at 28 d but diminishing effects were observed by 35 d. Experiment 3 intended to determine the responsiveness of Cobb MV × 700 broilers to commercially viable changes in energy concentration but found no response in BWG, FCR, or processing parameters. In an attempt to increase marginal AA density responses in live performance and processing, Experiment 4 assessed potential interactions between dietary energy and AA density in the latter phases of growout where AA effects had previously diminished. This experiment determined that energy is not a limiting factor for AA responses in Cobb MV × 700 broilers. Woody breast and white striping results were inconsistent throughout

Experiments 2 through 4 and a definitive conclusion could not be drawn as to how these myopathies are linked to broiler nutrition.

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DEDICATION

Dad, you have given up a lot to spend time with me and to get me to this point in my life. You are and always will be my superman. This one is dedicated to you.

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INTRODUCTION

With a population expected to reach over 9.7 billion by 2050 (UN DESA, 2015), the amount of food produced must increase by 70% (FAO, 2009). The combination of a drastic increase of needed food and a finite amount of available farmland requires sustainable protein production to feed the increasing population. Poultry is in a prime position to be the leading animal protein source to feed the world of the not so distant future since it has no religious restrictions and a feed efficiency second only to farmed fish (Brown, 2006).

The largest portion of poultry production costs are associated with feed costs. Of that, approximately 25% are attributed to meeting protein, and more specifically, amino acid (**AA**) needs. Traditionally, diets were formulated to a minimum crude protein (**CP**) content to meet the bird's AA requirements (Heuser, 1941). The problem with solely feeding intact proteins is that the AA profiles of most feed ingredients are imbalanced for efficient utilization by the bird, leading to the excretion of excess nitrogen into the environment when CP levels are high enough to adequately meet all of the bird's individual AA requirements (Si et al., 2004). This is extremely inefficient, leading to reduced profit and, of increasing concern, has a detrimental impact on the environment. To address these concerns, broiler diets are formulated to individual AA requirements instead of to a specified CP level, reducing nitrogen excretion and decreasing feed costs.

A solution to solely feeding intact whole proteins to meet AA needs is to supplement the diet with crystalline AA. Produced via chemical synthetization or bacterial fermentation, supplemental AA allow for correcting inadequacies in the AA profile of whole proteins to meet the bird's requirements. The use of crystalline AA reduces feed costs, minimizes nitrogen excreted into the environment and maximizes performance and meat yields. These improvements

not only help the poultry industry through economic gains, but improve the environmental sustainability of poultry production by reducing its environmental impact.

As advances in poultry genetics decrease feed conversion ratio (**FCR**) and increase body weight gain (**BWG**) of commercial broilers, nutrient requirements have to be adjusted to allow for optimal feeding. Differences in growth patterns and nutrient requirements can be seen when comparing genetic lines and crosses from different primary breeders but changes are also present within individual lines from a single primary breeding company. With a market geared toward white meat in the U.S., integrators are increasingly adopting high-yielding breast meat broilers to keep up with demand. Cobb-Vantress has recently released the MV male line that is commonly paired with the established Cobb 700 female line to create a new broiler cross. Published dietary requirements for AA and energy are lacking for this broiler package, and further investigation is needed so that poultry integrators can optimize feeding strategies for this high-yielding broiler cross.

Continued work to increase the genetic potential of broilers has recently come at a cost. The occurrence of breast muscle myopathies, specifically woody breast and white striping, in high yielding broilers has become increasingly prevalent, and discussions of how to treat affected meat products are currently underway. In severe cases, the presence of breast muscle myopathies can result in the downgrading or loss of salable meat. With this new cross, no data are currently available as to how dietary manipulation effects the incidence and severity of breast muscle myopathies. Therefore, the objectives of this thesis were to:

1. Determine the responsiveness of Cobb MV × 700 broiler live performance, carcass characteristics, and breast muscle myopathies to dietary AA and energy density.

2. Identify key feeding phases where AA responses are most pronounced, and implement strategies to capitalize on those pivotal time points in the growout period.
3. Evaluate the potential differences in responses between male and female broilers to determine if feeding strategies need to be adjusted when rearing sex separate.
4. Assess incidence and severity of breast muscle myopathies and determine if they are exacerbated by increased nutrient density.

CHAPTER I

LITERATURE REVIEW

LITERATURE REVIEW

Nutritional Requirements

Protein has long been known to contain individual AA that are the building blocks of the protein. The first AA discovery is credited to W. H. Wollatston, who in 1810 described a compound that had been found in a type of urinary calculus (Wollatston, 1810). This new substance, then known as cystic oxide, later became what we now know as cystine. Nine years later, Proust (1819) discovered leucine while conducting a series of experiments with cheese when he isolated a compound he called "oxide caséeux", identifying the first of what would later be known as one of the limiting AA for poultry. A year later, Braconnot (1820) isolated a compound by acid hydrolysis of muscle fiber and wool, previously identified by Proust as "oxide caséeux", and named it leucine. Work with AA continued throughout the 19th and 20th centuries ending with the discovery of threonine by McCoy et al. (1936). Threonine marked the discovery of the final essential AA and work could begin on supplying the optimal balance of AA instead of supplying protein as a whole.

Like other animals, poultry use 20 AA to produce proteins. Of those 20, 10 are considered as essential or indispensable (Leeson and Summers, 2001). A dietary essential, or indispensable AA, is one that cannot be synthesized by the body or synthesized rapidly enough to satisfy physiological requirements. For poultry, these include arginine, lysine, histidine, leucine, isoleucine, valine, methionine, threonine, tryptophan, and phenylalanine (Coon, 2002), meaning that requirements for all of these AA must be met through dietary intake. Glycine is sometimes considered to be conditionally essential during times of rapid growth when the bird cannot produce enough to meet its requirement (Almquist and Grau, 1944; Wixom et al., 1955; Greene et al., 1960; D'Mello, 1973).

Traditionally, diets were formulated to contain a minimum concentration of CP to meet the requirements of all AA (Heuser, 1941). This approach leads to the over-feeding of most AA since dietary protein concentration must be increased to meet the bird's requirement for the most limiting AA within the feed ingredients used, leading to an excess of the AA that are most abundant within the ingredient. Since excess AA cannot be stored within the body (Lin, 1981), some of the deficient or limiting AA are inadvertently lost when the excess AA are catabolized (Norris, 1958). The limiting order of AA in corn-soybean diets is methionine, threonine, lysine, valine, arginine, and then tryptophan, (Fernandez et al., 1994) although this limiting AA order can be altered by dietary ingrediets or ingredient quality. Therefore, growth is first limited by the levels of methionine found in the diet and then according to the levels of the other essential AA as dietary AA requirements are met. Whether or not an AA is limiting is dependent on if it is present in the diet in proper proportion to the other AA to support protein synthesis in the animal (Maynard, 1951).

With the discovery of a way to produce crystalline AA, research was conducted to assess the effectiveness of supplementing individual AA in a purified form to meet the bird's dietary needs for essential AA. In 1941, Hayward and Hafner were some of the first to look at the supplementary effect of adding crystalline cysteine and methionine to a corn soybean diet fed to chickens. These authors demonstrated that synthetic methionine supplementation could alleviate its deficiency symptoms, and that this approach could aid in identifying the next limiting AA in the diet. It was later found by Bornstein and Lipstein (1975) that the addition of 0.06 to 0.07% methionine could replace approximately 0.90% of the dietary protein supplied by soybean meal. This foundational research enabled nutritionists to formulate diets according to the bird's essential AA requirements rather than focusing on a CP level.

As work began to establish individual AA requirements, it was determined that AA requirements vary depending on the parameter being measured (BWG, FCR, breast meat yield, and fat pad percentage) (Table 1). Han and Baker (1994) found that the lysine requirement of male broilers from 22 to 43 d post hatch was 0.85% for maximum BWG, but 0.89% for optimum feed efficiency. These authors also found that increased lysine supplementation decreased the abdominal fat pad percentage of broilers, indicating that a requirement also exists for optimal body composition. Work by Tesseraud et al. (1996) demonstrated that the *Pectoralis major* was the most sensitive to dietary lysine content when assessed by protein turnover. As such, numerous studies have been conducted to evaluate the influence of lysine on breast meat growth and yield (Moran and Bilgili, 1990; Farrell, 1990; Han and Baker, 1991, 1993, 1994; Kidd et al., 1998; Kerr et al., 1999; Corzo et al., 2003, 2006, Dozier et al., 2008a, 2009a; b, 2010; Wang et al., 2014).

The other two commonly supplemented AA, methionine and threonine, both have different requirements for BWG, FCR, fat pad, and breast yield as well (Leclercq, 1998; Chamruspollert et al., 2002; Corzo et al., 2007). However, their biological uses differ. Methionine is supplemented to cover the requirement of both methionine and cysteine, which is often referred to as the total sulfur AA (TSAA) requirement, since methionine can be readily converted to cysteine *in vivo* (Almquist, 1947). Therefore, methionine serves as a precursor to cysteine, serves as a methyl donor, and is an indispensable AA in protein synthesis (Patrick and Schaible, 1980). Threonine is also used for protein accretion, gastrointestinal, and immune function (Kidd, 2000).

Valine is thought to be the fourth limiting AA (Fernandez et al., 1994) in corn and soybean meal-based diets and is also commercially-available in crystalline form. Some poultry

companies have begun using supplemental valine in feed, but it is generally excluded from diets based on least-cost formulation due to its high ingredient costs. Currently used crystalline AA are predominantly produced via microbial fermentation, with the exception of chemically synthesized methionine, and as production processes improve, it is likely that valine and other limiting AA will become more widely adopted. However, there are limits to supplemental AA use beyond those of availability and economic viability. Diets high in crystalline AA, created by reducing CP and compensating with supplemental AA, have been shown to reduce performance and appetite (Waldroup et al., 2005; Dean et al., 2006; Namroud et al., 2008; Hernández et al., 2012). Namroud et al. (2008) theorized that the reduction in performance was due to increased blood and excretory ammonia concentrations observed when they fed chicks 17% CP diets supplemented with methionine, lysine, threonine, arginine, tryptophan, isoleucine, and valine. Therefore, widespread adoption of supplemented AA beyond lysine, methionine, threonine, and potentially valine in diet formulation will be dependent on the broilers ability to perform on increasingly purified diets.

Dietary requirements for AA differ according to the response measurement being observed (BWG, FCR, fat pad, and breast meat yield) and can be set to produce desirable outcomes that match current economic conditions. It has been previously shown that breast meat price has a higher impact on gross feeding margin [bird return over feed costs (Dozier et al., 2006b)] than feed ingredient prices in normal economic conditions and that it should be considered when formulating broiler diet AA densities (Dozier et al., 2008b). For example, at times where breast meat prices are high, implementing AA strategies that maximize breast meat yield lead to highest profitability. Adjusting AA set points in formulation usually encompasses the entire AA density instead of single AA. This change in density can be universal, affecting all

phases in a feeding program, or varied across feeding phases to create different regimens that utilize a combination of high (**H**), medium (**M**), and/or low (**L**) density to target phases where AA may be most biologically and economically beneficial. Dozier et al. (2006a) found that by feeding Ross × Ross 708 broilers high AA density feed from 36 to 59 d (finisher 36 to 47 d, withdrawal 48 to 59 d) after a common starter increased gross feeding margins of $0.015, $0.047, $0.007, $0.011, and $0.043 per bird were observed when compared with HM, HL, MM, ML, and LL regimens, respectively. This was due to breast meat prices having a larger impact on gross feeding margins than feed ingredient costs, offsetting the expense of feeding high AA levels.

Ideal Protein Concept

The ideal protein concept was first described by H. H. Mitchell (1962) who attempted to produce a diet that exactly matched the AA needs of chicks. Instead of determining the absolute requirement of each individual AA, the ideal ratios of digestible AA to digestible lysine were used. Lysine was chosen as the baseline AA to which all other essential AA ratios would be established for multiple reasons. First, lysine is the second limiting AA in corn-soybean diets (Edmonds et al., 1985; Han et al., 1991), therefore it will almost always be supplemented and its levels will be known with relative certainty in the diet. Secondly, lysine analysis in feedstuffs is straightforward and does not have potential concerns during hydrolysis like methionine, which can be converted into several derivatives by partial oxidation (Fontaine, 2003). And thirdly, the volume of data published on the lysine required for production time points, sex, environmental, and disease challenge (Han and Baker, 1993; Webel et al., 1998; Dozier et al., 2009b, 2010) are vast. Additionally, lysine is predominantly used for protein accretion and maintenance, serving no precursor role (Emmert and Baker, 1997), whereas other AA, such as methionine, can serve

as a precursor to cysteine, methyl donor, and a building block for protein accretion (Patrick and Schaible, 1980).

Use of digestible AA values in feed formulation is superior to use of total analyzed AA as digestible AA represent the portion in the feed ingredient or diet that can be utilized by the birds and eliminates the discrepancies created by the variability of AA digestibility in different ingredient sources (Emmert and Baker, 1997). Rostagno et al. (1995) reported more consistent bird performance when formulating based on digestible AA instead of total, especially in diets containing ingredients other than corn and soybean meal (rice bran, poultry by-product meal, meat and bone meal, and feather meal). Furthermore, Dari et al. (2005) observed higher BWG for broilers fed diets formulated on digestible AA than birds fed diets formulated on total AA.

With the inherent complexities associated with experimental determination of single AA requirements for new poultry strains and crosses, the AA ratios simplify the process of estimating requirements for each phase. Since all other AA are set relative to relatively well-established lysine requirements, AA profiles can be rapidly assembled when new phase feeding programs are created. This solves one of the original issues of why CP was used in formulating diets, in that it is easier to deal with one well understood variable instead of 10 unknowns (Heuser, 1941).

Phase Feeding

As the bird ages, the essential AA:Lys ratios that optimize performance change (Emmert and Baker, 1997). In the early days of life, growth is primary focused on skeletal and organ formation (e.g. intestine, pancreas, liver) and subsequently transitions to muscle growth and finally, fat deposition (Katanbaf et al., 1988). This shift occurs at around 11 d of life when

relative daily growth rate peaks and begins to decline as the bird puts on lean muscle mass (Nitsan et al., 1991). Another factor affecting the AA ratios is that of maintaining nitrogen equilibrium (Leveille and Fisher, 1958). In young birds the maintenance requirement only makes up 3 to 6% of AA needs but increases significantly as the bird ages and increases in size (Emmert and Baker, 1997). Ratios of AA that are more important for maintenance (e.g., cystine, threonine, tryptophan, valine, arginine, and isoleucine) increase as the bird ages relative to lysine due to the decrease in the lysine needed since it does not play a large role in maintenance (Emmert and Baker, 1997).

To address the changing AA needs of the bird, growout times are divided into shorter periods, known as feeding phases, so that multiple diets can be formulated to meet changing nutrient requirements and minimize over- or under-feeding of nutrients. Holsheimer (1980) found that by manipulating dietary lysine levels by approximately 16%, FCR and BWG could be optimized over an 8 week growout. Feed conversion was lowered by feeding 1.03% (0 to 2 weeks), 0.86% (2 to 4 weeks), and 1.22% lysine (4 to 8 weeks) while BWG was maximized using a feeding program of 1.22% (0 to 2 weeks), 1.03% (2 to 4 weeks), and 0.86% lysine (4 to 8 weeks) compared with control diets (Holsheimer, 1980). Today broiler feeding programs typically utilize 3 to 5 dietary phases (Cobb-Vantress, 2008; Aviagen North America, 2014) for which all nutrient concentrations, including AA, are altered to meet changing requirements of the bird. This allows for a more efficient use of feedstuffs, increased economic efficiency and more environmentally sustainable production.

Timing of the change between phases plays a large role in the effectiveness of phase feeding. The transition from starter to grower is the first feed change used in poultry. The optimal time for this change was found to occur at 7 or 14 d, where highest body weight and

lowest feed costs/lb of gain were observed compared with starting birds on grower diets at d 0 or switching to a grower diet at d 21 (Watkins et al., 1993). When evaluating 3 phase diet regimens for broilers reared to 48 d post-hatch, Roush et al. (2004) found that body weight was maximized when birds were fed a starter diet (1.23% lysine) for 37 d and grower (1.01% lysine) for 11 d without a finisher phase, while FCR was minimized with a starter diet being fed for all 48 d. When diet cost in addition to body weight and FCR were taken into account, it was found that the ideal regimen would include feeding a starter diet until 18 d and a grower diet for the remaining 30 d. The longer required time to feed starter for minimized FCR results in a higher AA intake than what was needed to achieve maximum BWG, aligning with other research stating that lysine requirements are higher for optimal FCR than for BWG (Leclercq, 1998).

Due to their changing nature, dietary requirements would theoretically be most efficiently met by providing broilers a different diet each day. Brewer et al. (2002) evaluated the effects of feeding an optimized nutrient profile by changing diets every other day (18 to 58 d) for 4 strains of broilers grown to 58 d of age. All 4 strains achieved similar live performance with either feeding program but feed costs were reduced by 1 to 4 cents per kg of gain through the implementation of phase feeding. Although this style of feeding is impractical in current poultry production scenarios in the US (Brewer et al., 2002), it highlights the importance of meeting the changing nutritional needs of growing broilers. By establishing a dietary regimen that is optimized for the broilers used, feed costs can be lowered while maintaining performance levels using current feeding program approaches.

Factors Affecting Amino Acid Requirements

Genetics

Commercial broilers can be categorized into fast- and slow-feathering strains. Fast-feathering strains were traditionally used since they have fewer pin feathers at processing and are less prone to cannibalism (Sheridan and McDonald, 1963). Slow-feathering broilers have a delayed onset of feathering (Sheridan and McDonald, 1963) that allows for birds to utilize dietary AA for lean protein accretion rather than feathering during the period of rapid growth that occurs in the first two weeks of life (Maruyama et al., 1978; Lowe and Merkley, 1986). Research has been conducted to evaluate the potential influence of feathering rate on dietary AA requirements. Dozier et al. (2000) found that increasing the threonine content of the diet from 0.56 to 0.74% improved growth rate for fast-feathering birds but not for slow-feathering birds. This observation was likely due to the high concentration of threonine found in feathers, which combined with serine, makes up 20% of feather AA residues (Stilborn et al., 1997). Kalinowski et al. (2003) evaluated the methionine and cysteine requirements of fast- and slow-feathering broilers and found that there was no difference in the methionine requirement between strains, whereas fast-feathering birds required more cysteine (0.44% of diet) than slow feathering birds (0.39% of diet).

Broiler strain also plays a role in growth rate, independent of feathering rate. Research was conducted by Zhai et al. (2013) to evaluate AA needs of the Cobb 700, and Cobb 500 broilers were used as an industry control. In this study, Cobb 500 broilers had higher body weight and lower FCR than Cobb 700 broilers at 14 and 28 d when fed the same diet. By d 35, body weight and FCR were the same between the two strains. This indicates that Cobb 500 broilers have a higher early growth rate, whereas Cobb 700 broilers have a more rapid growth

rate in the latter period of their growth curve. As such, AA requirements may be similar for the two strains, but increased AA density may be more beneficial in early phases for the Cobb 500, whereas for the Cobb 700, it may be more beneficial in later phases.

Sex

Sex also plays a role in the AA requirements of broilers due to differences in AA metabolism between male and female birds. As early as 1958, it was suggested that male broilers had higher protein requirements than females (Douglas et al., 1958; Shutze et al., 1958), and most subsequent data have supported this theory (Table 2). Previous research has also shown that male broiler responses to increasing AA density are greater than those observed in females, and that to optimize production to its highest efficiency, broilers may need to be reared sex separately (Kidd et al., 2004b). The vast majority of AA research has been conducted using male broiler chicks, and requirement data for females is lacking. In 1982, Thomas and Bossard postulated that when requirement data for males and females are not available, AA requirements for females will be an estimated 6% less than those of males during the starter period (0 to 21 d), 8% less during the finisher period (22 to 42 d), and 10% less for the withdrawal period (43 to 53 d).

However, it has been suggested that feeding diets formulated separately for males and females is not justified, due to a lack of interactions between dietary nutrient content and bird sex (Waldroup et al., 1990). Therefore, although differences among individual requirements of males and females exist, these differences may not be enough to influence response variables when fed in a practical broiler diet. It is well known that the patterns of growth observed in males and females do differ, as evidenced by an earlier body weight plateau and onset of fat deposition in broilers (Waldroup et al., 1990). With continual advancements in genetics and increasingly improved nutrition practices, these differences may become a factor in broiler diet formulation.

Energy in Broiler Nutrition

Feed Energy and Partitioning

In accordance with the first law of thermodynamics, energy cannot be created nor destroyed but can be transformed, the energy partitioning of feedstuffs can be determined by monitoring energy inputs (i.e., feed energy) and outputs (i.e., tissue growth, fecal energy excretion, and heat). The total combustible energy in a feedstuff is known as gross energy and is typically measured using 25 to 30 atmospheres of oxygen in a bomb calorimeter (NRC, 1994). Gross energy values are of little use in nutrition as all of the energy in a feedstuff is not available for use to the animal, but they are used in the further determination of more precise energy values used in commercial formulation (Sibbald, 1978). The first step in determining the portion of available energy is subtracting the gross energy of the feces from that of the original feedstuffs (Sibbald, 1982). The derived value is known as the apparent digestible energy of the feedstuff, and typically represents 70% of the starting gross energy (Caldas, 2015). Energy losses also occur in the urine and because of the difficulty in separating urine and feces in avian species, apparent metabolizable energy (AME) values are commonly used in poultry feed formulation. Apparent metabolizable energy is defined as the gross energy of the feed consumed minus the gross energy of the feces, urine, and gaseous products, which are assumed to be negligible in poultry (Sibbald, 1982). These values are commonly adjusted for nitrogen retention (AME_n) to allow for comparison of AME values across species that have different rates of growth or egg production (Lopez and Leeson, 2008). Currently, AME is the commonly accepted standard used to express energy values and requirements in commercial poultry production (Lopez and Leeson, 2008), but it is not the true representation of the energy used by the animal for growth and maintenance. Net energy is the final step in energy partitioning and represents the portion of

energy retained in the body or used in the construction of useful end products (e.g., eggs and semen) (Sibbald, 1982). Net energy has been used in defining swine energy requirements (NRC, 2012), but has not been widely accepted in poultry due to a lack of absolute net energy values for each feedstuff (NRC, 1994).

Energy Responses of Broilers

Literature concerning dietary energy requirements and responses in broilers is far more limited than that concerning dietary AA requirements. This is due to the nature of energy studies where clean linear responses to dietary energy are rarely observed unless drastic changes in dietary energy content are implemented. Furthermore, responses in FI have not been shown to be proportional to changes in energy density (Saleh et al., 2004). Therefore, existing research has typically involved large increases in dietary energy content to establish general patterns of broiler responses to increasing dietary energy (Harms et al., 1957; Summers et al., 1965; Coon et al., 1981). Newcombe and Summers (1984) observed that optimal performance in broilers occurred when the calorie-to-protein ratio increased as the birds age. This study also demonstrated that previous diets could affect the future nutrient intake when diet energy values are changed. This was evident in that broilers fed a low, medium, high dietary energy regimen of 2,400 (0 to 14 d), 2,800 (15 to 28 d), 3,200 (29 to 42 d) kcal/kg had similar energy intakes as birds fed all high dietary energy regimen (3,200 kcal/kg from 0 to 42 d) kcal/kg). Despite similarities in energy intake, birds fed the low, medium, high energy regimen had the highest BWG due to heightened average daily gain in the second feeding phase (15 to 28 d). Newcombe and Summers (1984) postulated that the reason for this optimized growth in the low, medium, high regimen was due to heightened protein utilization. If energy is the controlling factor on FI, having a low energy content in earlier stages when protein intake is critical for the chick's

development by allowing for an increased protein intake relative to a diet with a higher energy content. Similarly, as broilers age and AA requirements decrease, higher energy diets facilitate the use of carbohydrates and fats in place of more costly protein sources to meet maintenance energy needs. Leeson et al. (1996) found that modern broilers retain the ability to adjust FI to control energy intake. Utilizing four diets ranging from 2,700 to 3,300 kcal/kg provided *ad libitum*, they found no differences in growth rate or energy intake, but carcass fatness was reduced as energy levels were lowered.

Energy and Amino Acid Interactions

As previously stated, FI of broilers appear to be driven by dietary energy density. Therefore, monitoring dietary protein and energy values is of paramount importance to ensure that an AA deficiency does not result from decreased voluntary FI. Although there is a known effect of dietary energy on FI that concomitantly influences AA intake, these effects are inconsistent for broilers (Fisher and Wilson, 1974). Consequently, no straightforward solution exists that can accurately predict changes in FI resulting from changes in dietary energy density.

There are no negative interactive effects between protein and energy *per se*, but negative effects can occur if both aren't taken into account when formulating poultry diets. Broilers will increase energy intake independent of protein content when offered a diet with decreased energy density, negatively affecting FCR (Leeson and Summers, 2001). This trend was observed by Kamran et al. (2008) who showed a stepwise increase in FCR during a 27 to 35 d finisher period and in overall (1 to 35 d) FCR as energy and CP were reduced in concert to maintain their ratio at 132, 143, 155 kcal metabolizable energy/% CP in the starter, grower, and finisher, respectively. It was also determined that carcass composition was unaffected without any

increase in abdominal fat pad percentage, but growth performance was negatively impacted when protein to energy ratios were maintained and energy and AA density of the diet decreased.

In a factorial study examining the interactive effects of protein, dietary energy, and sex, Jackson et al. (1982) found that body weight and feed efficiency of broilers increased with increasing dietary energy when CP was above 20%. When fed a 16% CP diet, a reduction in body weight was observed when dietary energy exceeded 3,200 kcal/kg. Combining these observations, it can be implied that these broilers were eating to an energy requirement. In the case of high CP diets, those above 20% in this experiment, broilers were using excess protein as an energy source instead of for protein accretion in the lowest energy diets. This is supported by the increasing feed efficiency as the energy density of the diet increased. Conversely, in birds fed the 16% CP diet, energy density above 3,200 kcal/kg reduced broiler FI to the point that growth was limited due to lack of protein intake. This effect of reduced body weight as energy density increased was also observed in previous research when CP was reduced below 18% (Summers et al., 1964).

Breast Muscle Myopathies

In recent years, the poultry industry has become increasingly concerned with breast muscle myopathies, which in severe cases can result in downgraded breast fillets used in products with less added value (Trocino et al., 2015). Two such myopathies of particular concern include woody breast and white striping, which can produce breast fillets that are texturally and visually unappealing to consumers (Kuttappan et al., 2012b; 2016).

White striping has been studied extensively since 2009 and is characterized by parallel white lines on the breast fillets (Kuttappan et al., 2016). These stripes are comprised of lipid

deposits that reduce the protein content of the breast fillet and result in a higher caloric value of the fillet (Kuttappan et al., 2012a). Research indicates that white striping is linked to increased growth rates of broilers caused by high nutrient density diets (Kuttappan et al., 2012a). Additional work has shown that the severity of white striping increases as birds become older and heavier (Kuttappan et al., 2013; 2017b).

Woody breast is a newer myopathy concerning the poultry industry and its causes are largely unknown (Kuttappan et al., 2016). Although the etiology of woody breast is not known, it has been associated with faster growth rate in broilers attributed to genetic selection pressure for this trait (Kuttappan et al., 2017a). Woody breast is characterized as a stiffness or hardness in the breast fillet and in severe cases can result in the formation of a ridge or out bulge on the distal end of the fillet (Owens, 2014). When assessing the effect of sex on woody breast, Trocino et al. (2015) found that males exhibited a higher occurrence than females and attributed this to higher male body weights. This difference may indicate that growth rate does play a role in the development of woody breasts more so than the sex of the bird. In a pair of nutritional studies, Meloche et al. (2018a; b) evaluated the effects of quantitative and qualitative feed restriction on the development of woody breast. In the first of these studies, it was determined that a 5% reduction in FI, achieved through quantitative nutrient reduction, substantially reduced the incidence of severe woody breast in Ross × Ross 708 broilers, but further restriction did not result in any added benefit (Meloche et al., 2018a). In a follow up study focusing on qualitative feed restriction, reductions in the incidence of severe woody breast were only observed when AA and energy density were reduced by 10% over the entire 49 d growout (Meloche et al., 2018b). These trials showed that the incidence of severe woody breast could be influenced by dietary manipulation. However, quantitative feed restriction, which is impractical to implement due to

logistical constraints in current production systems, was more effective in reducing myopathies than qualitative restriction (Meloche et al., 2018a).

Table 1. Amino acid requirements of growing chickens for different performance and carcass parameters

Reference	Age	AA[1]	BWG	FCR[2]	BMY[3]
Han and Baker, 1994	21 to 42 d	Lysine	0.85%	0.89%	U[4]
Leclercq, 1998	20 to 40 d	Lysine	0.92%	1.01%	0.98%
Leclercq, 1998	20 to 40 d	Threonine	0.61%	0.61%	0.61%
Leclercq, 1998	20 to 40 d	Valine	0.77%	0.73%	0.73%
Dozier et al., 2000	42 to 56 d	Threonine	U	0.67%	0.62%
Chamruspollert et al., 2002	11 to 14 d	Methionine	0.54%	0.52%	U
Kidd et al., 2004a	18 to 30 d	Isoleucine	0.61%	0.64%	U
Kidd et al., 2004a	30 to 42 d	Isoleucine	0.58%	0.60%	U
Kidd et al., 2004a	42 to 56 d	Isoleucine	0.50%	U	0.57%
Corzo et al., 2007	21 to 42 d	Threonine	0.74%	0.72%	0.73%
Dozier et al., 2010	28 to 42 d	Lysine	0.99%	1.05%	1.14%
Dozier et al., 2010	28 to 42 d	Lysine	0.97%	1.01%	0.98%

[1]Amino acid
[2]Feed conversion ratio
[3]Breast meat yield
[4]Undetermined

Table 2. Digestible amino acid requirements of males and female broilers

Reference	Age	AA	Interaction	Male	Female
Kessler and Thomas, 1976	28 to 49 d	Arginine[1]	Yes	1.10%	U[2]
Hunchar and Thomas, 1976	28 to 49 d	Tryptophan[1]	Yes	0.18%	0.17%
Thomas and Bossard, 1982	0 to 21 d	Threonine[1]	Yes	0.87%	0.82%
Han and Baker, 1993	8 to 22 d	Lysine	Yes	1.26%	1.15%
Han and Baker, 1994	21 to 42 d	Lysine	Yes	0.89%	0.85%
Rosa et al., 2001a	1 to 18 d	Tryptophan	No	0.17%	
Rosa et al., 2001b	1 to 18 d	Threonine	No	0.71%	
Chamruspollert et al., 2002	11 to 14 d	Methionine	No	0.54%	0.48%
Garcia et al., 2006	7 to 21 d	Lysine	Yes	0.96%	0.94%
Garcia et al., 2006	21 to 38 d	Lysine	Yes	0.97%	0.93%
Lumpkins et al., 2007	8 to 18 d	TSAA	Yes	0.78%	0.73%
Dozier et al., 2009a	14 to 28 d	Lysine	Yes	1.10%	1.00%

[1]Total amino acid
[2]Undetermined

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CHAPTER II

EFFECTS OF DIETARY AMINO ACID REGIMENS ON LIVE PERFORMANCE AND PROCESSING CHARACTERISTICS OF COBB MV × 700 MALE AND FEMALE BROILERS

SUMMARY

The magnitude and timing of broiler responses to dietary amino acid (**AA**) density can vary between sexes and among genetic lines. Two experiments (**Exp**) were conducted to determine the responsiveness of Cobb MV × 700 broilers to changes in dietary AA density. In Exp 1, low (L), medium (M), and high (H) AA density diets were maintained across starter and grower phases in a 28 d growth performance trial (all males). In Exp 2, combinations of L, M, and H AA density diets were varied across 4 feeding phases to evaluate the effect of 6 AA feeding regimens (HHHH, HHHM, HHMM, HMMM, MMMM, and HHLL) on growth performance, carcass composition, and *Pectoralis major* myopathies of broiler reared sex-separately. Body weight gain, FI, and FCR responded positively to increased AA density during the starter and grower phases (0 to 28 d) of Exp 1. In Exp 2, responses from 0 to 28 d were diminished by the conclusion of the finisher phase (d 35), and FCR was the only measurement impacted by dietary AA density through d 46. Carcass characteristics and *Pectoralis major* myopathies were unaffected by AA density, with the exception of fat pad percentage, which decreased with increasing AA density. Male broilers had a higher incidence of severe woody breast than females. In conclusion, Cobb MV × 700 broilers may be less responsive to dietary AA density than other high-yielding broiler strains and further research to establish digestible AA:Lys ratios or dietary energy concentrations that optimize responses to increased AA density are warranted.

DESCRIPTION OF PROBLEM

The poultry industry continually develops genetic lines to meet increasing global demands for chicken meat more efficiently. Nutritional research must coincide with genetic improvements to ensure that the genetic potential of the modern broiler is being attained (Smith

and Pesti, 1998). In particular, amino acids (**AA**) are priority nutrients for breast meat yield and overall performance in high yielding broilers (Kidd et al., 2005; Corzo et al., 2010; Taschetto et al., 2012; Vieira et al., 2012), making determination of AA requirements a top priority for optimizing broiler feeding programs.

As the rate and prioritization (i.e. tissue growth versus maintenance) of broiler growth changes over time, low (L), medium (M), and high (H) AA density diets can be varied among feeding phases to accurately meet AA demands. Kidd et al. (2004) demonstrated that Ross × Ross 508 broilers fed increased AA density diets from 0 to 28 d and reduced AA density diets from 28 to 49 d had similar growth performance and carcass yield compared with those fed increased AA density diets from 0 to 49 d. Therefore, programs that incorporate higher AA density during early growth phases followed by lower AA density diets may support acceptable performance and carcass composition and reduce overall feed costs.

Research conducted on Cobb × Cobb 700 broilers is limited, and due to the variability of AA responses across broiler strains (Kidd and Tillman, 2016), nutrient profiles and requirements must be optimized for each genetic cross. Using straight-run Cobb MX × Cobb 700 broilers, Zhai et al. (2013) found that broilers fed H and M AA density diets during early and late phases, respectively, had lower FCR than those fed M AA density phases early on followed by H AA density phases. However, this work was conducted using the Cobb MX male line rather than the more recently-released Cobb MV male, and published nutrient requirement data for this Cobb MV × 700 cross are sparse. Additionally, the influence of sex on response to dietary AA density has not been evaluated for the Cobb MV × 700.

Occurrence of the breast muscle myopathies referred to as woody breast and white striping in high-yielding broiler strains are of increasing concern to the poultry industry, and

some evidence suggests that these myopathies may be associated with increased growth rate elicited by nutrient dense diets (Kuttappan et al., 2012a). Recent data by Meloche et al. (2018) indicate that changes in nutrient density may not be a practical solution for controlling the incidence of woody breast or white striping in Ross 708 broilers. However, the incidence and severity of woody breast and white striping or the degree to which these myopathies are affected by nutrient density have not been extensively studied in Cobb MV × 700 broilers. Therefore, these experiments were conducted to assess the potential effects of dietary AA density on live performance, carcass composition, and incidence of muscle myopathies of male and female Cobb MV × 700 broilers.

MATERIALS AND METHODS

The University of Arkansas Institutional Animal Care and Use Committee approved all experimental procedures involving live birds.

General Procedures (Experiments 1 and 2)

A total of 2,160 Cobb MV × 700 broiler chicks were obtained from a commercial hatchery where they received *in ovo* vaccinations for Marek's disease. Birds were reared in floor pens in a solid-walled, climate-controlled facility at the University of Arkansas poultry research farm. Upon arrival, broiler chicks were group weighed and placed in 0.9 × 1.2 m floor pens at 12 chicks per pen (0.08 m^2 per bird). Each pen contained a hanging feeder, a nipple drinker line, and top-dressed built up (Exp 1) or new litter (Exp 2). Feed and water were provided on an *ad libitum* basis throughout the trial. Initial temperature was set to 32.8°C at placement and decreased gradually to 21.6°C (Exp 1) and 16.7°C (Exp 2) by the conclusion of the trial. A lighting schedule of 24L:0D from d 0 to 1, 23L:1D from d 2 to 7, and 16L:8D from d 8 to 46 d

was used. Light intensities were verified at floor level. Starter diets were provided as crumbled pellets from 0 to 14 d of age, whereas the grower, finisher, and withdrawal diets were fed as pellets from 15 to 28, 29 to 36, and 37 to 46 d of age, respectively. Representative feed samples were collected after pelleting, ground through a 1 mm screen, and submitted to the Experiment Station Chemical Laboratory at the University of Missouri for analysis of CP and crude fat (Exp 1 and 2) and AA (Exp 2) (methods 990.03, 920.39, and 994.12; AOAC International, 2006). Mortality were replaced for the first 3 days, and for the remainder of the trial, mortality were collected and weighed twice daily. Feed intake (**FI**) was calculated based on bird days, and FCR was corrected to include the weight of any dead birds.

Experiment 1

A total of 432 Cobb MV × Cobb 700 male broiler chicks were weighed and randomly distributed to 36 floor pens for a 28 d trial, with 12 replicate pens of 3 dietary treatments. Broilers were fed 1 of 3 diets formulated to contain low (L), medium (M), or high (H) AA density diets maintained across starter (0 to 14 d) and grower (15 to 28 d) feeding phases. Target AA densities were based on changes in calculated digestible Lys of approximately 7%, with other AA ratios relative to digestible Lys held constant. Digestible AA ratios used to formulate experimental diets were 75, 65, 76, 67, 105, and 17 in the starter for TSAA, Thr, Val, Ile, Arg, and Trp, respectively, and changed slightly in the grower phase. Diets were formulated to be isocaloric within each phase and met or exceeded breeder recommendations. Body weights and feed consumption were recorded by pen at 0, 14, and 28 d post-hatch.

Statistics

Pen was considered the experimental unit, and treatments were assigned to pens in a randomized complete block design with pen location as the blocking factor. Each treatment was replicated with 12 pens of 12 birds. Mortality data were arcsine square root transformed prior to statistical analysis. All data were subjected to a one-way ANOVA using the MIXED procedure of SAS 9.4 (SAS Institute, 2012) to assess effects of dietary AA density, and where appropriate, means were separated using a Tukey's honest significant difference (**HSD**) test.

Experiment 2

A total of 1,728 straight run Cobb MV × Cobb 700 broiler chicks were vent-sexed by professional sexers, weighed, and randomly distributed to 144 floor pens. Broilers were provided 1 of 6 dietary regimens based on various combinations of L, M, and H AA density diets fed across 4 feeding phases. Similar to Exp 1, target AA densities were based on changes in calculated digestible Lys of approximately 7%, with other ratios of digestible AA relative to digestible Lys held constant. Amino acid ratios used for the formulation of dietary treatments were 75, 65, 76, 67, 105, and 17 in the starter for TSAA, Thr, Val, Ile, Arg, and Trp, respectively, and differed minimally in subsequent phases. Two starter diets with either H or M AA density were provided at 0 d post-hatch. At 15 d post-hatch, birds were subdivided and fed either M or H AA density grower diets resulting in 3 regimens of HH, HM, and MM AA density. At 28 d post-hatch, birds were again subdivided and provided L, M, or H AA density finisher diets to result in 5 regimens of, HHH, HHM, HMM, MMM, and HHL. At 36 d post-hatch, groups were further subdivided when L, M, and H withdrawal diets were placed resulting in a total of 6 dietary AA density regimens from 0 to 46 d post-hatch: HHHH, HHHM, HHMM, HMMM, MMMM, and HHLL. Dietary treatments were fed to male and female broilers creating

a factorial arrangement of 12 treatments (diet × sex). Diets were formulated to be isocaloric within each phase and met or exceeded breeder recommendations for all other nutrients.

Measurements

Body weights and feed consumption were measured by pen at 0, 14, 28, 36, and 46 d post-hatch and used to calculate FCR and BWG. Cumulative total Lys intake (0 to 46 d) was calculated based on the summation of the pen FI multiplied by the analyzed total Lys values of diets within each feeding phase.

Processing

After final bird weights were taken at 46 d, 4 birds per pen were randomly selected for processing and wing-tagged. The weights of selected birds were confirmed to fall within 1.5 standard deviations of the average bird weight of their pen. On d 47, tagged birds were transported to the University of Arkansas Pilot Processing Plant following an overnight feed withdrawal. Birds were individually-weighed on the back dock, electrically-stunned, and exsanguinated via a jugular vein cut. Birds were then scalded and defeathered and the neck, heads, and feet were removed at the hock from each bird. Carcass and fat pad weights were taken immediately following manual evisceration, and carcasses were then placed in ice water for a 4 hour chill. Chilled carcasses were weighed and deboned to collect weights of breasts, tenders, wings, thighs, and drumsticks. Parts weights were divided by back dock live weight to determine percentage yields of each part.

Deboned breast fillets were visually scored for white striping and scored via tactile evaluation for woody breast by a trained individual, with both measurements based on a scale of 0 to 3 in increments of 0.5 (Tijare et al., 2016; Kuttappan et al., 2012b). To simplify data

presentation, woody breast scores ranging from 0 to 0.5, 1.0 to 1.5, and 2.0 to 3.0 were categorized as normal, mild, or severe, respectively, and white striping scores of 0, 0.5 to 1.5, 2.0 to 3.0 were categorized as normal, faint, or apparent, respectively.

Statistics

Pen was considered the experimental unit, and treatments were assigned to pens in a randomized complete block design with pen location serving as the blocking factor. Twelve treatments were comprised of a factorial arrangement of 6 dietary AA regimens × sex. Each treatment was replicated with 12 pens of 12 birds for the overall experimental period (0 to 46 d). Previous periods contained an uneven number of replicates to accommodate subsequent divisions into the final 6 dietary AA regimens. Prior to statistical analysis, pens were phenotypically evaluated for off sexes and excluded if they contained more than 3 birds of the opposite sex to reduce the possibility of outliers. Percentage mortality data were arcsine square root transformed prior to statistical analysis. All data were subjected to a two-way ANOVA using the MIXED procedure of SAS 9.4 (SAS Institute, 2012) to assess effects of dietary AA regimen, sex, and their interaction, and where appropriate, means were separated using a Tukey's HSD test.

RESULTS AND DISCUSSION

Overall livability was good in both experiments with observed mortality of 3.24 and 2.95% in Exp 1 and 2, respectively. Production variables closely followed breeder specifications throughout both trials.

Experiment 1

Analyzed values for dietary nutrient content are presented in Table 1. Calculated differences in CP between the L, M, M, and H AA diets were 0.96, 1.31, 1.01, and 1.00 percentage units in the starter and grower, respectively. Analyzed differences between the L, M, M, and H were determined as 0.88, 0.86, 0.82, and 1.03 percentage units in the starter and grower, respectively. Differences in analyzed values are reflective of calculated values, indicating that targeted differenced in digestible AA density were likely achieved.

No differences ($P > 0.05$) were observed for any growth performance parameter during the starter phase of Exp 1. Feed intake was highest for birds fed the M diet ($P < 0.05$), lowest for birds fed the H diet, and intermediate for birds fed the L diet when fed through 28 d (Table 4). There were no differences ($P > 0.05$) in BWG among the treatment groups, whereas FCR was reduced ($P < 0.05$) for birds fed the H diet compared with birds fed the L or M diets. Thus, preliminary data from Experiment 1 indicated that FCR of Cobb MV × 700 broilers grown to 28 d responded to changes in AA density (7% increase or decrease relative to M AA diet), with FI being the primary driver of changes in FCR.

Experiment 2

Live Performance

Analyzed differences in CP between the H and M diets averaged 1.42 percentage units, which is in good agreement with the calculated average difference of 1.27 percentage units. Differences in digestible AA density and digestible Lys were formulated to be 0.07 percentage units between the H and M diets in each phase and differences in analyzed total Lys content were 0.11, 0.14, 0.10, and 0.07 percentage units in the starter, grower, finisher, and withdrawal,

respectively. Similarities in calculated and analyzed values indicate proper mixing and that target changes in AA density were achieved.

In Exp 2, no diet × sex interactions ($P > 0.05$) were observed for any live performance or processing measurements and males consistently had higher ($P < 0.05$) FI and BWG and lower ($P < 0.05$) FCR than females after 28 d post-hatch. No differences ($P > 0.05$) were observed for any growth performance parameter during the starter phase of Exp 2. Average BWG and FI were 0.395 and 0.494 kg, respectively, with a corresponding FCR of 1.258.

During the 0 to 28 d period, FI was influenced by AA density and was highest ($P < 0.05$) for birds fed the HM regimen, lowest for birds fed the HH regimen, and intermediate for birds fed the MM regimen (Table 5), similar to the results from Exp 1. Body weight gain of broilers in Exp 2 was reduced ($P < 0.05$) by approximately 3% for birds fed the MM regimen compared with birds fed the HH or HM regimens from 0 to 28 d. Differences in FI and BWG during this period culminated in a stepwise reduction in FCR as AA density increased. In both studies, a decrease in FCR of approximately 5 points was observed when comparing birds fed the M AA density diets with birds fed the H AA density diets (M vs. H in Exp 1 and MM vs. HH in Exp 2). Feed intake responses from both Exp indicate that broilers adjusted FI to compensate for reduced AA density which agrees with previous research in which increased AA density was reported to reduce FI (Temim et al., 2000).

In Exp 2, differences in FI and BWG due to dietary AA observed at 28 d diminished by 36 d post-hatch and were no longer significantly different among the treatment groups (data not shown). However, numerical changes in both FI and BWG led to differences in FCR among dietary treatments. Birds fed the HHH regimen had the lowest FCR (1.506), birds fed the HMM (1.538), MMM (1.539), and HHL (1.544) regimens had the highest FCR, and birds fed the HHM

(1.525) regimen had an intermediate FCR. These results are in agreement with several studies reviewed by Dozier et al. (2008) that indicate that BWG is not a sensitive response parameter when considering changes in dietary AA density beyond 5 weeks of age.

At 46 d post-hatch, no differences ($P > 0.05$) in FI or BWG due to dietary regimen were observed, but effects on FCR persisted (Table 6). Feed conversion ratio was highest for birds fed the HHLL regimen (1.669), lowest for birds fed the HHHH regimen (1.619), and intermediate for birds fed the HMMM regimen (1.644). Birds fed the HHHM, HHMM, and MMMM regimens were intermediate of those fed HHHH and HMMM regimens. Feeding all H AA density diets throughout resulted in the same overall live performance as feeding regimens based on HHHM, HHMM, and MMMM diets. Relative to birds fed the HHHH regimen, FCR was significantly increased when broilers were fed a H AA density starter and then reduced to M AA density for the remainder of the grow out or fed H AA density starter and grower diets followed by L AA density finisher and withdrawal diets. These results are similar to Zhai et al. (2013), who found that FCR of Cobb × Cobb 700 broilers was improved when fed H AA density diets in early phases and M AA density diets in latter phases (HHMM regimen). Thus, results suggest that Cobb 700 broilers perform optimally when provided high AA density diets from 0 to 28 d.

Analyzed total Lys intake serves as an indicator of digestible Lys intake. Overall (0 to 46 d) total Lys intake was highest for birds fed the HHHH regimen and lowest for birds fed the MMMM regimen, with a difference of 5.5 g of Lys. Total Lys intake appears to have had the greatest effect on FCR. In general, FCR was reduced as total Lys intake increased, with reductions in FCR were more pronounced when total Lys intake exceeded 63 g.

Although trends in FCR were observed as total Lys intake increased, the importance of the timing in which Lys and AA are consumed was evident when comparing HMMM and HHLL

regimens. The difference in total Lys intake of birds fed these two regimens was less than 1 gram (0.8 g) and not significantly different, whereas FCR of birds fed the HHLL diet was significantly increased by 2.5 points compared with those fed the HMMM diet. The HHLL regimen was implemented to evaluate the effect of reducing AA density in latter phases when feed consumption is the greatest as a potential diet cost reduction strategy. Previous data have shown that Ross × Ross 508 broilers fed a HHLL regimen achieved similar BW and FCR as birds fed H AA density diets throughout all phases (Kidd et al., 2004). Our results indicate that the Cobb MV × 700 did not respond similarly, despite the fact that AA density was only reduced by 14% in our study compared with the greater 24% reduction in the study by Kidd et al. (2004). Previous research has indicated that an adaptation period of 7 to 10 days is required to overcome the effects of feed change and to normalize FI (Cherry et al., 1983; Leeson et al., 1996), and abrupt shifts in dietary nutrient or ingredient composition can decrease FI. This necessary adaptation time may occur during a critical time in the Cobb MV × 700 broiler's growth curve when maintaining AA intake is of the utmost importance. Furthermore, lipogenesis has shown to be influenced by the CP of diets, with a transition from H to L CP increasing lipogenesis and reported effects persisting through 14 d after the transition (Rosebrough and Steele, 1990). With conditions causing increased lipogenesis, ingested feed would be used less efficiency, leading to a higher FCR.

Processing Characteristics

There were no interactive effects ($P > 0.05$) between AA density and sex on processing measurements in Exp 2, which agrees with previous literature (Kidd et al., 2004; Corzo et al., 2005), although interactions between AA density and sex have been reported for tender weights and tender and wing yields (Kidd et al., 2005). Males had higher ($P < 0.05$) total breast meat

weights, but females had higher ($P < 0.05$) total breast yield. Abdominal fat pads were heavier ($P < 0.05$) in females than in males. Differences between males and females followed responses observed in previous research using high-yielding broiler lines (Corzo et al., 2004, 2005, Kidd et al., 2004, 2005; Taschetto et al., 2012).

Dietary AA regimen did not influence any processing characteristic for broilers in Exp 2, with the exception of fat pad percentage. Percentage fat pad was highest for birds fed the HHLL regimen, lowest for birds fed the HHHH regimen, and intermediate for birds fed all other dietary regimens. Thus, abdominal fat accumulation trends followed closely those observed for FCR, with both measurements indicating that lower AA intake decreased the efficiency by which broiler converted feed to lean protein gain.

The overall incidence of severe woody breast and white striping were 6.6 and 11.81%, respectively. Males had a higher ($P < 0.05$) incidence of mild and severe woody breast than females, whereas females had a higher ($P < 0.05$) incidence of normal woody breast scores, which is in agreement with previous findings (Trocino et al., 2015). The incidence of white striping was unaffected ($P > 0.05$) by sex. Dietary AA regimen had no effect ($P > 0.05$) on the incidence or severity of woody breast or white striping. These myopathies have been previously associated with higher BWG (Kuttappan et al., 2012a), and because increased AA densities used in this study did not increase BWG, the lack of influence on breast muscle myopathies is not unreasonable. Recent data by Meloche et al. (2018) indicates that the incidence of woody breast and white striping can be reduced through a 10% reduction in nutrient density during a 49 d growout. Specifically, Meloche et al. (2018) reported that a 4.2% reduction in total Lys intake reduced the occurrence of severe woody breast. In our study, there was a reduction of 8.4% in total Lys intake between birds fed the HHHH and MMMM regimens, although no corresponding

reduction in severe woody breast was observed. Thus, although our reduction in AA density was smaller (7%), total Lys intake was reduced by twice as much, with no effect on meat quality. Another contributing factor to the effects observed by Meloche et al. (2018) was reduced energy density, as their experimental treatments involved reductions in both AA and energy density, indicating that dietary energy may influence the impact of AA density on the development of woody breast. Similarly, Meloche et al. (2018) utilized Yield Plus × Ross 708 broilers and observed an overall incidence of 32.7% severe woody breast, far exceeding the values reported in the current study for Cobb MV × 700 broilers.

Responses of Cobb MV × 700 broilers to changes in dietary AA density were minimal for both live performance and processing. Previous research on dietary lysine requirements of broiler has indicated that performance responses will occur until the requirements are met for individual variables typically in the order of BWG, breast meat yield, FCR, and fat pad percentage (Leclercq, 1998). In Exp 2, AA density influenced both FCR and fat pad percentage 0 to 46 d with no effects on any other measurements. Therefore, it is possible that AA requirements for BWG and breast meat yield were satisfied by the lowest level of AA density used in this study, or that the balance of AA (i.e. digestible AA:Lys ratios) need to be further optimized for Cobb MV × 700 broilers. It is also possible that another dietary component, such as metabolizable energy content, limited responses of broilers to AA density. Dietary energy was not increased in concert with AA density in the current experiment, and therefore, the AA:energy ratio varied slightly among treatment groups. Thus, further work is needed to determine if dietary energy is a limiting factor to AA responses in Cobb MV × 700 broilers. Similarly, a lack of interactive effects between sex and AA density did not indicate an impact of sex on AA needs for the age of bird or within the range of AA density evaluated in this study.

The incidence of white striping reported in broilers averaging 3.2 kg from Exp 2 was high, with an average incidence of 98.8% (i.e. faint plus apparent). A study by Lorenzi et al. (2014) found an average incidence of white striping of 43.1% in medium (2.2 to 3.0 kg) and heavy (3.0 to 4.2 kg) commercially-reared broilers. Although this percentage increased to 60.3% when considering only heavy male broilers (3.8 to 4.2 kg), it was still far below that observed in the current Exp. As no published data on the incidence of white striping for the Cobb MV × 700 is currently available, the cause of the high incidence compared to published data is unknown, as imposed dietary treatments did not influence white striping.

CONCLUSIONS AND APPLICATIONS

1. Based on live performance data, feeding high AA density diets in the starter and grower phases is beneficial for lowering the FCR of broilers when AA density is maintained or followed by slight reductions in the finisher and withdrawal periods.
2. Diminishing effects of AA on live performance indicate that the Cobb MV × 700 may not be as sensitive to AA density in latter phases as reported for other high yielding broiler strains. Thus, further research addressing feeding periods beyond 35 d of age is needed to maximize benefits of increasing dietary AA density during earlier feeding phases.
3. A lack of interactive effects between diet and sex on performance and carcass characteristics indicate that sex-specific formulations for AA density may not be necessary when fed at the ranges used in this study.
4. Total Lys intake did not appear to have an effect on breast meat yield or the incidence of woody breast or white striping.

Table 1. Composition of low (L), medium (M), and high (H) amino acid starter and grower diets fed in Experiment 1

	0 to 14 d			15 to 28 d		
Item, % as-fed	L	M	H	L	M	H
Corn	61.94	59.16	54.83	66.14	62.93	59.73
Soybean meal	24.32	26.85	30.43	20.03	22.74	25.44
DDGS[1]	6.00	6.00	6.00	6.00	6.00	6.00
Animal protein blend[2]	4.00	4.00	4.00	4.00	4.00	4.00
Poultry fat	1.02	1.39	2.15	1.42	1.92	2.43
Calcium carbonate	0.81	0.78	0.74	0.80	0.77	0.75
Dicalcium phosphate	0.58	0.54	0.52	0.49	0.47	0.45
Sodium chloride	0.40	0.31	0.31	0.31	0.31	0.31
MHA calcium[3]	0.27	0.30	0.35	0.21	0.25	0.29
L-Lysine-HCl	0.24	0.24	0.24	0.23	0.23	0.24
Choline chloride, 60 %	0.13	0.11	0.10	0.11	0.09	0.08
L-Threonine	0.08	0.09	0.11	0.06	0.08	0.09
Mineral premix[4]	0.08	0.08	0.08	0.06	0.06	0.06
Sodium bicarbonate	0.05	0.05	0.05	0.05	0.05	0.05
Coccidiostat[5]	0.04	0.04	0.04	0.04	0.04	0.04
Vitamin premix[6]	0.03	0.03	0.03	0.02	0.02	0.02
Enzyme blend[7]	0.03	0.03	0.03	0.03	0.03	0.03
Calculated composition, % unless noted otherwise						
AME, kcal/kg	3,053	3,053	3,053	3,120	3,120	3,120
CP	20.37	21.33	22.64	18.70	19.71	20.71
Ca	0.98	0.97	0.97	0.92	0.92	0.92
Available P	0.46	0.46	0.46	0.44	0.44	0.44
Digestible Lys	1.11	1.18	1.27	1.00	1.07	1.14
Digestible TSAA	0.83	0.88	0.95	0.75	0.80	0.86
Digestible Thr	0.72	0.77	0.82	0.65	0.70	0.74
Digestible Val	0.87	0.91	0.97	0.80	0.84	0.88
Digestible Ile	0.75	0.79	0.85	0.68	0.72	0.77
Digestible Arg	1.17	1.24	1.34	1.05	1.12	1.20
Digestible Trp	0.19	0.21	0.22	0.17	0.18	0.20
Analyzed composition, %						
CP	20.79	21.67	22.53	18.90	19.72	20.75
Crude fat	3.26	3.58	4.39	3.73	4.16	4.50

[1]Dried distillers grains with solubles

[2]Pro-Plus (H. J. Baker & Brothers. Inc., Little Rock, AR)

[3]Methionine hydroxy analogue calcium (Novus International, Saint Charles, MO)

[4]The mineral premix contained (per kg of diet) when added at 0.06%: manganese, 150 mg; zinc, 90 mg; selenium, 0.3 mg; copper, 4.3 mg; iodine, 2.9 mg.

[5]Provided 60 g of salinomycin Na per 907.2 kg of diet to prevent coccidiosis

[6]The vitamin premix contained (per kg of diet) when added at 0.02%: vitamin A, 6173 IU; vitamin D_3, 4409 IU; vitamin E, 55 IU; vitamin B_{12}, 0.01 mg; menadione, 1.2 mg; riboflavin, 5.3 mg; D-pantothenie acid, 7.9; thiamine, 1.2 mg; niacin, 30.9; pyridoxine, 2.2 mg; folic acid, 0.7 mg; biotin, 0.07 mg.

[7]The enzyme premix contained (per kg of diet): amylase, 162 U; phytase, 750 FTU; protease, 3,240 U; and xylanase, 1,620 U (Dupont, St. Louis, MO)

Table 2. Composition of medium (M) and high (H) amino acid starter and grower diets fed in Experiment 2

	0 to 14 d		15 to 28 d	
Item, % as-fed	M	H	M	H
Corn	62.99	58.79	67.01	63.21
Soybean meal	29.37	32.96	25.11	28.35
Animal protein blend[1]	4.00	4.00	4.00	4.00
Poultry fat	1.00	1.67	1.43	2.03
Calcium carbonate	0.69	0.66	0.69	0.66
Dicalcium phosphate	0.65	0.62	0.57	0.54
Sodium chloride	0.34	0.34	0.34	0.34
MHA calcium[2]	0.33	0.36	0.28	0.31
L-Lysine-HCl	0.18	0.17	0.18	0.16
Choline chloride, 60%	0.13	0.11	0.11	0.10
L-Threonine	0.10	0.11	0.09	0.09
Mineral premix[3]	0.08	0.08	0.06	0.06
Sodium bicarbonate	0.05	0.05	0.05	0.05
Coccidiostat[4]	0.04	0.04	0.04	0.04
Vitamin premix[5]	0.03	0.03	0.02	0.02
Enzyme blend[6]	0.03	0.03	0.03	0.03
Calculated composition, % unless noted otherwise				
AME, kcal/kg	3,053	3,052	3,120	3,120
CP	20.64	21.99	18.94	20.16
Ca	0.97	0.97	0.92	0.92
Available P	0.46	0.46	0.44	0.44
Digestible Lys	1.18	1.26	1.07	1.14
Digestible TSAA	0.88	0.94	0.80	0.86
Digestible Thr	0.77	0.82	0.70	0.74
Digestible Val	0.90	0.96	0.82	0.88
Digestible Ile	0.79	0.85	0.72	0.77
Digestible Arg	1.27	1.37	1.15	1.24
Digestible Trp	0.21	0.23	0.19	0.20
Analyzed composition[7], %				
CP	20.91	22.36	19.73	21.07
Crude fat	3.15	3.88	3.57	4.58
Total Lys	1.30	1.41	1.19	1.33
Total TSAA	0.79	0.79	0.75	0.78
Total Thr	0.88	0.95	0.81	0.89
Total Val	1.00	1.10	0.96	1.03
Total Ile	0.90	0.99	0.85	0.92

[1]Pro-Plus (H. J. Baker & Brothers. Inc., Little Rock, AR)

[2]Methionine hydroxy analogue calcium (Novus International, Saint Charles, MO)

[3]The mineral premix contained (per kg of diet) when added at 0.06%: manganese, 150 mg; zinc, 90 mg; selenium, 0.3 mg; copper, 4.3 mg; iodine, 2.9 mg.

[4]Provided 60 g of salinomycin Na per 907.2 kg of diet to prevent coccidiosis

[5]The vitamin premix contained (per kg of diet) when added at 0.02%: vitamin A, 6173 IU; vitamin D_3, 4409 IU; vitamin E, 55 IU; vitamin B_{12}, 0.01 mg; menadione, 1.2 mg; riboflavin, 5.3 mg; D-pantothenie acid, 7.9; thiamine, 1.2 mg; niacin, 30.9; pyridoxine, 2.2 mg; folic acid, 0.7 mg; biotin, 0.07 mg.

[6]The enzyme premix contained (per kg of diet): amylase, 162 U; phytase, 750 FTU; protease, 3,240 U; and xylanase, 1,620 U (Dupont, St. Louis, MO)

[7]Total TSAA does not include the portion of Met supplied as methionine hydroxy analogue calcium

Table 3. Composition of low (L), medium (M), and high (H) amino acid finisher and withdrawal diets fed in Experiment 2

	29 to 36 d			37 to 46 d		
Ingredient, % as-fed	L	M	H	L	M	H
Corn	73.72	70.34	66.49	76.39	72.82	68.76
Soybean meal	19.58	22.44	25.72	17.17	20.18	23.57
Animal protein blend[1]	4.00	4.00	4.00	4.00	4.00	4.00
Poultry fat	1.00	1.54	2.15	1.01	1.59	2.25
Calcium carbonate	0.54	0.51	0.48	0.53	0.50	0.48
Dicalcium phosphate	0.11	0.08	0.06	0.02	0.00	0.00
Sodium chloride	0.39	0.39	0.39	0.39	0.39	0.39
MHA calcium[2]	0.21	0.25	0.28	0.18	0.21	0.25
L-Lysine-HCl	0.18	0.17	0.16	0.17	0.17	0.15
Choline chloride, 60%	0.07	0.06	0.04	0.00	0.00	0.00
L-Threonine	0.08	0.09	0.10	0.07	0.08	0.09
Mineral premix[3]	0.04	0.04	0.04	0.03	0.03	0.03
Coccidiostat[4]	0.05	0.05	0.05	0.00	0.00	0.00
Vitamin premix[5]	0.01	0.01	0.01	0.01	0.01	0.01
Enzyme blend[6]	0.03	0.03	0.03	0.03	0.03	0.03
Calculated composition, % unless noted otherwise						
AME, kcal/kg	3,176	3,176	3,176	3,208	3,208	3,208
CP	16.85	17.94	19.18	15.92	17.06	18.32
Ca	0.74	0.74	0.74	0.70	0.70	0.71
Available P	0.35	0.35	0.35	0.33	0.33	0.34
Digestible Lys	0.93	1.00	1.07	0.87	0.94	1.01
Digestible TSAA	0.71	0.76	0.82	0.66	0.72	0.77
Digestible Thr	0.62	0.67	0.72	0.58	0.63	0.68
Digestible Val	0.73	0.78	0.84	0.69	0.74	0.80
Digestible Ile	0.62	0.67	0.73	0.58	0.63	0.69
Digestible Arg	1.00	1.07	1.17	0.93	1.01	1.11
Digestible Trp	0.16	0.17	0.19	0.15	0.16	0.18
Analyzed composition[7], %						
CP	17.33	18.56	20.20	16.73	17.77	19.02
Crude fat	3.18	3.59	3.99	3.50	3.89	4.52
Total Lys	1.11	1.16	1.26	1.07	1.12	1.19
Total TSAA	0.66	0.68	0.76	0.69	0.69	0.71
Total Thr	0.74	0.79	0.86	0.71	0.75	0.81
Total Val	0.84	0.90	0.99	0.81	0.85	0.93
Total Ile	0.73	0.79	0.88	0.69	0.73	0.80

[1]Pro-Plus (H. J. Baker & Brothers. Inc., Little Rock, AR)

[2]Methionine Hydroxy Analogue Calcium (Novus International, Saint Charles, MO)

[3]The mineral premix contained (per kg of diet) when added at 0.03%: manganese, 60 mg; zinc, 36 mg; selenium, 0.1 mg; copper, 1.7 mg; iodine, 1.2 mg.

[4]Provided 60 g of salinomycin Na per 907.2 kg of diet to prevent coccidiosis

[5]The vitamin premix contained (per kg of diet) when added at 0.0125%: vitamin A, 3858 IU; vitamin D_3, 2756 IU; vitamin E, 28 IU; vitamin B_{12}, 0.01 mg; menadione, 0.8 mg; riboflavin, 3.3 mg; D-pantothenie acid, 5.0; thiamine, 0.8 mg; niacin, 19.3 mg; pyridoxine, 1.4 mg; folic acid, 0.4 mg; biotin, 0.04 mg.

[6]The enzyme premix contained (per kg of diet): amylase, 162 U; phytase, 750 FTU; protease, 3,240 U; and xylanase, 1,620 U (Dupont, St. Louis, MO)

[7]Total TSAA does not include the portion of Met supplied as methionine hydroxy analogue calcium

Table 4. Live performance of male (MV × 700) Cobb broilers fed low (L), medium (M), or high (H) amino acid density diets from 0 to 28 days post-hatch in Experiment 1

	0 to 14 d				0 to 28 d			
Item[1]	14 d BW, kg	BWG, kg	FI, kg	FCR	28 d BW, kg	BWG, kg	FI, kg	FCR
L	0.384	0.343	0.517	1.528	1.420	1.379	2.161[ab]	1.589[a]
M	0.396	0.354	0.514	1.475	1.438	1.396	2.166[a]	1.560[a]
H	0.386	0.344	0.510	1.503	1.459	1.417	2.104[b]	1.510[b]
SEM	0.0072	0.0072	0.0047	0.0305	0.0138	0.0132	0.0174	0.0111
P-values	0.446	0.471	0.662	0.472	0.146	0.154	0.029	<0.001

[a-b] Means within column without a common superscript were determined to be significantly different ($P < 0.05$) by a Tukey's multiple comparison test.

[1]Mean values of 12 pens of 12 birds for each diet

Table 5. Cumulative (0 to 28 d post-hatch) live performance of Cobb (MV × 700) broilers fed varying regimens of dietary amino acid densities across the starter (0 to 14 d) and grower (14 to 28 d) phases in Experiment 2

Treatment		28 d BW, kg	BWG, kg	FI, kg	FCR
Main effect of diet[1]					
HH	(n = 94)[2]	1.518[a]	1.476[a]	2.083[b]	1.423[c]
HM	(n = 24)	1.521[a]	1.479[a]	2.128[a]	1.448[b]
MM	(n = 24)	1.478[b]	1.435[b]	2.105[ab]	1.479[a]
SEM		0.0111	0.0113	0.0163	0.0079
Main effect of sex					
Male	(n = 72)	1.587[a]	1.544[a]	2.179[a]	1.423[b]
Female	(n = 70)	1.425[b]	1.383[b]	2.032[b]	1.477[a]
SEM		0.0080	0.0079	0.0117	0.0056
P-values					
Diet		0.005	0.004	0.036	<0.001
Sex		<0.001	<0.001	<0.001	<0.001
Diet × sex		0.997	0.997	0.682	0.282

[a-b] Means within column without a common superscript were determined to be significantly different ($P < 0.05$) by a Tukey's multiple comparison test.

[1]Dietary treatment consisted of high (H) or medium (M) amino acid density starter fed 0 to 14 d of age followed by H or M amino acid density grower fed 15 to 28 d.

[2]Due to the breakout nature of the experiment, the number of replications were not equal due to following regimens containing H starter and grower phases, whereas the HM and MM regimens were only used once

Table 6. Cumulative (0 to 46 d post-hatch) live performance of Cobb (MV × 700) broilers fed varying dietary regimens of amino acid densities across the starter (0 to 14 d), grower (15 to 28 d), finisher (29 to 36 d), and withdrawal (37 to 46 d) phases in Experiment 2

		0 to 46 d					
Treatment		46 d BW, kg	BWG, kg	FI, kg	FCR	Total Lys intake, g	Mortality, %
Main effect of diet							
HHHH	(n = 24)	3.215	3.173	5.116	1.619[c]	65.1[a]	1.74
HHHM	(n = 22)	3.245	3.203	5.163	1.625[bc]	64.7[ab]	3.13
HHMM	(n = 24)	3.223	3.180	5.155	1.640[bc]	63.0[bc]	3.47
HMMM	(n = 24)	3.211	3.169	5.161	1.644[b]	60.9[de]	3.82
MMMM	(n = 24)	3.166	3.123	5.094	1.641[bc]	59.6[e]	2.78
HHLL	(n = 24)	3.171	3.129	5.180	1.669[a]	61.7[cd]	2.78
SEM		0.0252	0.0251	0.0385	0.0060	0.46	1.058
Main effect of sex							
Male	(n = 72)	3.442[a]	3.399[a]	5.413[a]	1.604[a]	65.63[a]	3.59
Female	(n = 70)	2.969[b]	2.937[b]	4.876[b]	1.675[b]	59.34[b]	2.31
SEM		0.0141	0.0141	0.0216	0.0033	0.2641	0.611
P-values							
Diet		0.169	0.166	0.556	< 0.001	< 0.001	0.787
Sex		< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.155
Diet × sex		0.102	0.103	0.592	0.414	0.839	0.419

[a-e] Means within column without a common superscript were determined to be significantly different ($P < 0.05$) by a Tukey's multiple comparison test.

[1]Dietary treatment consisted of high (H) or medium (M) amino acid density starter fed 0 to 14 d of age, followed by H or M amino acid density grower fed 15 to 28 d of age, followed by H, M, or low (L) amino acid density finisher phase fed 29 to 36 d of age, followed by H, M, or L amino acid density withdrawal phases fed 36 to 46 d of age.

Table 7. Carcass characteristics of Cobb (MV × 700) broilers fed varying AA density regimens 0 to 46 d and processed at 47 d post-hatch in Experiment 2

	Hot Carcass		Hot Fat Pad		Chilled Carcass	
Treatment	Weight, kg	Yield[1], %	Weight, kg	Yield, %	Weight, kg	Yield, %
Main effect of diet[2]						
HHHH (n = 24)	2.427	76.13	0.053	1.67[b]	2.467	77.47
HHHM (n = 22)	2.428	75.84	0.055	1.73[ab]	2.476	77.36
HHMM (n = 24)	2.392	75.79	0.057	1.82[ab]	2.436	77.22
HMMM (n = 24)	2.413	76.00	0.056	1.78[ab]	2.458	77.42
MMMM (n = 24)	2.397	75.80	0.058	1.83[ab]	2.440	77.16
HHLL (n = 24)	2.366	75.50	0.059	1.88[a]	2.412	76.96
SEM	0.0209	0.166	0.0017	0.049	0.0207	0.159
Main effect of sex						
Male (n = 72)	2.626[a]	75.92	0.054[b]	1.56[b]	2.670[a]	77.18
Female (n = 70)	2.181[b]	75.77	0.058[a]	2.01[a]	2.227[b]	77.34
SEM	0.0121	0.096	0.0009	0.028	0.0120	0.092
P-values						
Diet	0.266	0.152	0.140	0.032	0.256	0.221
Sex	< 0.001	0.290	0.006	< 0.001	< 0.001	0.218
Diet × sex	0.590	0.323	0.209	0.233	0.496	0.497

[a-b] Means within column without a common superscript were determined to be significantly different ($P < 0.05$) by a Tukey's multiple comparison test.

[1]Yields calculated relative to live body weight taken immediately prior to processing

[2]Dietary treatment consisted of high (H) or medium (M) amino acid density starter fed 0 to 14 d of age, followed by H or M amino acid density grower fed 15 to 28 d of age, followed by H, M, or low (L) amino acid density finisher phase fed 29 to 36 d of age, followed by H, M, or L amino acid density withdrawal phases fed 36 to 46 d of age

Table 8. Parts weights of Cobb (MV × 700) broilers fed varying AA density regimens 0 to 46 d and processed at 47 d post-hatch in Experiment 2

	Total Breast		Wings		Leg Quarters	
Treatment	Weight, kg	Yield[1], %	Weight, kg	Yield, %	Weight, kg	Yield, %
Main effect of diet[2]						
HHHH (n = 24)	0.795	24.97	0.239	7.50	0.703	22.01
HHHM (n = 22)	0.791	24.75	0.242	7.54	0.713	22.20
HHMM (n = 24)	0.783	24.81	0.238	7.53	0.701	22.18
HMMM (n = 24)	0.783	24.68	0.240	7.57	0.705	22.12
MMMM (n = 24)	0.774	24.50	0.238	7.52	0.705	22.25
HHLL (n = 24)	0.757	24.19	0.234	7.48	0.694	22.08
SEM	0.0101	0.212	0.0022	0.052	0.0069	0.111
Main effect of sex						
Male (n = 72)	0.841[a]	24.31[b]	0.262[a]	7.58[a]	0.785[a]	22.68[a]
Female (n = 70)	0.720[b]	24.99[a]	0.215[b]	7.47[b]	0.633[b]	21.60[b]
SEM	0.0058	0.123	0.0013	0.030	0.0040	0.064
P-values						
Diet	0.100	0.147	0.307	0.881	0.518	0.667
Sex	< 0.001	< 0.001	< 0.001	0.020	< 0.001	< 0.001
Diet × sex	0.912	0.655	0.723	0.328	0.094	0.260

[a-b] Means without a common superscript were determined to be significantly different ($P < 0.05$) by a Tukey's multiple comparison test.

[1]Yields relative to live body weights taken immediately prior to processing

[2]Dietary treatment consisted of high (H) or medium (M) amino acid density starter fed 0 to 14 d of age, followed by H or M amino acid density grower fed 15 to 28 d of age, followed by H, M, or low (L) amino acid density finisher phase fed 29 to 36 d of age, followed by H, M, or L amino acid density withdrawal phases fed 36 to 46 d of age

Table 9. Breast muscle myopathy distribution, shown as percent incidence of each category, of Cobb (MV × 700) broilers fed varying AA regimens 0 to 46 d and processed at 47 d post-hatch in Experiment 2

	Woody Breast[1]			White Striping[2]		
Treatment	Normal	Mild	Severe	Normal	Faint	Apparent
Main effect of diet[3]						
HHHH (n = 24)	62.50	30.21	7.29	1.04	87.50	11.46
HHHM (n = 22)	67.71	28.12	4.17	1.04	83.33	15.62
HHMM (n = 24)	70.83	18.75	10.42	2.08	86.46	11.46
HMMM (n = 24)	69.79	20.83	9.38	1.04	90.63	8.33
MMMM (n = 24)	64.58	30.21	5.21	1.04	86.46	12.50
HHLL (n = 24)	70.83	26.04	3.13	1.04	87.50	11.46
SEM	4.777	4.616	2.513	1.125	3.375	3.368
Main effect of sex						
Male (n = 72)	54.17[b]	36.11[a]	9.72[a]	0.35	87.50	12.15
Female (n = 70)	81.25[a]	15.28[b]	3.47[b]	2.08	86.46	11.46
SEM	2.758	2.665	1.451	0.650	1.949	1.945
P-values						
Diet	0.708	0.525	0.305	0.982	0.772	0.577
Sex	< 0.001	< 0.001	0.004	0.061	0.727	0.855
Diet × sex	0.783	0.639	0.194	0.982	0.778	0.528

[a-b] Means without a common superscript were determined to be significantly different ($P < 0.05$) by a Tukey's multiple comparison test.

[1]Breast fillets were considered normal, mild, or severe for woody breast if the fillet was flexible throughout, stiff in cranial region, or if stiff in the cranial and caudal regions, respectively

[2]Breast fillets were considered normal, faint, or apparent for white striping if they displayed no visible stripes, stripes less than 1 mm, or stripes larger than 1 mm, respectively

[3]Dietary treatment consisted of high (H) or medium (M) amino acid density starter fed 0 to 14 d of age, followed by H or M amino acid density grower fed 15 to 28 d of age, followed by H, M, or low (L) amino acid density finisher phase fed 29 to 36 d of age, followed by H, M, or L amino acid density withdrawal phases fed 36 to 46 d of age

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CHAPTER III

EFFECTS OF DIETARY ENERGY AND AMINO ACID DENSITY DURING FINISHER AND WITHDRAWAL PHASES ON LIVE PERFORMANCE AND CARCASS CHARACTERISTICS OF COBB MV × 700 BROILERS

SUMMARY

Meeting dietary energy needs of broilers accounts for the largest proportion of feed costs, and energy has long been identified as a key driver of feed intake (**FI**) in poultry. Dietary energy content can also influence responses of broilers to dietary amino acids (**AA**). Therefore, two experiments (**Exp**) were conducted to determine the effects of energy density in the finisher (29 to 36 d) and withdrawal (37 to 46 d) diets on Cobb MV × 700 broiler performance and processing characteristics. Treatments in Exp 1 were a factorial arrangement of sex and energy density [low (**LE**), medium (**ME**), and high energy (**HE**)]**,** whereas treatments in Exp 2 were a factorial arrangement of energy (LE, ME, and HE) and AA density [medium AA (**MAA**) or high AA (**HAA**)]. In both Exp, ME diets contained 3,175 and 3,210 kcal/kg AME_n for the finisher and withdrawal phases, and were increased and decreased by 35 kcal/kg in the LE and HE diets, respectively. In Exp 1, no energy or energy × sex interactions were observed on overall (29 to 46 d) live performance or processing measurements of broilers. In Exp 2, decreasing dietary energy increased FI of broilers during the finisher period, but changes in FI did not influence body weight gain (**BWG**) or FCR during that period or overall. Birds fed MAA diets had higher FI and BWG than birds fed the HAA diets during the overall experimental period. Processed parts weights and yields were unaffected by AA density, except for tender yields, which were higher for birds fed HAA than for those fed MAA diets. These data indicated that changes in energy density of the magnitude used in this study did not influence responses of Cobb MV × 700 broilers to varying AA levels from 29 to 46 d post-hatch.

DESCRIPTION OF PROBLEM

Feed costs account for the largest portion of broiler live production expenses and meeting dietary energy requirements constitute approximately 70% of feed costs (Skinner et al., 1992).

Energy has also long been recognized as a driver of feed intake (**FI**) and body composition of broilers (Leeson et al., 1996). As such, dietary energy level is typically a general starting point in feed formulation (NRC, 1994), and therefore, research to determine the energy density required for optimal production is paramount for broiler diet formulation.

Research addressing the energy needs of modern broilers is rather limited, and classic studies evaluating the effects of dietary energy have typically implemented large changes in energy content to establish general response trends (Summers et al., 1965; Coon et al., 1981; Leeson et al., 1996). These studies and others have demonstrated that FI is linearly related, but not always at an equivalent rate (Saleh et al., 2004), to changes in dietary energy level (Skinner et al., 1992). Furthermore, there are only a few reports addressing interactions between amino acids (**AA**) and energy needs of broilers (Waldroup et al., 1990; Dozier et al., 2006; 2007; Zhai et al., 2014). Waldroup et al. (1990) found no interactions between dietary energy and AA when feeding Cobb 500 broilers diets that contained 3,135 or 3,245 kcal of ME/kg and 85 to 110% of AA requirements for male broilers suggested by Thomas et al. (1986). Similar findings were reported by Dozier et al. (2007) using Ross × Ross 708 broilers. Conversely, Zhai et al. (2014) found that increasing either dietary energy or AA density alone did not improve FCR of Cobb × Cobb 700 broilers, whereas increasing both resulted in an improvement in FCR of approximately 6 points at 42 d. Dozier et al. (2006) found that increasing AME from 3,175 to 3,310 kcal/kg during finisher (30 to 47 d) and withdrawal (48 to 59 d) phases linearly reduced FI and FCR but breast meat yield was reduced at higher AME levels above 3,265 kcal/kg. This reduction in breast meat yield was prevented with a 4% increase in dietary CP, TSAA, and Lys content. Therefore, dietary energy concentration may be a limiting factor to AA responses in Cobb × Cobb 700 broilers.

Data from the existing literature do not support feeding different dietary energy concentrations to males and female broilers due to a lack of interactions between sex and energy density (Waldroup et al., 1990; Skinner et al., 1992), despite apparent differences in energy utilization (Waldroup et al., 1976). Sex separate rearing is currently used by some broiler producers who rear female broilers for small bird markets and males for heavy debone markets to achieve higher flock uniformity. Therefore, studies must be conducted to determine if adjustments in dietary energy are warranted when feeding males and females of new broiler crosses such as the Cobb MV × 700, for which limited published data on nutrient responses are available.

The incidence and severity of breast muscle myopathies, including woody breast and white striping, are also of increasing concern to the poultry industry when considering changes in dietary nutrient density. Woody breast and white striping have been associated with increased growth rate (Kuttappan et al., 2012a; Sihvo et al., 2014), which can be influenced by nutrient density in the diet (Saleh et al., 2004; Meloche et al., 2018). The impact of nutrient density on the development of these myopathies may be dependent on the genotype of the broilers used (Trocino et al., 2015), and to these authors' knowledge, no data have been published evaluating the breast muscle myopathy responses of Cobb MV × 700 broilers to adjustments in dietary energy and AA density. Therefore, the objectives of these experiments (**Exp**) were to determine if there were interactive effects between dietary energy content and bird sex or dietary AA density on the live performance, processing yields, and breast muscle myopathies of Cobb MV × 700 broilers.

MATERIALS AND METHODS

The University of Arkansas Institutional Animal Care and Use Committee approved all experimental procedures involving live birds.

General Procedures

All broilers were reared in floor pens in a solid-walled, climate-controlled facility at the University of Arkansas poultry research farm. Upon arrival, broiler chicks were group weighed and placed in 0.9 × 1.2 m floor pens at 12 chicks per pen (0.08 m^2 per bird). Each pen contained a hanging feeder, a nipple drinker line, and fresh pine shaving. Feed and water were provided on an *ad libitum* basis throughout the trial. Initial temperature was set to 32.8°C at placement and decreased gradually to 16.7°C by the conclusion of the trial. A lighting schedule of 24L:0D from d 0 to 1, 23L:1D from 2 to 7, and 16L:8D 8 to 46 d was used, and target light intensities were verified at floor level via an Extech light meter. Starter diets were provided as crumbles from 0 to 14 d of age, whereas the grower, finisher, and withdrawal diets were fed as pellets from 15 to 28, 29 to 36, and 37 to 46 d of age, respectively. Representative feed samples were collected after pelleting, ground through a 1 mm screen, and submitted to the Experiment Station Chemical Laboratory at the University of Missouri for analysis of CP, EE, and AA (methods 990.03, 920.39, and 994.12; AOAC International, 2006). Mortality were replaced for the first 3 days, and for the remainder of the trial, mortality were collected and weighed twice daily. Feed intake (**FI**) was calculated based on bird days, and FCR was corrected to include the weight of any dead birds. Body weights and feed consumption were taken by pen at 0, 14, 28, 36, and 46 d post-hatch to calculate FCR and body weight gain (BWG).

Processing

After final bird weights were taken at 46 d, 4 birds per pen were randomly selected for processing. On d 47, tagged birds were transported to the University of Arkansas Pilot Processing Plant following an overnight (10 hour) feed withdrawal. Birds were individually-weighed at the plant, electrically-stunned, and exsanguinated via a jugular vein cut. Birds were then scalded and defeathered and the neck, head, and feet were removed at the hock from each bird. Hot carcass and fat pad weights were taken immediately following manual evisceration before carcasses were placed in ice water for a 4 hour chill. Chilled carcasses were weighed and deboned to collect weights of the *Pectoralis major*, *P. minor*, wings, and leg quarters. Part weights were divided by individual back dock live weights for each bird to determine percentage yields for each part.

Deboned *P. major* fillets were visually scored for white striping and scored via tactile evaluation for woody breast by a trained individual, with both measurements based on a scale of 0 to 3 in increments of 0.5 (Tijare et al., 2016; Kuttappan et al., 2012b). To simplify data presentation, woody breast scores ranging from 0 to 0.5, 1.0 to 1.5, and 2.0 to 3.0 were categorized as normal, mild, or severe, respectively, and white striping scores of 0, 0.5 to 1.5, 2.0 to 3.0 were categorized as normal, faint, or apparent, respectively.

Experiment 1

A total of 864 (432 male and 432 female) Cobb MV × Cobb 700 vent sexed broiler chicks were obtained from a commercial hatchery and randomly distributed to 72 floor pens. Chicks were vaccinated *in ovo* at the hatchery for Marek's disease. Broilers were reared on a common starter (1.27% digestible Lys, 3,053 kcal/kg) and grower diet (1.14% digestible Lys,

3,120 kcal/kg) and then fed 1 of 3 experimental diets formulated to contain low (**LE**), medium (**ME**), or high (**HE**) energy density in the finisher and withdrawal phases (Tables 1 and 2), resulting in a factorial arrangement of 6 treatments (energy density × sex). Targeted differences in metabolizable energy for the LE, ME, and HE were 3,140, 3,175, and 3,210 kcal/kg in the finisher and 3,175, 3,210, and 3,245 kcal/kg in the withdrawal phase, respectively. The 3 dietary treatments (LE, ME, and HE) were then paired with sex, resulting in a factorial arrangement of 6 treatments.

Experiment 2

A total of 864 male Cobb MV × Cobb 700 broiler chicks were obtained from a commercial hatchery and were then randomly distributed to 72 floor pens. Similar to Exp 1, broilers were fed a common starter (1.27% digestible Lys, 3,053 kcal/kg) and grower diet (1.14% digestible Lys, 3,120 kcal/kg) and were provided experimental diets at d 29 (Tables 1 and 2). Broilers were fed 1 of 6 dietary treatments that consisted of a factorial arrangement of dietary energy (LE, ME, and HE) and AA density (MAA and HAA). Energy concentrations of the LE, ME, and HE diets were formulated to be the same as used in Exp 1, which were 3,140, 3,175, and 3,210 kcal/kg in the finisher phase and 3,175, 3,210 and 3,245 kcal/kg in the withdrawal phase, respectively. Medium (MAA) and high AA (HAA) diets were formulated to contain digestible Lys concentrations of 1.00 and 1.07% in the finisher and 0.94 and 1.01% in the withdrawal diets, respectively. All other digestible essential AA were maintained as a ratio of digestible Lys with ratios of 76, 67, 78, 68, 108, and 18 for TSAA, Thr, Val, Ile, Arg, and Trp, respectively, in the finisher phase and varied minimally in the withdrawal phase. To confirm that target differences in dietary AA content were achieved, the ME MAA and ME HAA diets from

both experimental phases were analyzed for AA (method 994.12; AOAC International, 2006) since they represented the average energy content used at both AA densities.

Statistics

Pen was considered the experimental unit, and treatments were assigned to pens in a randomized complete block design with pen location serving as the blocking factor. Both Exp were comprised of a 3 × 2 factorial arrangement, with each treatment represented by 12 replicate pens of 12 birds. Percentage mortality data were arcsine square root transformed prior to statistical analysis. Meat quality data were analyzed based on percent incidence of each of the 3 aforementioned levels of both myopathies on a pen basis. Values were arcsine square root transformed prior to analysis to obtain *P*-values. All data were subjected to a two-way ANOVA using the MIXED procedure of SAS 9.4 (SAS Institute, 2012) to assess effects of sex or AA density, dietary energy density, and their interactions, and where appropriate, means were separated using Tukey's honest significant difference (**HSD**) test.

RESULTS AND DISCUSSION

Calculated and analyzed values for experimental diets fed in Exp 1 and 2 can be found in Tables 1 and 2. Only the ME diets in the finisher and withdrawal diets were submitted for AA analysis to confirm proper mixing and estimate changes in AA between the HAA and MAA treatments. Differences in analyzed CP between the MAA and HAA diets were 0.66 and 1.10 percentage points for the finisher and withdrawal feeds, respectively. Changes in dietary energy concentration were primarily driven by changes in poultry fat inclusion, and analysis of crude fat concentration confirms that target differences in dietary AME_n were likely achieved.

Effects of Sex in Exp 1

No interactions ($P > 0.05$) between sex and energy concentration were observed for any live performance or processing measurement. As expected, males had higher ($P < 0.05$) BWG and FI and lower ($P < 0.05$) FCR than females in Exp 1, similar to results shown in previous studies (Jackson et al., 1982; Waldroup et al., 1990). Female broilers in Exp 1 had higher ($P < 0.05$) total breast yields and fat pad weights and yields than male broilers, whereas males had higher leg quarter yields and weights for all processing measurements (Tables 5 and 6). Males had a significantly higher (2.5 fold) incidence of severe woody breast than females, which is in agreement with the findings of Trocino et al. (2015). However, this difference was not enough to influence ($P > 0.05$) the proportion of normal and mild categories of woody breast between the sexes. White striping was not affected ($P > 0.05$) by sex, which is in agreement with previous reports by Trocino et al. (2015) and Kuttappan et al. (2012a).

Effects of Dietary Energy in Exp 1 and 2

Dietary energy content had no effect on live performance of male or female broilers during the finisher phase or overall experimental period in Exp 1 (Tables 3 and 4). Feed intake was reduced with increasing dietary energy level in the withdrawal phase ($P = 0.044$), but the means were not separated when subjected to a Tukey's HSD multiple comparison test. Conversely, increasing dietary energy density in Exp 2 decreased FI of broilers during the finisher phase, which was lowest FI for birds fed the HE diets (1.396 kg), highest for birds fed the LE diets (1.439 kg), and intermediate for birds fed the ME diets (1.416 kg), but FI was not influenced during the withdrawal period of Exp 2 (Table 8). Dietary energy did not influence FI during the overall experimental period in either Exp (Table 9).

The moderate responses in broiler FI to dietary energy intake is in agreement with work by Plumstead et al. (2007) who observed no responses in overall FI when dietary AME was increased from 3,000 to 3,200 kcal/kg during a 0 to 21 d growout period. Conversely, Leeson et al. (1996) observed a dramatic decrease in overall FI (0 to 49 d) of 1.114 kg as ME levels increased from 2,700 to 3,300 kcal/kg. Plumstead et al. (2007) postulated that the divergence of their results from those of Leeson et al. (1996) were due to the levels of oil used in the studies. Although the differences between energy treatments in added poultry fat in our experiment (average of 0.73 percentage points) were larger than those used by Plumstead et al. (2007) (average of 0.21 percentage points), they were far smaller than those of Leeson et al. (1996), who used 2.5 percentage point increases to achieve differences in dietary AME. One of the extra-nutritional effects of supplemental dietary fat is decreased rate of passage, potentially increasing nutrient utilization and feed intake (Mateos et al., 1982). Results from our study support the hypothesis of Plumstead et al. (2007) that the responses to dietary energy observed by Leeson et al. (1996) may have been due to added fat and not a response to energy density *per se*.

No effects ($P > 0.05$) of dietary energy density were observed on any processing characteristic in Exp 1 or 2 (Table 5 and 10). Similar carcass composition of broilers fed diets containing varying dietary energy concentrations was unexpected, particularly when comparing birds fed the LE diets with birds fed the HE diets (70 kcal/kg difference). When considering the metabolizable energy:CP ratio, differences in this study averaged about 2 kcals between the LE/HE and ME diets and about 4 kcals between the LE and HE diets in both the finisher and withdrawal phases. Existing literature has shown that carcass characteristics such as abdominal fat and breast meat yield are unaffected by changes in energy density when the energy:CP ratio is maintained (Kamran et al., 2008; Saleh et al., 2004). These findings suggest that observed

differences in dietary energy density might have been inadequate to cause differences in carcass composition due to the relatively constant CP:energy ratio of the diets.

The average values of normal, mild, and severe woody breast were 27.78, 31.92, and 40.31% and 30.20, 40.85, and 28.93%, in Exp 1 and 2, respectively. Dietary energy density did not influence ($P > 0.05$) the incidence or severity of woody breast in Exp 1 (Table 7), whereas in Exp 2, the incidence of mild woody breast was highest ($P < 0.05$) for birds fed ME diets, lowest for birds fed LE diets, and intermediate for birds fed HE diets (Table 12). However, the difference observed in proportion of birds with mild woody breast was not enough to influence the incidence of normal or severe woody breast in Exp 2. The lack of continuity between experiments may be attributed to the exclusive use of male broilers in Exp 2.

We observed a relatively high incidence of white striping, with approximately 76% of birds having faint white striping (striations < than 1mm wide) and 24% displaying apparent white striping (striations > than 1 mm wide) in Exp 1. However, white striping was not affected ($P > 0.05$) by dietary energy in either Exp. In a study by Kuttappan et al. (2012a), the incidence of white striping was successfully reduced when dietary energy content was lowered by 200 kcal/kg ME. In addition to lowering the incidence of white striping, these authors reported a concomitant reduction in growth rate with reduced dietary energy content. We observed no impact of dietary energy on BWG in either of the current Exp, which may explain the lack of influence of dietary energy concentration on the incidence of white striping.

Effects of Amino Acids in Exp 2

Dietary AA density had a more pronounced influence on broiler performance than energy concentration. During the finisher period, birds fed MAA and HAA diets had similar ($P > 0.05$)

BWG and FCR, but FI was lower ($P < 0.05$) for birds fed HAA diets. During the withdrawal period, a higher ($P < 0.05$) FI increased ($P < 0.05$) BWG for MAA-fed birds compared with HAA-fed birds, leading to increased ($P < 0.05$) FI and BWG for birds fed the MAA diets for the overall experimental period (Tables 8 and 9). Similar responses to FI have previously been observed for Cobb 700 broilers (Zhai et al., 2014) and indicate that these broilers adjust FI to maintain AA intake.

Although there were differences ($P < 0.05$) in final body weights due to the influence of AA level, processing characteristics were not influenced ($P > 0.05$) by dietary AA density, with the exception of *P. minor* yields (Table 10 and 11). A 0.11 percentage point increase ($P < 0.05$) in *P. minor* yield was observed for birds fed HAA diets compared with birds fed the MAA diets (Data not shown). Previous research by our lab found no differences in any processing measurement, with the exception of fat pad, when Cobb MV × 700 broilers were fed diets differing in AA density that caused a 3.76 g difference in total Lys intake from 0 to 46 d. When considering only the ME diets, the difference in 29 to 46 d total Lys intake was only 1.0 g for birds fed the MAA over those fed the HAA diets in the current experiment. Since the difference in total Lys intake was smaller than that seen in our previous study, the similarity in carcass characteristics between birds fed the MAA and HAA diets is reasonable.

Dietary AA density influenced the incidence of normal woody breast with birds fed HAA diets having a higher incidence of normal breasts than birds fed MAA diets. Although the incidence of mild and severe woody breast were statistically unaffected ($P > 0.05$) by reduced AA density, severe woody breast tended to be lower for birds fed HAA diets ($P=0.061$). No effects were observed on white striping and the high incidence seen in Exp 1 was mirrored in Exp 2. Although a difference in final BW ($P < 0.05$) between the MAA and HAA groups in Exp

2 was observed, the differences were not enough to influence carcass characteristics and likely had minimal effect on overall growth rate. The incidence of normal white striping tended (P = 0.056) to be higher in birds fed the HAA diets despite the similar growth rates.

Energy × Amino Acid Interactions

No dietary energy × AA interactions ($P > 0.05$) were observed for any broiler live performance or processing measurements. Conversely, Zhai et al. (2014) observed no influence of increasing AA density on FCR when Cobb × Cobb 700 broilers were fed a low AME diet, but 42 d FCR improved ($P < 0.05$) by approximately 6 points when broilers were fed a high AME diet. The lack of interactions between AA and energy in our study may be due to the fact that treatments were only imposed during the finisher and withdrawal periods rather than the entire grow out as done by Zhai et al. (2014), as densities of AA and energy used in both the current study and by Zhai et al. (2014) were similar. Another difference between these experiments is genetic cross (MX male line vs MV), indicating that genetic changes may have influenced responses of the Cobb 700 from those reported by Zhai et al. (2014).

It has been classically demonstrated that broilers will eat to a minimum energy requirement or adjust their FI to maintain constant energy intake (Hill and Dansky, 1950, 1954; Hill et al., 1956; Scott et al., 1982), but this idea is being challenged by more recent data that indicate that intensive genetic selection may have reduced the sensitivity of FI to energy in the modern broiler (Burkhart et al., 1983; Bokkers and Koene, 2003; Richards, 2003; Plumstead et al., 2007). Further, combined results from the two Exp reported herein appear to support the observations of Dozier et al. (2007) that the modern broiler may have a strong ability to adjust FI according to dietary AA density.

The observation that 100% of birds in both Exp displayed some degree of white striping was in agreement with a previous study with Cobb MV × 700 broilers by our laboratory. Although the total incidence were similar, the incidence of severe white striping (24.2%) was doubled compared to the aforementioned study (11.8%). Similarly, the reported incidence of severe woody breast in our previous work was low at 6.6% incidence, whereas in these studies, severe woody breast averaged 28.4% across both Exp. This increase in severe white striping and woody breast is especially difficult to explain given that broilers in the current Exp were fed diets with comparable nutrient profiles, were reared to the same age (46 d) under similar management practices, and had similar final body weights (3.442 kg for males and 2.969 for females) as those in a previous study. Thus, it is logical to suspect that factors beyond nutrition, growth rate, and age may contribute to the occurrence of these myopathies.

CONCLUSIONS AND APPLICATIONS

1. A lack of interactive effects of sex and dietary energy indicate that males and female Cobb MV × 700 broilers respond similarly to dietary energy levels used in this study from 29 to 46 d of age.
2. Responses to dietary AA density do not appear to be limited by energy content within the AME concentrations used in this study.
3. Twenty-nine to 36 and 37 to 46 d ME needs may be below 3,140 and 3,175 kcal/kg, respectively.
4. Responses of woody breast to nutritional modification appear to be inconsistent, and more research is needed to clearly establish the influence of changes in dietary energy and AA density changes on the incidence and severity of this myopathy.

Table 1. Composition of finisher diets containing various energy and amino acid densities used in Experiments 1 and 2 from 29 to 36 d post-hatch[1]

	MAA			HAA		
Item, % as-fed	LE	ME	HE	LE	ME	HE
Corn	71.48	70.61	69.74	67.44	66.57	65.70
Soybean meal	22.58	22.73	22.87	26.00	26.14	26.29
Animal protein blend[2]	4.00	4.00	4.00	4.00	4.00	4.00
Poultry fat	0.54	1.27	1.99	1.19	1.91	2.64
Calcium carbonate	0.36	0.36	0.35	0.32	0.32	0.32
Sodium chloride	0.31	0.31	0.31	0.31	0.31	0.31
MHA calcium[3]	0.29	0.29	0.29	0.32	0.32	0.32
L-Lysine-HCl	0.22	0.21	0.21	0.20	0.20	0.20
Choline chloride, 60%	0.02	0.02	0.02	0.00	0.00	0.00
L-Threonine	0.09	0.09	0.09	0.09	0.09	0.09
Mineral premix[4]	0.04	0.04	0.04	0.04	0.04	0.04
Coccidiostat[5]	0.05	0.05	0.05	0.05	0.05	0.05
Vitamin premix[6]	0.01	0.01	0.01	0.01	0.01	0.01
Enzyme blend[7]	0.03	0.03	0.03	0.03	0.03	0.03
Calculated composition, % unless noted otherwise						
AME, kcal/kg	3,140	3,175	3,210	3,140	3,175	3,210
CP	19.05	19.05	19.05	20.39	20.39	20.39
Ca	0.74	0.74	0.74	0.74	0.74	0.74
Available P	0.41	0.41	0.41	0.42	0.42	0.42
Digestible Lys	1.00	1.00	1.00	1.07	1.07	1.07
Digestible TSAA	0.76	0.76	0.76	0.81	0.81	0.81
Digestible Thr	0.67	0.67	0.67	0.72	0.72	0.72
Digestible Val	0.78	0.78	0.78	0.83	0.83	0.83
Digestible Ile	0.68	0.68	0.68	0.73	0.73	0.73
Digestible Arg	1.08	1.08	1.08	1.18	1.18	1.18
Digestible Trp	0.18	0.18	0.18	0.19	0.19	0.19
Analyzed composition[8], %						
CP	19.25	19.25	19.51	20.94	19.49	19.57
Crude fat	2.61	2.99	3.62	2.98	4.13	4.45
Total Lys		1.21			1.24	
Total TSAA[7]		0.68			0.74	
Total Thr		0.82			0.85	
Total Val		0.92			0.95	
Total Ile		0.81			0.83	

[1]Experiment 1 utilized diets containing low (LE), medium (ME), and high energy (HE) diets, whereas Experiment 2 also used LE, ME, and HE diets with either medium (MAA) or high amino acid density (HAA)

[2]Pro-Plus (H. J. Baker & Brothers. Inc., Little Rock, AR)

[3]Methionine hydroxy analogue calcium (Novus International, Saint Charles, MO)

[4]The mineral premix contained (per kg of diet): manganese, 60 mg; zinc, 36 mg; selenium, 0.1 mg; copper, 1.7 mg; iodine, 1.2 mg

[5]Provided 60 g of salinomycin per 907.2 kg of diet to prevent coccidiosis

[6]The vitamin premix contained (per kg of diet): vitamin A, 3858 IU; vitamin D_3, 2756 IU; vitamin E, 28 IU; vitamin B_{12}, 0.01 mg; menadione, 0.8 mg; riboflavin, 3.3 mg; D-pantothenie acid, 5.0; thiamine, 0.8 mg; niacin, 19.3; pyridoxine, 1.4 mg; folic acid, 0.4 mg; biotin, 0.04 mg

[7]The enzyme premix contained (per kg of diet): amylase, 162 U; phytase, 750 FTU; protease, 3,240 U; and xylanase, 1,620 U (Dupont, St. Louis, MO)

[8]Due to the number of diets used in this study, only the ME diets were sent off for amino acid analysis to ensure proper mixing. Total TSAA does not include the portion of Met supplied as methionine hydroxy analogue calcium

Table 2. Composition of withdrawal diets containing various energy and amino acid densities used in Experiment 1 and 2 from 37 to 46 d post-hatch[1]

	MAA			HAA		
Item, % as-fed	LE	ME	HE	LE	ME	HE
Corn	72.59	71.72	70.85	68.52	67.65	66.77
Soybean meal	21.65	21.79	21.94	25.11	25.26	25.40
Animal protein blend[2]	3.00	3.00	3.00	3.00	3.00	3.00
Poultry fat	1.11	1.84	2.57	1.76	2.49	3.21
Calcium carbonate	0.66	0.65	0.65	0.63	0.63	0.63
Dicalcium phosphate	0.06	0.06	0.07	0.04	0.04	0.05
Sodium chloride	0.33	0.33	0.33	0.33	0.33	0.33
MHA calcium[3]	0.26	0.26	0.26	0.29	0.29	0.29
L-Lysine-HCl	0.20	0.19	0.19	0.18	0.18	0.18
Choline chloride, 60%	0.02	0.02	0.02	0.01	0.01	0.01
L-Threonine	0.07	0.07	0.07	0.08	0.08	0.08
Mineral premix[4]	0.03	0.03	0.03	0.03	0.03	0.03
Vitamin premix[5]	0.01	0.01	0.01	0.01	0.01	0.01
Enzyme blend[6]	0.03	0.03	0.03	0.03	0.03	0.03
Calculated composition, % unless noted otherwise						
AME, kcal/kg	3,175	3,210	3,245	3,175	3,210	3,245
CP	18.09	18.09	18.09	19.44	19.44	19.44
Ca	0.76	0.76	0.76	0.76	0.76	0.76
Available P	0.38	0.38	0.38	0.38	0.38	0.38
Digestible Lys	0.94	0.94	0.94	1.01	1.01	1.01
Digestible TSAA	0.71	0.71	0.71	0.77	0.77	0.77
Digestible Thr	0.63	0.63	0.63	0.68	0.68	0.68
Digestible Val	0.74	0.74	0.74	0.80	0.80	0.80
Digestible Ile	0.64	0.64	0.64	0.70	0.70	0.70
Digestible Arg	1.02	1.02	1.02	1.12	1.12	1.13
Digestible Trp	0.17	0.17	0.17	0.19	0.19	0.19
Analyzed composition[7], %						
CP	18.80	19.67	19.96	20.61	20.61	20.49
Crude fat	3.65	3.98	5.39	4.44	5.03	6.21
Total Lys		1.13			1.22	
Total TSAA		0.75			0.78	
Total Thr		0.82			0.87	
Total Val		0.96			1.01	
Total Ile		0.83			0.88	

[1]Experiment 1 utilized diets containing low (LE), medium (ME), and high energy (HE) diets, whereas Experiment 2 also used LE, ME, and HE diets with either medium (MAA) or high amino acid density (HAA)

[2]Pro-Plus (H. J. Baker & Brothers. Inc., Little Rock, AR)

[3]Methionine hydroxy analogue calcium (Novus International, Saint Charles, MO)

[4]The mineral premix contained (per kg of diet): manganese, 60 mg; zinc, 36 mg; selenium, 0.1 mg; copper, 1.7 mg; iodine, 1.2 mg

[5]The vitamin premix contained (per kg of diet): vitamin A, 3858 IU; vitamin D_3, 2756 IU; vitamin E, 28 IU; vitamin B_{12}, 0.01 mg; menadione, 0.8 mg; riboflavin, 3.3 mg; D-pantothenie acid, 5.0; thiamine, 0.8 mg; niacin, 19.3; pyridoxine, 1.4 mg; folic acid, 0.4 mg; biotin, 0.04 mg.

[6]The enzyme premix contained (per kg of diet): amylase, 162 U; phytase, 750 FTU; protease, 3,240 U; and xylanase, 1,620 U (Dupont, St. Louis, MO)

[7]Due to the number of diets used in this study, only the ME diets were sent off for amino acid analysis to ensure proper mixing. Total TSAA does not include the portion of Met supplied as methionine hydroxy analogue calcium

Table 3. Live performance of Cobb (MV × 700) broilers fed diets varying in energy densities in during finisher (28 to 35 d) and withdrawal (36 to 46 d) phases in Experiment 1

		Finisher (28 to 36 d)			Withdrawal (37 to 46 d)		
Treatment		BWG, kg	FI, kg	FCR	BWG, kg	FI, kg	FCR
Main effect of dietary energy[1]							
LE	(n = 22)	0.798	1.347	1.717	0.989	1.958	2.005
ME	(n = 23)	0.770	1.304	1.711	0.995	1.902	1.965
HE	(n = 22)	0.766	1.321	1.758	1.013	1.897	1.941
SEM		0.0100	0.0155	0.0181	0.0149	0.0178	0.0291
Main effect of sex							
Male	(n = 33)	0.859	1.422	1.683	1.104	2.058	1.915
Female	(n = 34)	0.699	1.228	1.772	0.897	1.784	2.024
SEM		0.0081	0.0127	0.0148	0.0146	0.0146	0.0237
P-values							
Diet		0.075	0.200	0.124	0.534	0.044	0.294
Sex		< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.002
Diet × sex		0.060	0.231	0.077	0.318	0.903	0.864

[a-b] Means within column without a common superscript were determined to be significantly different ($P < 0.05$) by a Tukey's multiple comparison test.

[1]Low (LE), medium (ME), and high energy (HE) density contained 3,140 and 3,175, 3,175 and 3,210, and 3,210 and 3,245 kcal/kg in the finisher and withdrawal phases, respectively

Table 4. Live performance of Cobb (MV × 700) broilers fed diets varying in energy densities during experimental period (28 to 46 d) and overall (0 to 46 d) in Experiment 1

		Experimental period (28 to 46 d)			Overall (0 to 46 d)			
Treatment		BWG, kg	FI, kg	FCR	46 d BW, kg	BWG, kg	FI, kg	FCR
Main effect of dietary energy[1]								
LE	(n = 22)	1.787	3.305	1.874	3.271	3.232	5.289	1.658
ME	(n = 23)	1.765	3.206	1.849	3.213	3.174	5.154	1.645
HE	(n = 22)	1.779	3.218	1.857	3.267	3.228	5.225	1.641
SEM		0.0182	0.0317	0.0174	0.0274	0.0274	0.0500	0.0083
Main effect of sex								
Male	(n = 33)	1.964	3.480	1.810	3.525	3.485	5.551	1.614
Female	(n = 34)	1.596	3.012	1.909	2.983	2.944	4.901	1.681
SEM		0.0149	0.0259	0.0142	0.0224	0.0224	0.0408	0.0068
P-values								
Diet		0.887	0.083	0.529	0.429	0.435	0.242	0.326
Sex		< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Diet × sex		0.106	0.551	0.559	0.080	0.082	0.342	0.485

[a-b] Means within column without a common superscript were determined to be significantly different ($P < 0.05$) by a Tukey's multiple comparison test.

[1]Low (LE), medium (ME), and high energy (HE) density contained 3,140 and 3,175, 3,175 and 3,210, and 3,210 and 3,245 kcal/kg in the finisher and withdrawal phases, respectively

Table 5. Carcass characteristics of Cobb (MV × 700) broilers fed varying dietary energy concentrations from 28 to 46 d and processed at 47 d post-hatch in Experiment 1

		Hot carcass		Hot fat pad		Chilled carcass	
Treatment		Weight, kg	Yield[1], %	Weight, kg	Yield, %	Weight, kg	Yield, %
Main effect of dietary energy[2]							
LE	(n = 22)	2.538	76.02	0.057	1.72	2.583	77.35
ME	(n = 23)	2.464	75.81	0.057	1.77	2.510	77.22
HE	(n = 22)	2.511	75.95	0.054	1.66	2.555	77.24
SEM		0.0229	0.112	0.0015	0.042	0.0236	0.115
Main effect of sex							
Male	(n = 33)	2.734	76.02	0.054	1.51	2.780	77.26
Female	(n = 34)	2.281	75.83	0.058	1.92	2.324	77.28
SEM		0.0187	0.091	0.0019	0.034	0.0192	0.094
P-values							
Diet		0.139	0.425	0.277	0.224	0.166	0.671
Sex		< 0.001	0.151	0.045	< 0.001	< 0.001	0.847
Diet × sex		0.687	0.550	0.460	0.637	0.749	0.630

[a-b] Means within column without a common superscript were determined to be significantly different ($P < 0.05$) by a Tukey's multiple comparison test.

[1]Yields calculated relative to live body weight taken immediately prior to processing

[2]Low (LE), medium (ME), and high energy (HE) density contained 3,140 and 3,175, 3,175 and 3,210, and 3,210 and 3,245 kcal/kg in the finisher and withdrawal phases, respectively

Table 6. Parts weights of Cobb (MV × 700) broilers fed varying dietary energy concentrations from 28 to 46 d and processed at 47 d post-hatch in Experiment 1

		Total breast		Wings		Leg quarters	
Treatment		Weight, kg	Yield[1], %	Weight, kg	Yield, %	Weight, kg	Yield, %
Main effect of dietary energy[2]							
LE	(n = 22)	0.873	26.46	0.250	7.51	0.743	22.17
ME	(n = 23)	0.866	26.80	0.244	7.50	0.721	22.13
HE	(n = 22)	0.894	26.57	0.250	7.55	0.737	22.22
SEM		0.0107	0.216	0.0026	0.064	0.0072	0.122
Main effect of sex							
Male	(n = 33)	0.941	26.17	0.271	7.52	0.822	22.80
Female	(n = 34)	0.814	27.05	0.226	7.52	0.648	21.56
SEM		0.0088	0.177	0.0021	0.053	0.0059	0.100
P-values							
Diet		0.171	0.539	0.196	0.886	0.205	0.928
Sex		< 0.001	< 0.001	< 0.001	0.956	< 0.001	< 0.001
Diet × sex		0.586	0.764	0.460	0.087	0.797	0.977

[a-b] Means without a common superscript were determined to be significantly different ($P < 0.05$) by a Tukey's multiple comparison test.

[1]Yields calculated relative to live body weight taken immediately prior to processing

[2]Low (LE), medium (ME), and high energy (HE) density contained 3,140 and 3,175, 3,175 and 3,210, and 3,210 and 3,245 kcal/kg in the finisher and withdrawal phases, respectively

Table 7. Breast muscle myopathy distribution of Cobb (MV × 700) broilers fed varying dietary energy concentrations from 28 to 46 d and processed at 47 d post-hatch in Experiment 1

		Woody breast[1]			White striping[2]		
Treatment		Normal	Mild	Severe	Normal	Faint	Apparent
Main effect of dietary energy[3]							
LE	(n = 22)	27.42	41.67	30.92	0.00	68.04	31.96
ME	(n = 23)	30.21	42.67	27.05	0.00	76.75	23.25
HE	(n = 22)	41.67	32.63	25.71	0.00	81.96	18.04
SEM		4.734	5.143	5.107	0.000	4.765	4.765
Main effect of sex							
Male	(n = 33)	27.78	31.92	40.31	0.00	74.78	25.22
Female	(n = 34)	38.42	46.06	15.50	0.00	76.39	23.61
SEM		3.865	4.199	4.170	0.000	3.891	3.891
P-values							
Diet		0.302	0.246	0.550	-	0.254	0.132
Sex		0.218	0.188	< 0.001	-	0.797	0.912
Diet × sex		0.136	0.208	0.718	-	0.289	0.639

[a-b] Means without a common superscript were determined to be significantly different ($P < 0.05$) by a Tukey's multiple comparison test.

[1]Breast fillets were considered normal, mild, or severe for woody breast if the fillet was flexible throughout, stiff in cranial region, or if stiff in the cranial and caudal regions, respectively

[2]Breast fillets were considered normal, faint, or apparent for white striping if they displayed no visible stripes, stripes less than 1 mm, or stripes larger than 1 mm, respectively

[3]Low (LE), medium (ME), and high energy (HE) density contained 3,140 and 3,175, 3,175 and 3,210, and 3,210 and 3,245 kcal/kg in the finisher and withdrawal phases, respectively

Table 8. Live performance of Cobb (MV × 700) broilers fed diets varying in energy and amino acid densities during finisher (28 to 35 d) and withdrawal (36 to 46 d) phases in Experiment 2

		Finisher (28 to 36 d)			Withdrawal (37 to 46 d)		
Treatment		BWG, kg	FI, kg	FCR	BWG, kg	FI, kg	FCR
Main effect of dietary energy[1]							
LE	(n = 24)	0.863	1.439[a]	1.685	1.136	2.084	1.906
ME	(n = 24)	0.858	1.416[ab]	1.668	1.120	2.064	1.868
HE	(n = 24)	0.832	1.396[b]	1.697	1.141	2.043	1.881
SEM		0.0110	0.0102	0.0170	0.0170	0.0183	0.0252
Main effect of dietary amino acid density[2]							
HAA	(n = 36)	0.839	1.402	1.689	1.113	2.032	1.881
MAA	(n = 36)	0.862	1.432	1.678	1.152	2.094	1.889
SEM		0.0090	0.0083	0.0139	0.0139	0.0149	0.0206
P-values							
Energy		0.107	0.015	0.496	0.644	0.290	0.560
Amino acid		0.069	0.014	0.566	0.049	0.005	0.788
Energy × amino acid		0.849	0.967	0.664	0.599	0.765	0.698

[a-b] Means within column without a common superscript were determined to be significantly different ($P < 0.05$) by a Tukey's multiple comparison test.

[1]Low (LE), medium (ME), and high energy (HE) density contained 3,140 and 3,175, 3,175 and 3,210, and 3,210 and 3,245 kcal/kg in the finisher and withdrawal phases, respectively

[2]High (HAA) and medium amino acid (MAA) density contained 1.07 and 1.01 and 1.00 and 0.94% digestible Lys in the finisher and withdrawal phases, respectively

Table 9. Live performance of Cobb (MV × 700) broilers fed diets varying in energy and amino acid densities during experimental period (28 to 46 d) and overall (0 to 46 d) in Experiment 2

		Experimental period (28 to 46 d)			Overall (0 to 46 d)			
Treatment		BWG, kg	FI, kg	FCR	46 d BW, kg	BWG, kg	FI, kg	FCR
Main effect of dietary energy[1]								
LE	(n = 24)	1.999	3.522	1.804	3.576	3.537	5.622	1.613
ME	(n = 24)	1.978	3.480	1.778	3.546	3.506	5.568	1.601
HE	(n = 24)	1.973	3.443	1.798	3.559	3.520	5.555	1.607
SEM		0.0186	0.0261	0.0148	0.0221	0.0221	0.0343	0.0070
Main effect of dietary amino acid density[2]								
HAA	(n = 36)	1.952	3.435	1.793	3.534	3.495	5.544	1.605
MAA	(n = 36)	2.015	3.529	1.794	3.587	3.547	5.619	1.609
SEM		0.0152	0.0213	0.0121	0.0181	0.0180	0.0280	0.0057
P-values								
Energy		0.577	0.107	0.453	0.629	0.622	0.348	0.470
Amino acid		0.005	0.003	0.952	0.045	0.044	0.061	0.570
Energy × amino acid		0.824	0.835	0.504	0.806	0.794	0.863	0.547

[a-b] Means within column without a common superscript were determined to be significantly different ($P < 0.05$) by a Tukey's multiple comparison test.

[1]Low (LE), medium (ME), and high energy (HE) density contained 3,140 and 3,175, 3,175 and 3,210, and 3,210 and 3,245 kcal/kg in the finisher and withdrawal phases, respectively

[2]High (HAA) and medium amino acid (MAA) density contained 1.07 and 1.01 and 1.00 and 0.94% digestible Lys in the finisher and withdrawal phases, respectively

Table 10. Carcass characteristics of Cobb (MV × 700) broilers fed varying dietary energy and amino acid density from 28 to 46 d and processed at 47 d post-hatch in Experiment 2

		Hot carcass		Hot fat pad		Chilled carcass	
Treatment		Weight, kg	Yield[1], %	Weight, kg	Yield, %	Weight, kg	Yield, %
Main effect of dietary energy[2]							
LE	(n = 24)	2.741	75.60	0.049	1.34	2.782	76.74
ME	(n = 24)	2.766	75.67	0.054	1.47	2.806	76.76
HE	(n = 24)	2.742	75.45	0.053	1.43	2.785	76.51
SEM		0.0213	0.162	0.0018	0.047	0.0217	0.168
Main effect of dietary amino acid density[3]							
HAA	(n = 36)	2.745	75.65	0.050	1.37	2.787	76.75
MAA	(n = 36)	2.755	75.49	0.053	1.45	2.795	76.60
SEM		0.0174	0.132	0.0014	0.039	0.0177	0.138
P-values							
Energy		0.631	0.622	0.097	0.138	0.687	0.504
Amino acid		0.681	0.394	0.184	0.154	0.755	0.453
Energy × amino acid		0.589	0.881	0.918	0.948	0.658	0.640

[a-b] Means within column without a common superscript were determined to be significantly different ($P < 0.05$) by a Tukey's multiple comparison test.

[1]Yields calculated relative to live body weight taken immediately prior to processing

[2]Low (LE), medium (ME), and high energy (HE) density contained 3,140 and 3,175, 3,175 and 3,210, and 3,210 and 3,245 kcal/kg in the finisher and withdrawal phases, respectively

[3]High (HAA) and medium amino acid (MAA) density contained 1.07 and 1.01 and 1.00 and 0.94% digestible Lys in the finisher and withdrawal phases, respectively

Table 11. Parts weights of Cobb (MV × 700) broilers fed varying dietary energy and amino acid density from 28 to 46 d and processed at 47 d post-hatch in Experiment 2

		Total breast		Wings		Leg quarters	
Treatment		Weight, kg	Yield[1], %	Weight, kg	Yield, %	Weight, kg	Yield, %
Main effect of dietary energy[2]							
LE	(n = 24)	0.946	25.99	0.275	7.59	0.813	22.39
ME	(n = 24)	0.952	26.04	0.273	7.48	0.817	22.31
HE	(n = 24)	0.951	26.25	0.271	7.46	0.814	22.41
SEM		0.0101	0.178	0.0025	0.050	0.0076	0.126
Main effect of dietary amino acid density[3]							
HAA	(n = 36)	0.952	26.21	0.274	7.54	0.815	22.42
MAA	(n = 36)	0.948	25.98	0.273	7.48	0.814	22.32
SEM		0.0082	0.145	0.0020	0.041	0.0062	0.103
P-values							
Energy		0.909	0.570	0.481	0.150	0.924	0.831
Amino acid		0.763	0.281	0.668	0.267	0.918	0.466
Energy × amino acid		0.970	0.535	0.900	0.562	0.781	0.890

[a-b] Means without a common superscript were determined to be significantly different ($P < 0.05$) by a Tukey's multiple comparison test.

[1]Yields calculated relative to live body weights taken immediately prior to processing

[2]Low (LE), medium (ME), and high energy (HE) density contained 3,140 and 3,175, 3,175 and 3,210, and 3,210 and 3,245 kcal/kg in the finisher and withdrawal phases, respectively

[3]High (HAA) and medium amino acid (MAA) density contained 1.07 and 1.01 and 1.00 and 0.94% digestible Lys in the finisher and withdrawal phases, respectively

Table 12. Breast muscle myopathy distribution of Cobb (MV × 700) broilers fed varying dietary energy and amino acid densities from 28 to 46 d and processed at 47 d post-hatch in Experiment 2

		Woody breast[1]			White striping[2]		
Treatment		Normal	Mild	Severe	Normal	Faint	Apparent
Main effect of dietary energy[3]							
LE	(n = 24)	32.63	33.67[a]	33.67	0.00	78.17	21.83
ME	(n = 24)	23.25	51.75[b]	25.00	0.00	73.63	26.38
HE	(n = 24)	34.71	37.17[ab]	28.13	0.00	76.04	23.96
SEM		5.158	4.734	5.486	0.000	4.342	4.342
Main effect of dietary amino acid density[4]							
HAA	(n = 36)	37.25	39.81	22.92	0.00	78.72	21.28
MAA	(n = 36)	23.14	41.92	34.94	0.00	73.17	26.83
SEM		4.211	3.865	4.479	0.00	3.546	3.546
P-values							
Energy		0.188	0.009	0.584	-	0.784	0.853
Amino acid		0.040	0.366	0.061	-	0.158	0.646
Energy × amino acid		0.960	0.413	0.468	-	0.568	0.369

[a-b] Means without a common superscript were determined to be significantly different ($P < 0.05$) by a Tukey's multiple comparison test.

[1]Breast fillets were considered normal, mild, or severe for woody breast if the fillet was flexible throughout, stiff in cranial region, or if stiff in the cranial and caudal regions, respectively

[2]Breast fillets were considered normal, faint, or apparent for white striping if they displayed no visible stripes, stripes less than 1 mm, or stripes larger than 1 mm, respectively

[3]Low (LE), medium (ME), and high energy (HE) density contained 3,140 and 3,175, 3,175 and 3,210, and 3,210 and 3,245 kcal/kg in the finisher and withdrawal phases, respectively

[4]High (HAA) and medium amino acid (MAA) density contained 1.07 and 1.01 and 1.00 and 0.94% digestible Lys in the finisher and withdrawal phases, respectively

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CONCLUSION

The Cobb MV × 700 represents a new modern high-yielding broiler cross for the poultry industry. Responses of this strain to both amino acids (**AA**) and energy have shown that it may not respond similarly to other high-yielding broiler strains. Breast meat yield has long been a key indicator of AA response in other high yielding broiler strains but was unaffected in these studies. Similarly, it has traditionally been demonstrated that increasing dietary energy levels will decrease broiler feed intake (**FI**), but FI responses to commercially-relevant changes in dietary energy were minimal. Conversely, observations from these trials indicate that the AA content of the diet influence FI, and support the idea that modern broilers increase FI to maintain AA intake. These data may support the idea that genetic selection has produced a broiler that can adapt to a wide variety of diet types with little to no impact on live performance or processing characteristic. Regarding meat quality data, the overall incidence of woody breast varied greatly, with the overall incidence of severe woody breast ranging from 6.6 to 28.9% among the 3 trials in which birds were processed. The greatest influence on woody breast in these trials was due to sex (higher in males), with minimal effects of dietary AA or energy content. The variation in the incidence and severity of woody breast appears to be due to factors not evaluated or controlled in our studies which could include hatchery or environmental conditions. Compared with woody breast, the occurrence of white striping was far more consistent, with almost every bird in these studies exhibiting some degree of white striping.

Results from these trials indicate that more research examining the ideal nutrient profile for the Cobb × 700 broiler is warranted. Neither AA nor energy in the 28 to 46 d period appear to be limiting live performance or carcass composition responses of this broiler cross using the

current ideal protein ratios. Whether this bird is truly insensitive to changes in AA content or if the AA ratios need to be optimized to this broiler remain unknown.

APPENDIX

UNIVERSITY OF ARKANSAS

Office of Research Compliance

To:	Samuel Rochell
Fr:	Craig Coon
Date:	November 2nd, 2018
Subject:	IACUC Approval
Expiration Date:	September 8th, 2019

The Institutional Animal Care and Use Committee (IACUC) has APPROVED your protocol # **17019:** *Optimizing dietary amino acid levels for Cobb 700 broilers*.

In granting its approval, the IACUC has approved only the information provided. Should there be any further changes to the protocol during the research, please notify the IACUC in writing (via the Modification form) prior to initiating the changes. If the study period is expected to extend beyond September 8th, 2019 you must submit a newly drafted protocol prior to that date to avoid any interruption. By policy the IACUC cannot approve a study for more than 3 years at a time.

The following individuals are approved to work on this study: Howard Lester, Alyson Gautier, Sklyer West, Chelsea Ellington, Craig Maynard, Sonia Liu, Michael Kidd, Kenia Mitre, and Samuel Rochell. Please submit personnel additions to this protocol via the modification form prior to their start of work.

The IACUC appreciates your cooperation in complying with University and Federal guidelines involving animal subjects.

CNC/tmp

17019