Functional properties of amino acids: improve health status and sustainability

Jason T. Lee,*[,1] Sam J. Rochell ,[†] Ruben Kriseldi ,[‡] Woo K. Kim ,[§] and Randy D. Mitchell[#]

[*]CJ Bio America, Downer Grove, IL, USA; [†]University of Arkansas, Fayetteville, AR, USA; [‡]Aviagen, Huntsville, AL, USA; [§]University of Georgia, Athens, GA, USA; and [#]Perdue Farms, Salisbury, MD, USA

ABSTRACT The combination of increased genetic potential and changes in management strategies (i.e., antibiotic-free, no antibiotics ever, and every day feeding of replacement pullets) influences the nutritional needs of poultry. Traditionally, nutritionists have focused on meeting the amino acid needs for production performance and yield however, increasing specific amino acid concentrations can benefit gastrointestinal development and integrity, enhance immune response potential, influence behavior, and benefit sustainability. Commercialization of additional feed grade amino acids beyond methionine, lysine, and threonine, enables targeted increases to achieve these benefits. As such, this paper addresses the functional roles of amino acids in meeting poultry production, health, and sustainability goals.

Key words: amino acid, poultry, intestinal health, heat stress, breeder

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FUNCTIONAL ROLE OF AMINO ACIDS TO IMPROVE HEALTH STATUS IN POULTRY

Woo Kim

Amino acid metabolism is the foundation for numerous physiological pathways and activities to include, but not limited to, internal organ development, skeletal muscle accretion through proliferation of satellite cells (Florini et al., 1996), and skeletal development (Castro et al., 2019a). Numerous factors including intestinal disease challenge and heat stress can result in gastrointestinal damage, oxidative stress, and inflammation which can decrease growth performance, nutrient digestibility, as well as organ, muscle, and bone development. Aside from the foundational impacts of amino acid metabolism, some amino acids such as methionine and arginine have additional functional roles. Methionine is an important amino acid for protein synthesis and has antioxidant functions, acting as a precursor of cysteine and glutathione in the transsulfuration pathway (Swennen et al., 2011) and through methionine sulfoxide reduction action (Luo and Levine, 2009). Arginine is associated with metabolically important molecules such as creatine, nitric oxide, glutamate, polyamines, proline, and glutamine. Arginine influences bone development by its involvement with the formation of collagen and connective tissue (Corzo et al., 2003) and through stimulation of the release of growth hormone which acts on the growth of epiphyseal growth plate (Liu and LeRoith, 1999). Aside from these benefits, elevated arginine levels have been shown to alleviate oxidative stress (Atakisi et al., 2009), stimulate protein synthesis through activation of mTOR pathway (Bauchart-Thevret et al., 2010), improve antioxidant capacity, and humoral and cell-mediated immunity (Tayade et al., 2006; Munir et al., 2009).

While concentrated sources of methionine or their analogs have been available for many decades, only recently has feed grade crystalline form of arginine been commercialized for use in animal production. In recent years due to the availability of feed grade arginine, there has been increased interest in these functional properties and their potential use to improve health status and performance of broiler chickens. Castro et al. (2019a) reported positive effects of increasing dietary arginine concentrations on bone mineral density, body muscle weight, and feed efficiency while decreasing relative abdominal fat pat percentage in a noninduced stress situation.

Production animals are often subjected to periods of stress including temperature stress (heat stress) and intestinal pathogen challenges such as coccidiosis, both of which can compromise intestinal integrity and barrier function (Allen and Fetterer, 2002; Castro et al., 2019b, 2020). Heat stress can negatively influence production parameters of all commercially reared poultry. Related to egg producing laying hens and pullets, inadequate dietary total sulfur amino acids can reduce body weight

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[1]Corresponding author: jason.lee2@cj.net

gain, feed efficiency, feed intake, and egg production. However, Castro et al. (2019b,2020) demonstrated the benefits of increasing of methionine levels in a series of experiments in pullets and laying hens with varied TSAA levels and temperatures. Inadequate levels of TSAA reduced body weight gain, feed efficiency, and egg production in laying hens between 19 and 45 wk of age. In TSAA inadequate diets, when subjected to heat stress, an additional drop in egg production was reported. Dietary TSAA levels also influence bone quality. In 18-wk-old pullets, as TSAA levels increased bone ash weight increased and bone porosity decreased, indicating higher level of bone mineralization (Castro et al., 2020). Similar observations were observed in 45-wk-old laying hens, with elevated bone volume associated with increasing TSAA levels that correlated with increased cortical and trabecular bone mineral density, while medullary bone density was decreased with elevated TSAA levels due to higher levels of egg production (Castro et al., 2019b). In regard to heat stress, benefits on growth performance, specifically in feed efficiency, have been reported in multiple experiments by increasing arginine ratio beyond breeder recommendations (Brake et al., 1988). This observation of improved efficiency under heat stress conditions may be related to multiple modes of action to include reduced absorption of arginine via the sodium independent pathway (Brake et al., 1988) or improved intestinal mucosal barrier function by enhancing the expression of tight junction proteins (Xia et al., 2019).

Another commonly occurring stressor in poultry production is intestinal pathogen challenge resulting in intestinal damage and reduced activity. Coccidiosis is the most common parasitic disease caused by *Eimeria* spp., leading to over $14 billion in economic losses worldwide (Blake et al., 2020). *Eimeria* infection causes epithelial cell damage and intestinal inflammation leading to gastrointestinal tract permeability (Teng et al., 2020) and decreased digestive and absorptive capacity of the gastrointestinal tract leading to decreased apparent ileal digestibility of amino acids and growth performance (Rochell et al., 2016). As *Eimeria* infection reduces methionine digestibility and increases oxidative stress and inflammation, methionine supplementation increases serum SOD activity and total antioxidant potential (Chen et al., 2013) and improves antioxidant defense via increased GSH and reduce oxidative stress (Castro et al., 2020a).

Eimeria infection influences the partitioning of arginine throughout the body as it plays key roles in antioxidant system and the immune system. *E. acervulina* infection not only reduced arginine digestibility and plasma arginine level but increases nitrogen oxide production via arginine degradation (Allen and Fetterer, 2002; Rochell et al., 2016). This infection and the resulting physiological responses can result in insufficient arginine availability for optimal growth efficiency. Benefits of elevated arginine ratios during coccidial challenge have recently been reported. Teng et al. (2021) reported that dietary arginine supplementation in coccidial challenged broilers reduced gastrointestinal permeability. Similarly, Castro et al. (2020b) reported that increasing arginine ratio during coccidial challenge increased body weight, decreased feed conversion ratio, and elevated level of tight junction protein Zonula occludens expression post challenge. This growth benefit was correlated with the decrease in gastrointestinal permeability and improvement in intestinal health, integrity, and functionality.

The previously discussed data demonstrates the "functional role" of both methionine and arginine in situations when an animal is exposed to nonoptimal conditions. The nature of the stress can vary however, when the animal is exposed to these different stressors, its response can be the repartition of some bodily amino acids due to the physiological response necessary. This response can reprioritize amino acids away from growth efficiency and ultimately influence the animal's optimal nutrient requirement. In the instance of heat stress and intestinal stress, methionine and arginine are excellent examples of functional amino acids and the benefit that increasing dietary concentration can have on the animal.

UTILIZING AMINO ACID BALANCE AND FUNCTIONAL PROPERTIES TO IMPROVE PRODUCTION IN BROILER BREEDER PULLETS AND HENS

Ruben Kriseldi

The goal in raising broiler breeders is to obtain the greatest number of chicks for every bird placed (chicks/hen housed). The number of chicks a hen can produce depends on many factors, such as management, incubation, environment, health, and nutrition. Among these factors, nutrition, especially energy plays a crucial role in providing the resources that a hen uses to produce chicks. The total energy requirement for hens is comprised of energy for maintenance, growth, and egg mass (Combs, 1968). Since it was first established, the concept of energy for maintenance + growth + egg mass has been fundamental in providing the accurate amount of energy to produce the most number of chicks per hen. Because of its importance, broiler breeders are fed based on the balance between dietary energy content and the amount of energy they need. Any changes in dietary energy content must be compensated by the adjustment in feed allocation to obtain the proper energy intake. For example, the peak energy requirement for Ross 708 is 456 kcal/bird/d. When provided a 2,800 kcal/kg diet, the hen should receive 163 g per d. If the diet is formulated to contain 2,900 kcal/kg, hen should be provided 157 g per d to obtain the same amount of energy.

The concept of amino acids for broiler breeders is quite similar to energy. The hen also requires amino acids for growth, maintenance, and egg mass (Hurwitz and Bronstein, 1973). However, specification of dietary amino acids must be formulated in relation to feed allocation, since feed allocation is adjusted according to energy needs (Fisher, 1998). This can be done by maintaining the quantity of amino acids per unit of energy. For instance, nutrition specifications for a "Breeder 1" diet for Ross 708 include digestible Lys of 0.60% for an energy content of 2,800 kcal/kg. When energy content is formulated to 2,900 kcal/kg, digestible Lys content should be adjusted to 0.62%. Maintaining this ratio allows for changes in energy content and feed intake without changing the intake of amino acids.

Over time, energy, and amino acid needs for broiler breeders have changed due to genetic progress. The genetic progress in broilers has generated broilers that present high appetites while also being feed efficient. These characteristics also translate to broiler breeders, which have the capacity to gain muscle efficiently while also having high appetite. Data according to industry reporting services indicated that the US industry has been feeding less feed to breeder pullets, while achieving higher body weights at 25 wk of age. Similarly, abdominal fat pad accumulation between 20 and 22 wk has been declining by more than 2.0% from 1988 to 2010 (van Emous, 2015). The increased appetite and efficiency in converting feed to muscle may pose some unintended challenges in feeding these modern breeders. The increase in appetite causes these birds to have shorter feed cleanup times while the increased feed efficiency signifies rapid weight gain with a lower feed amount. These characteristics may present challenges as the lower amount of feed and shorter feed cleanup time can decrease flock uniformity. Furthermore, while it is more cost effective to have birds that are more proficient at muscle accretion, it also indicates that these birds may have a lower ability to accumulate fat for egg production.

There are many ways to deal with increased feed efficiency and appetite, such as feeding lower energy content, altering feeding schedule, and using different feed forms. When focusing on amino acid balance, lysine is the most important amino acid in broiler breeder feed. Not only is lysine used as a reference amino acid, lysine is also the main amino acid for breast meat development. Controlling lysine can also assist in promoting abdominal fat reserves which are important for egg production (Alfaro-Wisaquillo et al., 2021). Previous research demonstrated that increasing dietary lysine to 110% during rear increased breast meat yield and decrease abdominal fat yield of pullets at 20 wk of age (Alfaro-Wisaquillo et al., 2021). This was evident as pullets receiving a 110% lysine diets had a higher percentage of over fleshed birds than those receiving diets with 80, 90, and 100% lysine content (Alfaro-Wisaquillo et al., 2021). The consequence of having larger breast meat may be realized in fertility. Hens having larger breast meat may have more difficulties in exposing their cloaca for mating, which can lead to incomplete mating and decreased fertility (Aviagen, 2018). In addition, hens provided with 110% lysine diets produced fewer eggs compared to when feeding according to recommendations during rear (Oviedo-Rondon et al., 2021). Interestingly, feeding an 80% lysine diet also caused a slight reduction in egg production indicating the importance of feeding diets with balanced amino acids.

Controlling lysine can also be beneficial in dealing with high appetite. A previous study conducted by Aviagen with Ross 308 AP indicated that lowering dietary lysine content during rear while feeding pullets to the same body weight target lowers feather licking behavior at 18 wk of age compare to providing a high lysine diet. This finding could be attributed to the higher feed allocation in pullets fed the lower lysine content. A second study with a similar aim also emphasized that when pullets are fed with a 0.62% lysine diet during the grower period, feather licking incidence between photostimulation and point of lay was higher than when feeding 0.51 or 0.48% lysine. Reducing feather licking behavior between photostimulation and point of lay could be beneficial as this behavior can be enhanced due to light stimulation during this period. Another study evaluating behavior in male breeders showed that supplementing tryptophan to achieve a total Trp concentration of 0.38% was beneficial in reducing the incidence of aggressive pecking during rear compared to feeding the control diet (0.19% Trp) (Shea et al., 1990). This positive result may be attributed to the role of tryptophan as a precursor of serotonin, which involves in mood and behavior (Jenkins et al., 2016).

Lysine control in the laying period is as critical as in was during the rear phase. Feeding diets with excess lysine may appear to be beneficial at the beginning of lay as it provides higher peak egg production compared with lower lysine. However, this higher lysine diet causes hens to drop egg production faster than those with a lower lysine diet (Lopez and Leeson, 1995). Moreover, excess protein can also result in larger eggs (Spratt and Leeson, 1987), which is not conducive for incubation due to thinner shells, increased contamination, and eggs not fitting into trays. The importance of other amino acids during lay is evident when evaluating nitrogen retention in egg mass. In an amino acid deletion study, hens consuming diets deficient in lysine, tryptophan, valine, and isoleucine had at least 20% lower nitrogen retention in the egg mass compared to those consuming diets formulated to be adequate in all amino acids between 31 and 35 wk of age (Dorigam et al., 2017). The reduction in nitrogen retention indicated that lysine, tryptophan, valine, and isoleucine, may play important roles in egg formation early in lay.

In a similar way, providing low amino acid diets to broiler breeders can also produce negative outcomes. Lowering amino acid content in breeder diets is not suitable for maintaining feather development and egg production of broiler breeders. Many previous studies demonstrated the importance of amino acids on feathering, such as Met+Cys, Val, Arg, Leu, Pro, and Gly+Ser (Penz et al., 1984; Farran and Thomas, 1992; Alfaro-Wisaquillo et al., 2021). Pullets fed diets with low amino acid contents were reported to have poor feather cover in lay (Alfaro-Wisaquillo et al., 2021). The poor feather cover is typically connected with poor egg production and fertility as hens are less likely to mate when having poor feather cover.

Balancing amino acids in feed formulations to obtain optimum production for broiler breeders is not an easy task. While lysine should be strictly controlled, other amino acids must be supplied to support physiological, feathering, skeleton, and immune system of the bird. Unlike feed formulation for broilers, which focuses on the ratio of amino acids to lysine, breeder feed formulation should consider the ratio of essential amino acids to energy content. This strategy allows for adequate intake of amino acids at a certain level of energy intake; thus, allowing for flexible adjustment of dietary energy content.

There are several applicable formulation strategies to meet the goal of feeding broiler breeders. Feed formulation for breeders should consider the use of alternative ingredients other than corn/wheat and soybean meal. The inclusion of diluents, such as wheat middlings, sunflower meal, oat hulls, rice hulls, and soy hulls can be an effective strategy to lower dietary energy content to increase feed volume. In order to meet nutrient specification for amino acids, ingredients, such as corn gluten meal, canola meal, and peanut meal, can be great sources of protein. However, using these alternative ingredients could lead to imbalances or deficiencies in essential amino acids. For example, corn gluten meal contains excessive levels of leucine which could lead to a branched chain amino acid imbalance with isoleucine and valine which plays a vital role in feather composition (Farran and Thomas, 1992). Similarly, soy hulls contain low amounts of tryptophan which can results in marginal or deficient levels which may negatively influence behavior. This strategy of using alternative ingredients can also be combined with allowing supplemental amino acids beyond methionine, lysine, and threonine to avoid imbalances or deficiencies. Currently, L-Val, L-Ile, L-Arg, and L-Trp are available as feed grade, which can be used to meet amino acid specification while limiting lysine. Furthermore, these formulation strategies should be accompanied by having multiple feeding phases. As amino acid needs at each growth and production stage are different, utilizing multiple feeding phases allows for more flexibility in controlling feed allocation, thus daily amino acid intake, concurrently with body weight, egg size, and flock uniformity control.

UNDERSTANDING AMINO ACID FUNCTIONALITY TO ADVANCE PRECISION NUTRITION AND SUSTAINABILITY GOALS IN POULTRY PRODUCTION

Sam Rochell

Wu (2010) defined a functional amino acid in the context of animal nutrition as ‘those that regulate key metabolic pathways to improve health, survival, growth, development, lactation, and reproduction of an organism. This definition requires us to consider needs for amino acids beyond their use as building blocks for proteins and recognize them as key metabolic regulators for specific functions. The functional roles of amino acids include the maintenance amino acid needs of an animal under thermoneutral and homeostatic conditions as well as heightened needs for specific functions as animals respond to environmental, pathogenic, or other stressors. In theory, the greater the relative contribution an amino acid has toward functional roles versus its use as a substrate for protein synthesis makes its overall requirements more dynamic and difficult to determine experimentally. This is partly why lysine, which has relatively fewer maintenance roles compared with other essential amino acids, is used as the denominator for expressing amino acid ratios to Lys when applying the ideal protein concept (Emmert and Baker, 1997). In diets that contain the feed grade Lys, Met, Thr, Val, and Ile, Arginine, and Gly can be limiting for the bird and both of these amino acids have extensive functional roles. Moreover, metabolic needs for Arg and Gly converge in the synthesis of several important proteins and functional molecules, warranting a better understanding of the potential interactions of these important amino acids.

Arginine

Arginine is considered a functional amino acid due to its extensive secondary metabolic roles beyond protein synthesis including being as a precursor nitric oxide (**NO**), proline, hydroxyproline, polyamines, glutamine, ornithine, and creatine (Wu et al., 2009; Castro and Kim, 2020). It is involved in several critical roles related to immune function, wound healing, and alleviation of oxidative stress (Murrell et al., 1997; Atakisi et al., 2009; D’Amato and Humphrey, 2010). Regarding wound healing, polyamines derived from Arg catabolism by arginase have been shown to stimulate cell proliferation, while ornithine and proline derived from Arg are predominant amino acids within collagen (Albina et al., 1993; Marti i Lindez and W. Reith, 2021). Nitric oxide is also a key cytotoxic mediator for nonspecific host defenses required to eliminate intracellular pathogens (Bowen et al., 2009; Khajali and Wideman, 2010), including *Eimeria* infections in poultry as previously described in this paper. Reponses of broilers to dietary Arg level have been inconsistent in the literature, and it has long been hypothesized that dietary Arg requirements that optimize bird health and immune function may not be the same as those required for growth and tissue accretion (Kidd, 2004). Hence, understanding the demand of Arg for functional roles under a given scenario (e.g., disease or environmental state) will be key to advancing precision nutrition goals by ensuring that its dietary levels are optimized, especially in reduced CP diets. Furthermore, understanding if the potential exists for Arg to enhance wound healing for poultry affected by skin scratches or pododermatitis with dietary Arg supplementation, as has been demonstrated in human clinical wound care protocols (Gould et al., 2008), may provide an opportunity to enhance both the welfare and sustainability goals for producers, as well as improve carcass quality and characteristics during processing.

Glycine

The functional roles of glycine have been extensively described by Wang et al. (2013) and include antioxidative capacity, improved immunity, promotion of wound healing, and enhanced gut integrity. In broilers, much of the existing literature on Gly requirement and dietary limitations has been conducted in birds less than 3 wk of age. Recently, Lee et al. (2022) evaluated total Gly+Ser (tGly +Ser) responses in growing broilers across 3 feeding phases when grown to market ages (0−48 d). This was done in 2 separate experiments, each with different degrees of CP reduction using feed-grade amino acids as well as different litter conditions. In the first experiment, a CP reduction of 1.68 percentage units (average across all phases) vs. the control diet did not impact cumulative body weight gain, feed conversion, or meat yield of broilers. Restoring tGly + Ser concentrations to levels equal to the control diet had no impact on these outcomes, whereas supplementing Gly to exceed the tGly+Ser content of the control diet had negative impacts on growth performance. In the second experiment, a greater CP reduction of 2.38 percentage units (average across all phases) vs. the control diet impaired cumulative feed conversion and breast meat yield of broilers. Feed conversion, but not breast meat yield, responded positively in a linear fashion to increasing tGly +Ser even beyond those of the control diets. There are a number of factors that may have influenced the different responses to Gly addition in these 2 experiments. First, a mild environmental challenge brought forth by rearing birds on used litter may have increased the relative functional needs for Gly. More likely, the dietary composition and extent of CP reduction and resulting performance differences relative to birds in the control groups likely influenced the Gly responses. In particular, higher Met:Cys ratios that occur when feed-grade Met is used to meet TSAA requirements in reduced CP diets potentially increases the need for Ser produced from Gly to synthesize Cys from Met, as indicated in a meta-analysis by Siegert et al. (2015). However, in a recent experiment in our lab, we did not observe a performance response to tGly +Ser levels ranging from 1.75 to 3.05% in birds fed a 20.75% CP starter diet (0−21 d) when formulated with Met:Cys ratios of either 60:40 or 74:36. Thus, further empirical work is needed to delineate the impact of Met:Cys ratio on Gly needs, especially since higher Met:Cys ratios are a natural consequence in reduced protein diets formulated with feed-grade amino acids.

Arginine × Glycine Interactions

There are several metabolic pathways and functions at which dietary Arg and Gly have the potential to interact. As described above, polyamines and nonessential amino acids derived from Arg catabolism are important substrates for collagen synthesis. Additionally, Gly is the most predominant amino acid in collagen and elastin proteins (Li and Wu, 2018). It is, therefore, necessary that both of these amino acids are adequately supplied to ensure skin integrity and proper wound healing. Furthermore, synthesis of glutathione, which is produced from Gly, Cys, and Glu, has been shown to be influenced by supplemental Arg in rodents (Liang et al., 2018). Creatine and phosphocreatine are integral in maintaining cellular energy homeostasis, and guanidinoacetate, a critical precursor for creatine synthesis, is formed from Arg and Cys. Dietary responses and possible interactions among dietary Arg, Cys, and guanidinoacetic acid have been extensively reviewed by Portocarero and Braun (2021).

In the context of reduced CP diets, it is important to note that dietary CP level may influence the requirements of both Arg and Gly. Regarding Arg, chickens have approximately 30 times greater kidney arginase activity than mammals (Tamir and Ratner, 1963), and as a result, dietary essentiality for Arg in chickens represents the metabolic requirement for protein synthesis and functional roles plus that required to replace Arg degraded by kidney arginase (Ball et al., 2007). Excess essential amino acids including His, Tyr, and Ile, as well as excess total nitrogen content have been shown to increase Arg degradation by kidney arginase in chickens (Austic and Nesheim, 1970; Robbins and Baker, 1981), but this has not been evaluated in modern broiler genotypes. Nonetheless, it is possible that reduced CP diets may lower the bird's needs for dietary Arg. Similarly, because 1 mole of Gly is needed for uric acid synthesis, reduced CP diets should theoretically lower the amount of Gly used for N excretion via uric acid, but only a few studies have addressed this relationship directly (Siegert et al., 2016).

In conclusion, Arg and Gly are clearly functional amino acids that require careful attention to their many roles and interactions when assessing their dietary requirements. In addition to bird genotype and growth phase, the estimated requirements for these amino acids will be dependent on CP and precursor (Gly) content of the diet and environment (e.g., thermal and pathogen) and health (e.g., immune, physical, or oxidative stress) states of the bird. This may require more frequent use of complex experimental designs and multivariate modeling to predict separate requirements for each functional role of these amino acids. Such approaches will help ensure that knowledge on the functional roles of Arg and Gly are not limiting the success of nutritional strategies aimed at advancing sustainability and performance goals.

INDUSTRY PERSPECTIVE: ROLE OF AMINO ACIDS IN TURKEY NUTRITION – PAST, PRESENT, AND FUTURE

Randy Mitchell

In reviewing, Nutrition of the Turkey by Scott (1987), it is quite clear that much has changed in the last 35 yr, but many issues are still the same regarding nutritional programs for turkeys. What has changed is the growth rate, market weights, focus on meat yield, nutritional requirements, and tools that are used (e.g., feed additives) in rearing the modern commercial turkey. However, the principles by which we optimize our programs are the same as they were 35 yr ago. Also the same, is the relatively small, in comparison to the broiler chicken, amount of scientific literature that is available for turkey nutritionists to help in assessing their nutritional programs. On the job experience and training, paired with lessons from the previous generation of turkey nutritionists, is how this field has continued to advance. Turkey formulas from the previous era were more complex and contained a larger number of macroingredients in addition to corn and soybean meal and nearly all included fish meal as a source of critical amino acids. The complexity of dietary formulations were necessary to meet the nutrient requirements of the turkey without access to current commercial feed additives such as L-Lysine and L-Threonine and still balance/avoid any potential antinutritive factors associated with elevated levels of any particular ingredient. Today, the vast majority of commercial turkey diets contain at minimum 3 synthetic amino acids as well as enzymes, probiotics, prebiotics, and various other feed additives. These advancements in technology have increased the digestibility of turkey diets and reduced the need for such complexity within feed formulations.

In Scott (1987), the combined average weight of a finished turkey tom and hen was listed as 15.6 and 7.4 kg at 24 wk and 18 wk of age with a feed conversation ratio of 3.15 and 2.71, respectively. It is now expected for a modern turkey tom to reach 25.1 kg at 22 wk of age with a 2.63 feed conversion ratio, with hens reaching 13.3 kg with a 2.47 feed conversation ratio at 18 wk of age. This acceleration in growth rate is correlated with a higher nutrient requirement and higher feed intake level. Modern diets for commercial turkeys are considerably higher in amino acid density as well as an in energy level than those in previous generations. Much of the increase in dietary density is related to the emphasis on deboning yield vs. whole birds. Interestingly, when reviewing amino acid publications prior to 2000, it is rare to have all essential amino acids of current importance included in the dietary tables. All tables included methionine, total sulfur containing amino acids, and lysine; however, in many cases, no concentrations are given for arginine, tryptophan, or any of the branch chained amino acids (**BCAA**). This is despite the fact that the lysine:arginine antagonism and the known BCAA antagonisms were reported as early as D'Mello (1975).

Over the past 25 yr, significant advancements have been made in poultry amino acid nutrition. Prior to the turn of the century, turkey nutritionists only had access to economical sources of supplemental methionine and lysine resulting in the need for the complex diets previously mentioned. Currently, feed grade L-threonine, L-valine, L-isoleucine, L-tryptophan, and L-arginine are accessible and available on the global market for use. Although the introduction of these amino acids to the market have resulted in significant amounts of broiler research providing a clear understanding of the amino acid requirements of broiler on an individual strain of broiler, the same cannot be said in the turkey segment. The differences between the sizes of these markets, cost of production, and length of growout all contribute to significant barriers to matching the advancements in the broiler segment, preventing quick and universal adoption of these additional feed grade amino acids as has been seen in the broiler market.

The high amino acid requirement for young turkeys provides a significant challenge to turkey nutritionists. Early turkey poult diets can contain well over 40% soybean meal. While soybean meal is a highly digestible ingredient and contains high levels of essential amino acids, there are antinutritive properties such as β-mannan that can cause inflammation and feed induced immune responses (Hsiao et al., 2006) and have negative impacts on gastrointestinal health and performance (Arsenault et al., 2017). Recently, research in turkeys has demonstrated the benefits of reducing dietary crude protein and reducing the amount of soybean meal in turkey diets (Veldkamp et al., 2017). Reducing dietary crude protein level in turkey diets decreased foot pad dermatitis score. The reduction in soybean meal correlates with a reduction in dietary potassium, lowering the dietary electrolyte balance, water intake, and litter moisture (Hocking et al., 2018). The combination of reduced litter moisture and reduced litter nitrogen has a beneficial impact on foot pad health. Adhikari et al. (2021) demonstrated that feed grade amino acids can be used to both reduce the amount of soybean meal and dietary crude protein by up to 9% of total protein without affecting body weight or feed conversion ratio.

As we look at the current situation and the near future, the past several months have been marked with highly volatile commodity markets amid the global pandemic recovery, renewable energy mandates, and geopolitical affairs affecting global grain and energy production and markets. The result has been unstable supply of ingredients, increased freight costs, and significantly increased supplemental fat prices, especially vegetable oil. Feed grade amino acids beyond methionine, lysine, and threonine can be an aid to turkey nutritionists in adapting to these challenges. Their use can reduce dietary cost, especially when facing high supplemental fat costs, as their dietary inclusion will increase the amount of corn in the diet and decrease the amount of needed supplemental fat, particularly in high energy turkey diets. Additionally, their use could aid in the gastrointestinal health and bird welfare with benefits on intestinal barrier function (Castro et al., 2020), foot pad health (Veldkamp et al., 2017; Hocking et al., 2018), and potentially performance (Adhikari et al., 2021). However, the general lack of recent information and data on amino acid requirements of commercial turkeys, especially relating to arginine, valine, tryptophan, and isoleucine, currently limit their widespread adoption in turkey diet formulations.

CONCLUSIONS

Historically, diet formulation as it relates to flexibility in amino acid concentration has been limited based on ingredient availability. At times, nutritionists had to try and balance individual amino acid concentration and dietary crude protein level for broilers and replacement breeders. In recent years, commercialization of feed grade amino acids for arginine, valine, isoleucine, and tryptophan allows for targeted increases of amino acid ratios to capture performance, health, environmental or behavioral benefits. As previously discussed, these amino acids can be added to provide functional benefits on intestinal function, oxidative stress, thermal stress, intestinal challenge, feathering, balance amino acid antagonisms, etc. These benefits improve efficiency and sustainability of production. However, it is clear that research gaps exist as it relates to a clear understanding of the minimum ratios (to lysine in broilers and to energy in breeders) to observe these functional benefits, and to the exact amino acid requirements for turkeys.

DISCLOSURES

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