Chapter

Cysteine in Broiler Poultry Nutrition

Iyakutye Jacob Nte and Hollinshead Holly Gunn

Abstract

The SAAs are limiting in the major poultry feed ingredients, ranking first and fifth in soya bean meal and maize, respectively. Feed ingredients rich in protein, in particular and other nutrients, enhance Energy supply and protein accretion. Modern commercial broilers have reduced maintenance needs and high amino acid requirements, and are more responsive to protein (amino acids) than energy. Cysteine is a semi-essential amino acid belonging to the SAAs. It plays essential roles in protein synthesis, structure and function, causing growth depressing effects in broiler chicks when there is methionine:cysteine imbalance. Genetically predetermined amino acid sequences in proteins are essential for production of adequate quantities of meat, milk and eggs. Therefore, ideal amino acid ratios which conform to the requirements of broilers should be utilized. In nutrition, amino acids are equivalent to proteins, hence the shift in focus from proteins to individual amino acids, expressed as ideal ratios to lysine. The SAAs are practically relevant and have critical nutritional roles in animal nutrition with over 90% production being used to fortify animal (particularly poultry) diets. A balance in the methionine:cysteine ratio is necessary to ensure efficient utilization of the SAAs for proper growth and development in broiler poultry.

Keywords: Cysteine, Sulfur-containing amino acids, Methionine-cysteine ratio, Broiler poultry

1. Introduction

The diets of broilers, and indeed most poultry, consists of maize and soya bean meal, primarily. These ingredients are limiting in certain amino acids, with the sulfur-containing amino acids (SAAs) ranking first and fifth in soya bean meal and maize, respectively [1]. Sulfur-containing amino acids are amino acids containing at least one sulfur atom, and therefore are considered as a group of sulfur bioactive molecules [2]. Generally, they affect protein metabolism, like other amino acids, leading to reduced protein synthesis when they are deficient in animal diets [3]. Among the four common sulfur-containing amino acids, namely methionine, cysteine, homocysteine, and taurine, only methionine and cysteine are incorporated into proteins [4]. However, all amino acids as constituents of proteins are a-amino acids, in which the molecular structure has the amino group attached to the same carbon atom as the carboxyl group [5], and only such amino acids are relevant for animal nutrition [1]. Apart from the ideal protein concept proposed for different categories of poultry, ideal amino acid ratios have also been proposed for broiler chickens [6]. Since methionine and lysine are the first and second limiting amino acids in poultry diets, their supplementation enhances the efficiency of protein utilization and hence, excretion of nitrogen.

The remarkable increase in the growth potentials of broilers in recent times, following their genetic improvement, has been attributed to artificial genetic selection [7], resulting in increased appetite and early attainment of market weight. However, some authors [8, 9] have suggested that other factors in combination with genetic make-up, such as nutrition, environment, age, sex, management, and health care, account for the successes achieved in managing dietary energy intake of broilers. Modern broilers perhaps eat to their physical capacity or adjust their feed intake in response to several factors including dietary energy [10], and increased nutrient density results in a linear improvement in weight gain and feed efficiency, without reduction in intake [11]. According to [12] constant intake of feeds high in protein and other nutrients increases supply of energy and results in a linear increase in protein accretion in tissues, until a maximum rate - a genetically defined term, is reached. Although the commercial objective in meat production is fostered by protein accretion, increased supply of energy beyond the "maximum rate", would merely translate into an excess of body fat [13], which is undesirable in terms of energetic efficiency [12].

There is the notion that today's broilers are more responsive to dietary protein (amino acids) and less to energy concentration due to reduced maintenance needs. This is occasioned by the significant reduction in market age and increased amino acid requirement, as driven by increase in the lean (muscle) growth as a percent of body weight [12]. It was reported by [14] that as little as 0.10% supplemental cysteine is growth depressing in chicks fed methionine deficient diets. This creates an imbalance in cysteine:methionine ratio, which affects the efficiency of DL-2-hydroxy-4-(methylthio) butyric acid, a precursor of methionine [6]. Apart from this imbalance, bioavailability of amino acids in proteins, which implies metabolism after digestion and absorption, is important in ensuring that they are absorbed in suitable chemical forms that can enhance protein synthesis [15–17]. Consequently, there is a dire need to ensure a balance in amino acid content of feeds using the ideal amino acid ratio, under the assumption that the ratio should remain largely unaffected by the variables that affect amino acid requirements [18]. It is also essential to supply dietary amino acids in their required profile conforming to the requirements of poultry [19].

2. Amino acids nutrition in poultry

It is well accepted that amino acids, as nutrients, are building blocks of proteins and play essential roles in the nutritional composition of all feed stuffs and vital physiological roles in the body of all livestock [20, 21]. The fact that it would have been very difficult, if not impossible, to produce the quantity of meat, milk, eggs, and fish demanded by consumers, without amino acids, accentuates their importance. The series of amino acids within the protein molecule, referred to as the amino acid sequence, is genetically predetermined, and they are essential nutrients which are a vital integral part of animal feeding regimens [1]. From direct hydrolysis of common nutritional feed proteins, about 20 different amino acids have been identified. These are known as the twenty canonical amino acids [2, 22]. In poultry nutrition, 21 amino acids are needed to form body proteins [23].

As functional and structural units of proteins, they are nutritionally classified into two groups: non-essential (synthesized in the body) and essential (cannot be synthesized rapidly and in sufficient quantities to meet their metabolic requirements) [24]. However, a number of non-essential amino acids can only be synthesized from essential amino acids (EAAs) and are called semi-essential amino acids (**Table 1**). It was further noted by [1] that the classification of amino acids into essential and non-essential should not be taken to imply that non-essential amino acids are not required for the synthesis of proteins. Consequently, [23] opined that a sufficient amount of non-essential amino acids must also be supplied alongside the essential amino acids by the diet, to prevent the conversion of essential into non-essential amino acids. To undertake such amino acid inter-conversions the animal requires sources of carbohydrates and suitable nitrogen compounds [1].

The amino acids relevant in animal nutrition are only α-amino acids, which exist as two optically active isomers i.e. the L-forms and D- forms, with one being a mirror image of the other (**Figure 1**). However, only the L-forms are found in proteins. Consequently, if both forms are supplied in animal diets in a 47:47 ratio, known as a "racemic mixture", the D-forms will be converted to the L-forms for ease of metabolism. There are differences in recommended essential amino acid levels in various guidelines, which raise concerns for the poultry sector [24]. Nevertheless, in the diet of poultry, amino acids must be balanced to avoid loss of energy that can be diverted to the synthesis of fats [25].

Amino acids chemically bound in proteins must be separated from the parent protein unit, before they can pass from the lumen of the gut across the intestinal wall (absorption) into the bloodstream. This separation occurs with the help of proteolytic digestive enzymes (proteases). The absorbed amino acids are transported via the hepatic portal vein into the liver, which is the principal organ for the metabolism of amino acids. The metabolism of proteins is made up of two opposing processes which occur simultaneously: accretion of proteins (anabolism i.e. synthesis) and breakdown of proteins (catabolism i.e. proteolysis) [1]. They further noted that whereas in mature animals a balance is reached between synthesis and proteolysis with no increase in the mass of the muscle but with continuous turnover, synthesis supersedes proteolysis in young growing animals, building up the proteins into muscle. Although, broilers are able to compensate for deficiencies of non-essential amino acids within certain limits through auto-synthesis, protein synthesis is terminated if one of the essential amino acids is lacking because some amino acids (the essential ones) cannot be synthesized by the organism [1]. Therefore, they opined that since the amino acid sequence of a protein is genetically predetermined, all the required amino acids must be present at the same time for individual amino acids to be synthesized (synchronous synthesis).

Once digested and absorbed, amino acids are used as the building blocks of structural proteins (muscle, skin, ligaments), metabolic proteins, enzymes, and precursors of several body components. Because body proteins are constantly being synthesized and degraded, an adequate amino acid supply is critical to support growth or egg production [23]. Broilers, like other poultry, are believed to develop better immune function when adequate levels of dietary amino acids are provided.

Essential	Arginine[1], Histidine, Isoleucine, Leucine, Lysine, Methionine, Phenylalanine, Threonine, Tryptophan, Valine
Semi-essential	Cystine (Cysteine)[2], Tyrosine
Non-essential	Alanine, Asparagine, Aspartic Acid, Glutamic Acid, Glutamine, Glycine, Proline, Serine

[1]*In swine, Arginine is essential only in young animals.*
[2]*Cystine = dimer of cysteine.*
Source: Dalibard et al. [1].

Table 1.
Essentiality of amino acids in pigs and poultry nutrition.

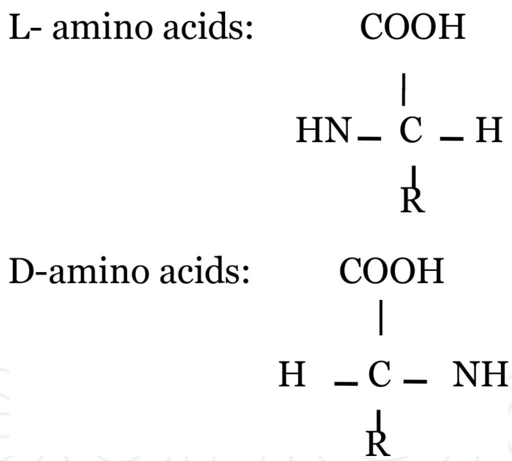

Figure 1.
General structure of L - D- isomers. Source: Dalibard et al. [1].

Since the health status and productivity of poultry are directly related to their immune status, there will be an increased demand for amino acids, particularly essential amino acids, under conditions of immune stress [23]. This is because amino acids are indispensable in the production of antibodies and cytokine, and hence in immune function [26–28].

Amino acids are analogous to proteins, from the standpoint of the fundamentals of nutrition. The main emphasis in the nutrition of animals has therefore, been shifted from a focus on protein as a whole to a focus on individual amino acids [1]. The authors also noted that great importance is therefore attached to the concept of amino acid flux - the continuous supply of free amino acids from the feed into the animal's metabolism and in the ideal ratios. These should be taken into account, when supplementing amino acids to mixtures of feed. In modern practical feeding systems, amino acid supplementation has been proven to be an effective method to continuously balance the amino acid supply at the site of protein synthesis. Therefore, the knowledge of digestible amino acid requirements and their digestibility in common feed ingredients fed to poultry are viewed as important tools in advancing knowledge in amino acid nutrition and metabolism of poultry [4]. However, according to [29–31] there are variations in the utilization efficiencies of individual essential amino acids.

2.1 Ideal amino acid ratios

A myriad of dietary, genetic and environmental factors impinge on the amino acid requirements of all livestock. The general notion nowadays is that, poultry requirement for any amino acid is proportionally linked to the requirement for the others. The indication is that the supply of one amino acid will improve performance only if no other amino acid is limiting [32]. Consequently, they also noted that poultry and swine nutritionists use lysine as a reference point in the ideal amino acid concept, and express the requirement for other amino acids as a percentage of the requirement for lysine. However, this was first established for swine for different weight categories [33]. The choice of lysine as the reference amino acid was based on a number of conditions namely, its position as the second limiting amino acid and ease of supplementation in commercial diets; its exclusive post-absorption use in protein accretion, maintenance and lack of a precursor role; relative ease of analysis in feedstuffs; and availability of a large pool of data on responses under different dietary concentrations, body compositional and varying environmental conditions [34, 35].

It has been well recognized that the requirements for amino acids by poultry cannot be valid under all dietary, sex and body compositional scenarios [36, 37]. A way out of this challenge, in order to obtain reliable amino acid requirements, is to express all amino acid requirements as ideal ratios to lysine. The ideal amino acid ratio utilizes the concept that the ideal ratios of the absolute or indispensable amino acids to lysine as published by [38] are slightly altered by drastic deviations in their requirements occasioned by genetic or environmental factors. Normally, the ideal amino acid profile only includes provisions for essential amino acids implying that the diet supplies sufficient non-essential amino acids. The non-essential amino acids should make up about half of the dietary protein with the remainder supplied by essential amino acids [39–41]. Ideal amino acid profiles should be based on digestible amino acids, particularly when diet formulation is done with other ingredients other than maize and soya bean [34]. If the amino acids supplied are in the proper, or ideal, ratio in relation to the needs of the animal, then amino acids in excess of the least limiting amino acid will be deaminated [42] and likely used as a source of energy rather than towards body protein accretion.

The overall benefits of the concept of ideal amino acid ratios are two fold namely, it enables the calculation of the requirements for the indispensable amino acids after an accurate determination of lysine requirement, and it allows the most efficient and economical use of proteins in diet formulation to allow for maximum utilization and minimum excretion of nitrogen [34].

2.2 Sulfur-containing amino acids

Sulfur is an abundant element in biological systems, which plays an important role in processes essential for life as a constituent of proteins, vitamins and other crucial biomolecules [22]. Sulfur-containing amino acids (SAAs) are amino acids which contain a sulfydryl group and are considered to be non-polar and hydrophobic [43, 44]. Generally, they play crucial roles in protein structure, metabolism, immunity, and oxidation [2, 44–46]. As noted earlier, there are four common sulfur-containing amino acids namely, methionine, cysteine, homocysteine, and taurine (**Figure 2**), but only methionine and cysteine are incorporated into proteins [5]. On this account, they are deemed as the principal or primary Sulfur-containing amino acids, although homocysteine and taurine also play important physiological roles. They are, therefore, classified as proteinogenic, canonic amino acids incorporated into the structure of proteins [22].

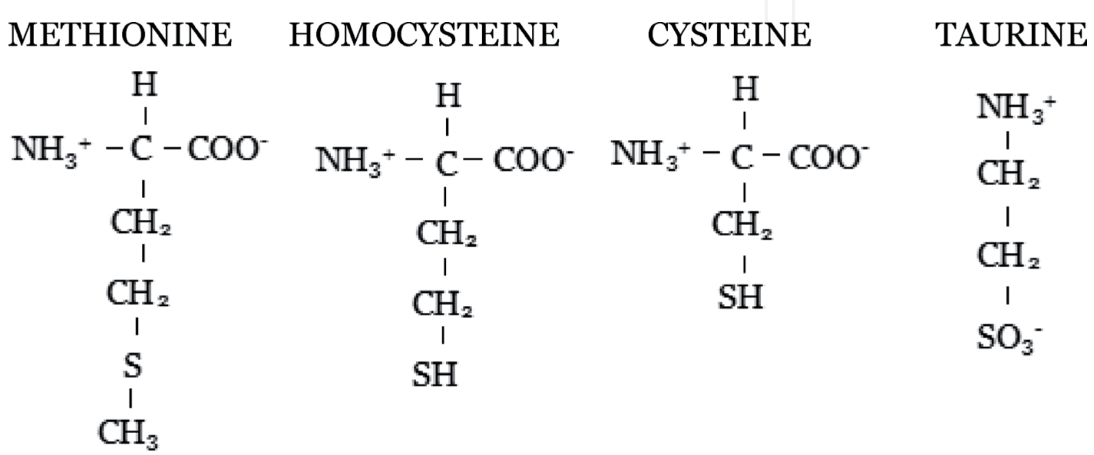

Figure 2.
Structures of the sulfur-containing amino acids. Source: Brosnan and Brosnan [4].

2.2.1: Primary SAAs: Methionine and cysteine are generally considered to be non-polar and hydrophobic, and are present in animal and plant proteins in varying proportions. Methionine is one of the most hydrophobic amino acids and is almost always found in the interior of proteins. Cysteine, which is genetically encoded by two possible codons (nucleotide triplets of mRNA) UGU and UGC [45], ionizes and readily forms disulfide linkages because of the ease with which it dissociates to yield a thiolate anion. Cysteine is also confined to the interior of proteins because the thiol group can be easily oxidized to form disulphide bonds. Methionine is an essential amino acid whereas cysteine is semi-essential because it can be synthesized from methionine and serine by trans-sulfuration [47]. Both methionine and cysteine are gluconeogenic, but methionine is a neutral amino acid while cysteine is basic [48].

Depending on the species of animal, cysteine may be responsible for up to 47% of the dietary methionine requirement, and this proportion has been shown to be lower in high performance animals [1]. The requirement for SAAs in the diet of animals is assessed on the basis of the content of methionine and cysteine [43]. When fed at supplemental levels well above the dietary requirement, methionine causes more serious growth depressing effects than other essential amino acids, but not much is known about responses of broilers to excess dietary cysteine [6, 49]. However, [50] suggested that excess dietary L-cysteine causes acute metabolic acidosis in chicks but not in pigs and rats. According to [6], no other amino acid, even at far higher doses, is known to elicit such lethality as observed with excess L-cysteine.

Sulfur-containing amino acids play critical roles in protein synthesis, structure and function. Sulfur amino acids are involved in the synthesis of intracellular anti-oxidants such as glutathione and N-acetyl cysteine, and represent a powerful part of cell antioxidant system [22]. Thus, they are essential in the maintenance of normal cellular functions and health. In addition to their worthy antioxidant action, sulfur-containing amino acids may offer a chelating site for heavy metals. Accordingly, they may be supplemented during chelating therapy, providing beneficial effects in eliminating toxic metals [22]. When animals are fed cysteine deficient diets, the SAAs and their derivatives (L-cysteine, L-cystine, N-acetyl-L-cysteine, and L-methionine) are not known to have depressing effects on their growth at iso-sulfurous levels [51]. L-cysteine and L-cystine can partially replace or reduce the metabolic requirement for methionine in different species of animals to the level of 38–77%, and are known as "spare amino acids" [52]. Research efforts into SAAs is of great practical relevance to animal nutrition in that well over 90% of their production is used to fortify diets for animals, particularly poultry [53]. He further indicated that poultry diets around the world are based on corn and soybean meal, and these diets for poultry, without fortification, are deficient in SAAs. Therefore, the nutritional roles of SAAs are of critical importance to the animal nutritionist as well as to the metabolic scientist.

This chapter focuses on cysteine which is biosynthesized from methionine, plays critical roles in protein structure, apparently irreplaceable by any other amino acid, amidst its role in broiler chicken nutrition – particularly the need for a balance between it and other amino acids to foster the growth, development and overall productivity of broilers.

2.2.2: Forms and derivatives of cysteine: Cysteine is special among coded amino acids because it contains a reactive sulph-hydryl group. Cysteine therefore, easily undergoes oxidation and, like methionine, it is confined to the interior of proteins. In the process it reacts with itself to form a disulphide bond, or with other thiols (Sulfur-containing compounds), yielding cystine [48]. Cystine is therefore a dimer of cysteine. In the plasma, and in fact the extracellular space, cysteine occurs primarily as cystine [54], and these are the two primary forms of cysteine relevant to animal nutrition. From its metabolic pathway it produces few intermediate substrates and derivatives namely, cystathionine, homocysteine, γ-glutamylcysteine, glutathione, hypotaurine and taurine.

The levels of cysteine and cystine in the cell milieu are maintained by adjustments in the ratio of L-cystine to L-cysteine by cellular control of their efflux and uptake. According to [50], the intracellular ratio of L-cystine to L-cysteine is improved by the efflux and uptake of L-cysteine and L-cystine from and by the cells, respectively. Conversely, their extracellular ratio is increased by uptake of L-cysteine and its oxidation to L-cystine, and efflux of L-cystine by the cells. This is illustrated in **Figure 3**.

3. Cysteine requirements

An animal's amino acid requirement is made up of the total requirement for protein accretion and maintenance. Due to faster growth rate and earlier market age of modern commercial broilers, the requirement for maintenance function becomes reduced [53]. Consequently, the relative need for protein accretion to maintenance varies for individual amino acids. Therefore, the requirement for cysteine and other amino acids with high maintenance needs relative to lysine will reduce [35]. In broiler poultry nutrition, optimum amino acid density must be maintained when considering the balance between energy and proteins in their feed, indicating a higher ratio of essential amino acids to energy in modern broilers [13]. This conforms to the fact that modern commercial broilers are different from those offered by the poultry industry in the 90s when the NRC nutrient requirement for poultry was published. Genetic selection, management practices, and changes in feed are believed to be partially responsible for this [55, 56].

The requirement for total SAAs recommended by [37] were 0.9, 0.69, and 0.57 for 0–3, 3–6, and 6–8 weeks, respectively, as against weekly requirements of 0.94, 0.9, 0.82, 0.78, 0.74, 0.71, and 0.67% for 1–7 weeks of age in modern broilers as presented by [57]. However, proper assessment of amino acid requirements have remain unresolved owing to the difficulty posed by underestimation and overestimation by the oxidation and nitrogen balance methodologies, respectively [51]. Biosynthesis of cysteine occurs in animals and plants via the trans-sulfuration pathway from methionine, in the presence of adequate nitrogen and sulfur [58]. However, since cysteine is synthesized from methionine via the trans-sulfuration pathway, its requirement is usually considered together with methionine [59].

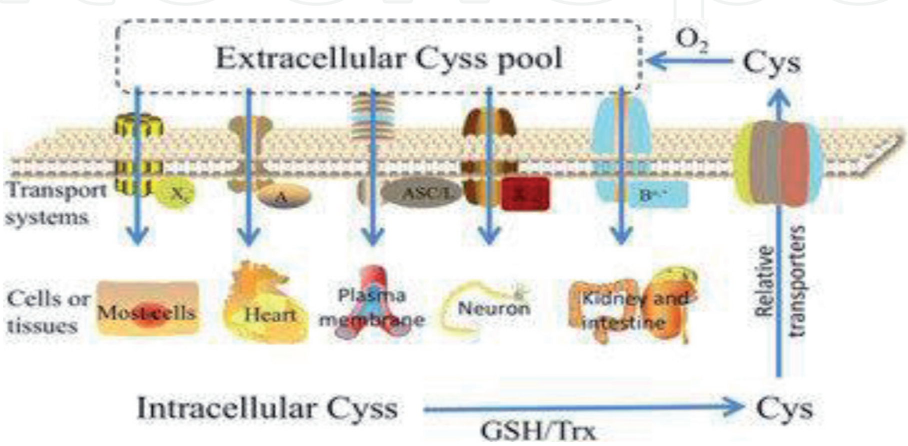

Figure 3.
Extracellular and intracellular L-cysteine/L-cystine balance and L-cysteine/L-cystine transport systems. Glu, L-glutamate; Cyss, L-cystine; Cys, L-cysteine; GSH, glutathione; Trx, thioredoxin. Source: Baker [50].

Although there is adequate physiological concentrations of cysteine, many cells still rely on the trans-sulfuration pathway for a minimum of 47% of their cysteine requirements [60]. Cysteine requirement is therefore subsumed in the total SAAs requirement as captured by [35, 55] for different age ranges in poultry. Commercial diets are traditionally formulated to meet broiler requirements for methionine + cystine (Met + Cys), based on the assumption that amounts of dietary Met are converted into Cys [61].

4. Cysteine digestibility and bioavailability

Following a combination of heat treatment and alkaline food processing some alterations occur in the chemical nature of cysteine leading to some effects in its digestibility and subsequent absorption. These two processes are vital in ensuring the assimilation of amino acids by broilers. Heat processing causes the oxidation of a significant portion of protein-bound cysteine to cystine, which has lower digestibility [62]. This may probably be due to the formation of disulphide bridges during the transformation process. Dietary cystine is also converted to lanthionine under the influence of heat and alkali treatment [63]. The reduced SAA activity of lanthionine results in reduced availability of protein-bound cysteine [64]. Since protein metabolism continues even when no protein is being consumed, some of the amino acids released are oxidized and are not available for re-synthesis of new proteins. Feeding a protein-free diet to broilers, therefore, elicit a cysteine response (reduction in body weight loss and improves nitrogen balance) [65], indicating that it could be substantially depleted in the body pool making it the first limiting amino acid for endogenous protein synthesis [53].

All the nutrients ingested by an animal via its diet cannot be utilized by the animal because some are undigested. Furthermore, some are either absorbed in forms that cannot be utilized for physiological and metabolic functions in the body or are not absorbed at all. The available nutrients refer to the portion of the nutrients that are digested, absorbed and metabolized [20]. The same is true of amino acids, which are bioavailable if they occur in forms that can be utilized by the cells for maintenance or production. Digestibility of amino acids, therefore, is the digestion of the amino acids consumed in the diets and their subsequent absorption from the lumen of the small intestine into the bloodstream [66]. The portion of the absorbed amino acids present in chemical forms amenable to protein synthesis indicates their bioavailability [17]. The concept of digestible amino acids is critical to establish ideal protein ratios [67], and broiler diets are now formulated based on digestible proteins and amino acids [68].

5. Vital roles of cysteine in broiler poultry nutrition

Cysteine can be synthesized from methionine and serine by trans-sulfuration [47]. As one of the naturally occurring biogenic amino acids, cysteine plays crucial roles at all the levels of protein structure because it is easily oxidized to cystine, a feature that is very vital for the analysis of the primary structure of proteins; for effects on changes in secondary structure and for stabilization of tertiary and quartenary structure of proteins [69]. It was further noted that it possesses a sulfhydryl group in its side chain, according it a special position that cannot be replaced by any other amino acid. Cysteine, by virtue of its ability to form inter- and intra-chain disulfide bonds, plays a crucial role in protein structure and in protein-folding pathways. Such bonds, known as disulphide linkages, are common in proteins destined for export or residence on the plasma membrane [70]. He also noted that any mismatched disulfide bonds are rearranged to ensure the correct protein folding under the influence of protein disulfide isomerase (an endoplasmic reticulum protein).

Basically, cysteine (and methionine too) is incorporated into structural proteins, and it is also required for normal growth. The two are major protein constituents of feathers and hair, with methionine occurring in greater percentage in muscle while cysteine is higher in feather keratin [61]. Cysteine has been reported to be thirteen (13) times higher in broiler feathers than methionine [71, 72]. This indicates their importance in growth and feather development of broiler poultry. Reduced feed intake and weight gain have been associated with L-cysteine supplementation in young animals. Its anoretic effects have been reported to manifest as reduced final body weight, body weight gain, feed intake, and feed efficiency in rats [73]. This was attributed to the bitter taste imparted by L-cysteine. However [74], reported that reduced (Cys) and oxidized (cystine) forms of cysteine support animal growth equally when provided in a cyst(e)ine deficient and methionine adequate diet. Since L-cysteine is a spare amino acid for Methionine, as the adverse effects of L-methionine deficiency can be ameliorated by L-cysteine supplementation in the diet of animals [75]. In the opinion of [54], whole body protein synthesis and physiological Homeostasis can be maintained by dietary supplementation of L-cysteine under conditions of impaired L-methionine catabolism.

Cysteine is involved in the biosynthesis of methionine by accelerating the pathway leading to the formation of pheomelanin, thereby blocking the formation of eumelanin that produces dark colors [76]. Cysteine itself is a powerful antioxidant and has the potential to trap reactive oxygen species (ROS) [5]. It plays a central role in the antioxidant protection system of the body such as glutathione (GSH), by functioning as a precursor of some constituents [77, 78]. GSH is a potent antioxidant which protects the body against toxic effects of elevated levels of endogenous and exogenous electrophiles [79]. Taurine, another SAA, and Hydrogen sulphide are also produced from dietary L-cysteine and they play vital roles in the reduction of oxidative stress and protection against several environmental toxins [80].

It has the capacity to improve intestinal histomorphometric indices of broiler chickens with a consequent increase in absorption of nutrients [81]. High L-cysteine concentration has been observed in proteins and mucins that contribute to the maintenance of gut integrity and plays key roles in intestinal structure and function [82, 83]. The indications are, therefore, that L-cysteine deficiency causes certain degrees of intestinal distortions and is essential in the maintenance of intestinal integrity and function.

Lipid metabolism is also mediated by L-cysteine and its derivatives such as S-methyl L-cysteine with hypoglyemic and antihyperlipidemic characteristics, through reduction in fasting blood sugar and total triglycerides [84], and N-acetlycysteine which improves lipid metabolism by affecting serum cholesterol, triglycerides, Very High Density Lipoproteins (VHDL), and High Density Lipoproteins (HDL) levels [85]. The mode of action of L-cysteine underlying these effects are not clear, but it is believed to be partially accounted for by its target on gene expression of certain biochemical substances such as element-binding protein and fatty acid synthase [85]. Its roles in lipid metabolism and positive correlation with fat mass are eloquent testimonies [75].

Cysteine is, in fact, a rather potent reducing agent in addition to its capacity of being capable of either chelating or complexing trace elements [6]. Its reducing agent bio-activity when supplemented in diets at 0.38%, is capable of converting pentavalent to trivalent organic arsenic, which is up to 100 times more toxic and of great significance in poultry and animal nutrition [86]. The authors also opined that this has great implication in the use of certain poultry drugs e.g. coccidiostats containing pentavalent organic arsenic, whose toxicity is accentuated by pharmacologic cysteine. It is well established that modest excesses of SAAs, particularly cysteine, can have marked pharmacologic effects on trace-mineral utilization, but far less is known about effects of excess cysteine ingestion [87].

6. Methionine-cysteine balance

Methionine and cysteine are closely related in that the latter is endogenously synthesized from the former via the trans-sulfuration pathway by L-methionine degradation [43]. In this pathway, methionine is converted to homocysteine, which in turn donates a sulfur group to serine (a non-essential amino acid) to ultimately form cysteine. The production of cysteine accounts for 47% of methionine dietary requirement [48]. L-cysteine can furnish up to 47% and 77% of the requirements for SAAs in young and older animals, respectively [88]. Nevertheless, the practice of formulating commercial diets to contain adequate methionine+cysteine, with the assumption that dietary methionine is converted to cysteine, is common. This may lead to reduced efficiency of amino acid utilization, since methionine will be supplied in excess. This can be addressed by adequate knowledge of methionine:cysteine ratio in relation to total sulfur amino acids (TSAAs), and the quantity of methionine converted to cysteine [61]. Another condition of imbalance is created when excess cysteine is provided in methionine deficient diets, with growth depressing effects in chicks [14]. Such imbalances need to be addressed to ensure efficient utilization of the SAAs by broilers.

As broilers age or increase in weight, maintenance needs for amino acids, including methionine and cysteine, and ideal amino acid ratios will alter. However, not much is known about the methionine:cysteine ratio, although a ratio of 52:43 [89] and a minimum of 49:45 [61] has been recommended for poultry and growing broilers, respectively. Also, little is known about the effects of excess cyst(e)ine on chicks, but among the EAAs, excess methionine is known to have the most adverse effects on growth [71, 90]. Variations in the ratio of these amino acids affect growth responses in broilers, and the utilization and efficacy of hydroxyl analogues of methionine or its precursors [6]. Therefore, determination of the optimum methionine:cysteine ratio in relation to TSAAs is necessary to foster proper growth and development of broilers.

7. Conclusions

The primary ingredients used in broiler poultry nutrition are limiting in SAAs in particular. Methionine and cysteine as the major SAAs, are α-amino acids which are important in animal nutrition. The recent increase in growth potentials of modern commercial broilers has been attributed to genetic improvement resulting in increased appetite and early market weight. They are more responsive to proteins (amino acids) than to energy concentration due to reduced maintenance need. Amino acids play vital nutritional and physiological roles in all livestock and must be supplied in appropriate ratios to foster protein accretion, the major objective in broiler poultry production. Nutritionally, amino acids are equivalent to proteins, warranting a shift in focus from proteins to individual amino acids.

Dietary amino acids must be in the ideal ratios for efficient use of proteins in diet formulation, maximum utilization and minimum excretion of nitrogen. Among the SAAs, methionine and cysteine are gluconeogenic and need to be balanced to circumvent the lethality associated with excess cysteine, an apparently irreplaceable amino acid. However, biosynthesis of cysteine occurs in animals and plants via the trans-sulfuration pathway from methionine, and its requirement is subsumed in the TSAAs requirement in poultry. Basically, cysteine is incorporated into structural proteins, and is required for normal growth. A balance in the methionine:cysteine ratio is therefore, necessary to ensure efficient utilization of the SAAs, so as to foster proper growth and development in broiler poultry.

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Conflict of interest

The authors declare no conflict of interest.

Author details

Iyakutye Jacob Nte* and Hollinshead Holly Gunn
Department of Animal Science, Faculty of Agriculture, Rivers State University, Port Harcourt, Nigeria

*Address all correspondence to: nte.iyakutye@ust.edu.ng

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