# THE IDEAL AMINO ACID PROFILE FOR LAYING HENS

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## INTRODUCTION

Laying hens have a physiological requirement for amino acids for synthesis of body and egg proteins as well as non-protein, amino acid–derived compounds (e.g., serotonin, adrenaline, nitric oxide, glutathione, and carnitine). Nevertheless, diets can be formulated on a crude protein basis as long as only a few protein-supplying feed ingredients are used (e.g., corn, soybean meal, and meat and bone meal). However, if it is accepted that hens need amino acids, not protein, the need to monitor or formulate laying hen diets with a crude protein minimum disappears. Instead, diets can be formulated to meet individual amino acid requirements, which is done by specifying minimum dietary amino acid contents in the least-cost formulation software (and avoiding specifying a minimum crude protein content). Essentially, the computer program balances for the second- or third-limiting amino acid using protein-supplying ingredients (e.g., corn and soybean meal) and supplements the now deficient first- and second-limiting amino acids with crystalline amino acids, while at the same time considering ingredient and finished-diet costs. Of course, this approach requires accurate estimates of the hens' amino acid requirements and of the contents of available amino acids in feed ingredients.

## AMINO ACID REQUIREMENTS

Amino acid recommendations for laying hens are published by the National Research Council (**NRC**) (1994). However, the experiments upon which these requirements are based are dated and do not account for the genetic progress of laying hens in the last 15 years. Amino acid requirements have been reported since the publication of the NRC requirements (Table 1). However, the reported requirements are based on data from experiments which have been conducted for one amino acid at a time, performed under different experimental conditions with different basal diets, genetic lines, feed consumption rates, egg production rates, dietary energy contents, ambient temperature, cage and feeder space, health status, and body weights (ages) of laying hens—all of which influence the amino acid requirements. As a result, there is little agreement between amino acid requirements among studies, making it difficult at best to decide which requirement to use in diet formulation.

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**Table 1.** Amino acid requirements of single-comb white leghorn laying hens for maximal egg mass.

| Amino acid | Age | Requirement | Basis[1] | Maximal response | Genetic line | Source |
|---|---|---|---|---|---|---|
| | *weeks* | *mg × hen⁻¹ × d⁻¹* | | *g × hen⁻¹ × d⁻¹* | | |
| Arginine | — | 700 | Total | — | — | NRC (1994) |
| | — | — | Digestible | — | — | CVB (1996) |
| | 32–45 | 760 | Total | — | — | Leeson and Summers (2005) |
| | 33–49 | 968 | Digestible | 50 | Hy-Line W-36 | Coon and Zhang (1999), Exp. 2 |
| | 35–47 | 791 | Digestible | 52 | Hy-Line W-36 | Coon and Zhang (1999), Exp. 3 |
| Isoleucine | — | 650 | Total | — | — | NRC (1994) |
| | — | 550 | Digestible | — | — | CVB (1996) |
| | 32–45 | 600 | Total | — | — | Leeson and Summers (2005) |
| | 33–49 | 603 | Digestible | 50 | Hy-Line W-36 | Coon and Zhang (1999), Exp. 2 |
| | 35–47 | 555 | Digestible | 52 | Hy-Line W-36 | Coon and Zhang (1999), Exp. 3 |
| | 37–43 | 469 | Total | 57 | Hy-Line W-36 | Shivazad et al. (2002) |
| | 38–44 | 601 | Total | 48 | Hy-Line W-36 | Harms and Russell (2000a) |
| Lysine | — | 690 | Total | — | — | NRC (1994) |
| | — | 700 | Digestible | — | — | CVB (1996) |
| | 32–45 | 760 | Total | — | — | Leeson and Summers (2005) |
| | 24–36 | 715 | Total | 56 | Lohmann LSL | Schutte and Smink (1998) |
| | 24–36 | 539 | Digestible | 56 | Lohmann LSL | Schutte and Smink (1998) |
| | 33–49 | 705 | Digestible | 50 | Hy-Line W-36 | Coon and Zhang (1999), Exp. 2 |
| | 35–47 | 636 | Digestible | 52 | Hy-Line W-36 | Coon and Zhang (1999), Exp. 3 |
| | 38–50 | 683 | Digestible | 56 | Dekalb delta | Coon and Zhang (1999), Exp. 4 |
| Methionine | — | 300 | Total | — | — | NRC (1994) |
| | — | 350 | Digestible | — | — | CVB (1996) |
| | 32–45 | 390 | Total | — | — | Leeson and Summers (2005) |
| | 25–45 | 371 | Total | 43 | Shaver 288 | Waldroup and Hellwig (1995) |
| | 29–35 | 350 | Digestible | 54 | Dekalb XL | Coon and Zhang (1999), Exp. 6 |
| | 33–49 | 354 | Digestible | 50 | Hy-Line W-36 | Coon and Zhang (1999), Exp. 2 |
| | 51–58 | 402 | Total | 43 | Shaver 288 | Waldroup and Hellwig (1995) |
| | 60–72 | 283 | Digestible | 51 | Hy-Line W-36 | Coon and Zhang (1999), Exp. 5 |
| | 64–71 | 378 | Total | 43 | Shaver 288 | Waldroup and Hellwig (1995) |
| Methionine + cystine | — | 580 | Total | — | — | NRC (1994) |
| | — | 650 | Digestible | — | — | CVB (1996) |
| | 32–45 | 670 | Total | — | — | Leeson and Summers (2005) |
| | 25–37 | 645 | Total | 56 | Lohmann LSL | Schutte et al. (1994) |
| | 25–45 | 622 | Total | 43 | Shaver 288 | Waldroup and Hellwig (1995) |
| | 29–35 | 595 | Digestible | 54 | Dekalb XL | Coon and Zhang (1999), Exp. 6 |
| | 33–49 | 551 | Digestible | 50 | Hy-Line W-36 | Coon and Zhang (1999), Exp. 2 |
| | 51–58 | 691 | Total | 43 | Shaver 288 | Waldroup and Hellwig (1995) |
| | 60–72 | 496 | Digestible | 51 | Hy-Line W-36 | Coon and Zhang (1999), Exp. 5 |
| | 64–71 | 676 | Total | 43 | Shaver 288 | Waldroup and Hellwig (1995) |
| Threonine | — | 470 | Total | — | — | NRC (1994) |
| | — | 460 | Digestible | — | — | CVB (1996) |
| | 32–45 | 610 | Total | — | — | Leeson and Summers (2005) |
| | 29–37 | 425 | Total | 54 | Dekalb XL | Ishibashi et al. (1998) |
| | 31–38 | 462 | Total | 53 | Hy-Line W-36 | Faria et al. (2002) |
| | 33–49 | 560 | Digestible | 50 | Hy-Line W-36 | Coon and Zhang (1999), Exp. 2 |
| | 35–47 | 430 | Digestible | 52 | Hy-Line W-36 | Coon and Zhang (1999), Exp. 3 |
| | 37–45 | 457 | Total | 53 | Dekalb XL | Ishibashi et al. (1998) |
| | 45–52 | 447 | Total | 47 | Hy-Line W-36 | Faria et al. (2002) |

*Continues*

Table 1. *Continued.*

| Amino acid | Age *weeks* | Requirement $mg \times hen^{-1} \times d^{-1}$ | Basis[1] | Maximal response $g \times hen^{-1} \times d^{-1}$ | Genetic line | Source |
|---|---|---|---|---|---|---|
| Tryptophan | — | 160 | Total | — | — | NRC (1994) |
| | — | 130 | Digestible | — | — | CVB (1996) |
| | 32–45 | 160 | Total | — | — | Leeson and Summers (2005) |
| | 30–36 | 149 | Total | 45 | Hy-Line W-36 | Harms and Russell (2000b) |
| | 33–49 | 122 | Digestible | 50 | Hy-Line W-36 | Coon and Zhang (1999), Exp. 2 |
| | 55–59 | 137 | Total | 44 | Hy-Line W-36 | Russell and Harms (1999) |
| | 60–72 | 143 | Digestible | 51 | Hy-Line W-36 | Coon and Zhang (1999), Exp. 5 |
| Valine | — | 700 | Total | — | — | NRC (1994) |
| | — | 600 | Digestible | — | — | CVB (1996) |
| | 32–45 | 680 | Total | — | — | Leeson and Summers (2005) |
| | 33–49 | 731 | Digestible | 50 | Hy-Line W-36 | Coon and Zhang (1999), Exp. 2 |
| | 35–47 | 646 | Digestible | 52 | Hy-Line W-36 | Coon and Zhang (1999), Exp. 3 |
| | 41–47 | 619 | Total | 47 | Hy-Line W-36 | Harms and Russell (2001) |

[1]The requirement is expressed on a total or apparent fecal digestible amino acid basis.

## THE IDEAL AMINO ACID PROFILE

Because multiple factors affect amino acid requirements, those requirements determined under experimental conditions are unlikely to be applicable under field conditions. The solution to obtaining reliable amino acid requirements is therefore *not* to use the absolute amino acid recommendations shown in Table 1, but rather to use the ideal amino acid profile for laying hens. The ideal amino acid profile employs the concept that, while absolute amino acid requirements change drastically due to genetic or environmental factors, the ratios among them are only slightly affected. Thus, once the ideal amino acid profile has been determined, the requirement for a single amino acid (e.g., lysine) can be determined experimentally or modeled for a given field situation and the requirement for all the other amino acids calculated using the individual ideal amino acid ratios in the profile. Such an approach has been adopted with success by the swine industry (NRC, 1998) and is finding use in the broiler industry as well (Mack et al., 1999; Baker, 2003; Dari et al., 2005).

To ensure a valid measurement of the ideal amino acid profile, the same basal diet, the same genetic line, and the same assay period should be used in all assays of amino acid requirements (Baker, 2003). Preferably, the ideal amino acid profile should also be defined with separate ratios for maintenance, body weight gain, and egg production, because the relative amino acid needs partitioned among these change with changing body weight (age), egg production rate, and egg weight (Fisher et al., 1973; Baker, 1997; NRC, 1998). Normally, the ideal amino acid profile only includes provisions for essential amino acids and it is implied 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 (Heger et al., 1987, 1998; Lenis et al., 1999).

### The ideal amino acid profile for laying hens

The NRC (1994), the Dutch Centraal Veevoederbureau (**CVB**) (1996), and Leeson and Summers (2005) report individual amino acid requirements from which the ideal amino acid profile can be calculated (Table 2). However, these requirements were estimated from data compiled from a variety of experiments and, therefore, influenced by genetics and environmental factors as mentioned previously. Rostagno (2005) reports a single ideal amino acid profile for white- and brown-egg laying hens (Table 2), but the sources of the data from which the ideal ratios are derived are not mentioned. In contrast, Coon and Zhang (1999) conducted five separate experiments to determine the amino acid requirements of laying hens and reported the ideal amino acid profile using average amino acid requirements from the five experiments (Table 2). However, although better than the NRC (1994) and CVB (1996) approaches, these experiments were still performed under different experimental conditions with different basal diets, ages, and genetic lines of hens. Thus, the ideal amino acid profile (or requirements) reported by Coon and Zhang (1999) is subject to similar criticism as that of NRC (1994) and CVB (1996). Indeed, to ensure a valid measurement of the ideal amino acid profile, the same basal diet, the same genetic line, and the same assay period should be used in all experiments of amino acid requirements used to calculate the profile (Baker, 2003). Bregendahl et al. (2008) recently conducted a study to determine the ideal amino acid profile for laying hens following the guidelines by Baker (2003). In this study, seven separate experiments were conducted simultaneously to determine the ideal ratios of arginine, isoleucine, methionine, methionine+cystine, threonine, tryptophan, and valine relative to lysine for maximal egg mass. A single basal diet was used in the study to which crystalline amino acids were added to create the graded level of the respective assay amino acid and to ensure that the assayed amino acid was first limiting. The requirement for each amino acid (on a true digestible basis) was determined using the broken-line regression method, considered best for determining the ideal amino acid profile (Mack et al., 1999), and the ideal amino acid profile was subsequently calculated from the observed requirements (Table 2).

**Table 2.** Ideal amino acid profiles for single-comb white leghorn laying hens.[1]

| Amino acid | NRC (1994)[2] | CVB (1996)[3] | Coon and Zhang (1999)[4] | Leeson and Summers (2005)[5] | Rostagno (2005)[6] | Bregendahl et al. (2008)[7] |
|---|---|---|---|---|---|---|
| Lysine | 100 | 100 | 100 | 100 | 100 | 100 |
| Arginine | 101 | — | 130 | 103 | 100 | —[8] |
| Isoleucine | 94 | 79 | 86 | 79 | 83 | 79 |
| Methionine | 43 | 50 | 49 | 51 | 50 | 47 |
| Methionine+cystine | 84 | 93 | 81 | 88 | 91 | 94 |
| Threonine | 68 | 66 | 73 | 80 | 66 | 77 |
| Tryptophan | 23 | 19 | 20 | 21 | 23 | 22 |
| Valine | 101 | 86 | 102 | 89 | 90 | 93 |

[1]Amino acid requirements expressed as a percentage of the requirement or recommendation for lysine.
[2]Calculated from total amino acid requirements.
[3]Calculated from digestible amino acid recommendations.
[4]Based on digestible amino acid requirements.
[5]Calculated from total amino acid recommendations for 32-to-45-week-old laying hens.
[6]Digestible amino acid basis.
[7]Based on true digestible amino acid requirements for maximal egg mass in 28-to-34-week-old laying hens.
[8]The arginine:lysine ratio was estimated to be 107 or less.

The ideal amino acid profile determined by Bregendahl et al. (2008) indicated that hens need less true digestible methionine, isoleucine, and valine and more true digestible threonine in relation to lysine than that suggested by Coon and Zhang (1999) and that calculated from recommendations published by the NRC (1994) (Table 2). The determined ideal amino acid profile agreed well with the profile calculated from amino acid recommendations suggested by Leeson and Summers (2005) for 32-to-45-week-old hens and is similar to that reported by Jais et al. (1995) with the exception of tryptophan and valine. The ideal methionine:lysine and methionine+cystine:lysine ratios in the study by Bregendahl et al. (2008) were higher than those reported by the NRC

(1994) and the methionine+cystine:lysine ratio of 75% reported by Liu et al. (2005), but agree well with the ratios suggested by the CVB (1996), Leeson and Summers (2005), and Rostagno (2005). The ideal isoleucine:lysine ratio determined by Bregendahl et al. (2008) corresponded well with that calculated from amino acid recommendations by the CVB (1996) and Leeson and Summers (2005). The hens in the study by Bregendahl et al. (2008) did not respond to the consumption of arginine, but, if the lowest arginine consumption observed (574 mg/d) is accepted as meeting or exceeding the arginine requirement, the ideal arginine:lysine ratio should be no higher than 107%—similar to that calculated from the arginine and lysine recommendations by NRC (1994) and CVB (1996), but substantially less than the 130% recommended by Coon and Zhang (1999).

The differences in individual ideal amino acid ratios shown in Table 2 reflect differences in how they were determined (i.e., by calculation from averages of amino acid requirements from many or few experiments) and likely by differences in body weight and production rate of the hens used in the respective experiments (i.e., partitioning of amino acid needs among maintenance, body weight gain, and egg production). Given the differences in the ideal amino acid profiles in Table 2, validation or fine-tuning of the ideal amino acid ratios is needed to determine which is the most accurate. Validation of individual ideal amino acid ratios can be done using a series of diets in which the ratio of the amino acid of interest to Lys increases from levels below the expected ideal ratio to above, the amino acid of interest is first-limiting, and Lys is second-limiting. Moreover, a modeling approach to partition the ideal amino acid ratios among those for maintenance, body weight gain (perhaps including feathering), and egg production would be valuable to better be able to estimate the amino acid needs of hens of different ages, housed under different management, and in different environments.

Using the ideal amino acid profile

Most nutritionists have a good idea of their hens' Met+Cys and Lys needs under the specific conditions on the farm. However, the hens' need for especially Thr, Trp, Ile, and Val are more difficult to estimate. Knowing these are especially important when supplemental L-Lys and L-Thr are used in the diet formulation, because Thr and Trp are third- and fourth-limiting, respectively, followed closely by Ile and Val in corn–soybean meal based diets for laying hens. In reality, the dietary contents of those amino acids will likely be set by trial and error, because the nutritionist will have less practical experience determining the recommended levels for those four amino acids than with Met+Cys and Lys. This is where the ideal amino acid profile is beneficial, because the recommended dietary content for all amino acids can be calculated using the hens' Lys needs. Given a desired Lys consumption of, say, 720 mg/day and using the ideal amino acid profile reported by Bregendahl et al. (2008), the dietary Thr content should be (720 mg/day × 77% =) 554 mg/day, the dietary Trp content should be (720 mg/day × 22% =) 158 mg/day, and so on. The dietary Met+Cys content (677 mg/day) can also be determined in a similar fashion. Of course, the recommended level of Lys will still have to be determined for the hens under the specific field conditions. But, at least the recommendation for only one single amino acid must be considered instead of that of several. Alternatively, the recommended dietary Lys content can be modeled using relatively simple equations based on the hens' body weight, body weight gain, and egg production (e.g., Hurwitz and Bornstein, 1973; Rostagno, 2005). Some diet-formulation software programs (e.g., Brill from Feed Management Systems and Concept 5 from Creative

Formulation Concepts) allow nutritionists to enter the ideal amino acid ratios directly in the program, akin to the nutrient specifications with minimum and maximum allowances, therefore only requiring specifications of the desired Lys content. The procedures for using ideal ratios in least-cost software programs have been described in detail by Tillman (2008).

## TAKE-HOME MESSAGE

The ideal amino acid profile for laying hens is not as well developed as those for broilers and pigs, and there is a lack of consensus as to which of several ideal profiles for laying hens most accurately reflects the 'true' profile. Nevertheless, using the ideal amino acid profile to determine dietary amino acid contents has advantages over empirically determined amino acid requirements and the profile should be used to set the amino acid contents in laying hen diets.

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