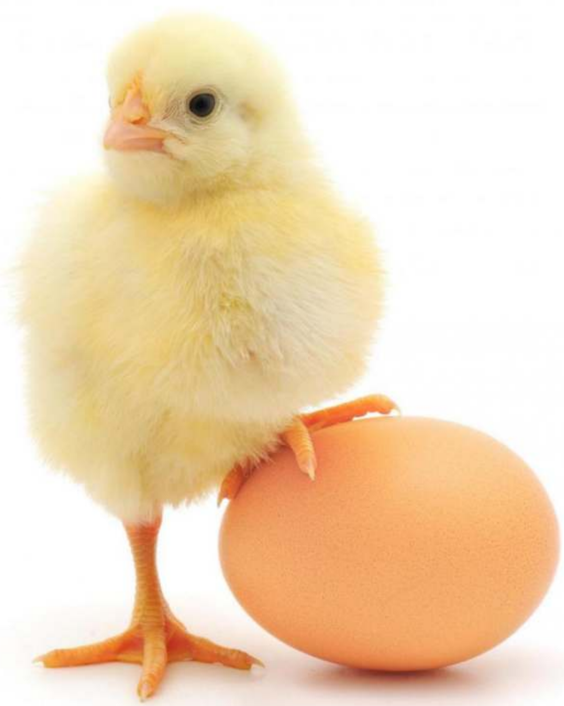
ISSN 1682-8356
ansinet.org/ijps



INTERNATIONAL JOURNAL OF POULTRY SCIENCE

ANSInet
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan
Mob: +92 300 3008585, Fax: +92 41 8815544
E-mail: editorijps@gmail.com

International Journal of Poultry Science 2 (1): 38-43, 2003

Digestible Sulfur Amino Acid Requirement of Male Turkeys During the 12 to 18 Week Period

D. T. Moore, K. Baker, K. Thompson, E. Blair and J. D. Firman
University of Missouri-Columbia, 116 Animal Sciences Department, Columbia, MO 65211, USA
Email: FirmanJ@missouri.edu

Abstract: Two floor pen trials were conducted to determine the digestible sulfur amino acid (SAA) requirement of male turkeys for the periods of 83 to 92 days and 106 to 116 days. The experiments were designed using 48 pens allowing eight treatments of six replicate pens using a randomized block design. For the 83 to 92 day period, 192 toms were sorted by weight and assigned a treatment. Digestible SAA levels ranged from 3.5 to 5.9 g/kg of diet. For the 106 to 116 day period, 144 toms were sorted by weight and assigned a treatment. Digestible SAA levels ranged from 3.0 to 5.0 g/kg of diet. These levels were obtained by titrating synthetic methionine into a low protein diet. The other synthetic amino acids were added back to the low protein diet at levels sufficient to provide growth similar to a positive control diet. The positive controls for the periods were standard corn, soybean meal, and meat meal diets based on NRC (1994) recommendations. Performance parameters measured for the trial were body weight gain and feed conversion. Parts yield of birds on the second trial were also taken with no significant differences between SAA levels found. The data were analyzed by analysis of variance followed by splined regression analysis. The digestible SAA requirements for body weight gain and feed conversion of male turkeys are 3.9 and 4.0 g/kg for the 83 to 92 day period and 3.7 and 3.4 g/kg for the 106 to 116 day period, respectively.

Key words: Turkey; amino acid; methionine; cysteine

Introduction

Over $1 billion a year is spent on turkey feed in the United States (Firman, 1997). One of the most expensive components of turkey diets is protein or more specifically amino acids. In corn and soybean meal based diets methionine is the most limiting amino acid, at least during the starter period (Warnick and Anderson, 1968). The importance of methionine is indicated by its three major functions in poultry: as a methyl donor, in protein synthesis, and as a precursor to cysteine (Graber and Baker, 1971).

The total sulfur amino acid (SAA) requirement for the starting turkey has been tested previously (Boling and Firman, 1997; Almquist, 1952; D'Mello, 1976; Kummero *et al.*, 1971; Murillo and Jensen, 1976; Potter and Shelton, 1979; Warnick and Anderson 1973; Hurwitz *et al.*, 1983). Behrends and Waibel (1980) found the requirement of SAA for turkeys 8 to 12 weeks of age to be 0.71% and for turkeys 16 to 20 weeks of age to be 0.48%. The total SAA requirements for turkeys 8 to 12 and 12 to 16 weeks of age were found to be 0.93 and 0.75%, respectively (Potter and Shelton, 1980). Hurwitz *et al.* (1983) found the requirement to be 0.48 and 0.38% for the 16 to 20 and 20 to 24 week periods respectively. The NRC (1994) suggested requirement during the 83 to 92 day period is 0.55% SAA and during the 106 to 116 day period is 0.45%. These data are somewhat out of date given the changes in genetic potential of modern turkeys and were determined using total rather than digestible amino acid levels.

An ideal amino acid ratio for the turkey has recently been developed (Firman and Boling, 1998). An ideal protein is one that contains the exact amounts of amino acids needed for the animal without deficiencies or excesses (Baker *et al.*, 1993). In order to determine an ideal amino acid ratio it is necessary to know the digestible amino acid requirement of each essential amino acid for the turkey. Utilization of an ideal amino acid ratio for turkeys may reduce feed costs. It has been shown that diets formulated on a digestible basis were superior to diets formulated on a total amino acid basis (Fernandez *et al.*, 1994). Previous research in our lab found the digestible SAA of starting hen poults to be 0.76% (Boling and Firman, 1997). The digestible SAA requirement's found in this series of experiments for gain for 7 to 16, 21 to 35, 47 to 56, and 67 to 78 days are 0.83, 0.78, 0.65, and 0.53%, respectively and feed: gain for these periods are 0.82, 0.77, 0.66, 0.47, and 0.40% respectively. No research has been done on the digestible SAA requirement of the turkey beyond 12 weeks.

Therefore, the objective of these experiments was to determine the digestible SAA requirement for male turkeys beyond 12 weeks of age.

Materials and Methods

For the 83 to 92 day and the 106 to 116 day experiments, basal diets containing 89.2 and 80 g/kg intact crude protein were formulated using corn, soybean meal, and a meat product meal (Tables 1 and 2). Crystalline amino acids were added back to the diet (with the exception of methionine) to meet essential amino acid levels. Methionine was titrated to the basal diet for the desired total sulfur amino acid levels for each treatment. All other essential amino acids were added back at levels estimated to be the digestible requirement (shown in Tables 1 and 2) for turkeys from 12 to 15 and 15 to 18 weeks of age based on previous work in our lab (Firman and Boling, 1998). Glutamic acid was added to all experimental diets to obtain a level of nitrogen equivalent to 130 g/kg crude protein for the first period and 120 g/kg crude protein for the second period for all experimental diets.

All experimental diets were formulated on a digestible basis using least-cost diet formulation software. The digestibilities of the feedstuffs were determined by analyzing the corn, soybean meal, and meat meal product for protein and AA content at the Experiment Station Chemical Laboratory (University of Missouri, Columbia, MO) using the AOAC method 15:982.30 (1990). A Beckman 6300 analyzer equipped with a high performance cation exchange resin column performed the separation of the AA. Norleucine was used as the internal standard and the amino acid detection was accomplished with postcolumn ninhydrin derivitization. Caecectomized turkeys were then utilized to determine the digestible amino acid content of the feedstuffs using procedures previously published (Firman and Remus, 1993). This information was then used to formulate the basal diets using least-cost formulation software. Basal rations were mixed and each dietary treatment was acquired by the titration of DL-methionine and glutamic acid into the basal diet. The positive control diet was an industry standard corn, soybean meal, and meat meal diet that contained 165 g/kg crude protein in the first experiment and 140 g/kg crude protein in the second experiment. (Tables 1 and 2).

In the 83 to 92 day experiment, the basal diet contained 3.5 g/kg digestible SAA of which 49% was from methionine. For the second experiment, the basal diet contained 3.0 g/kg digestible SAA of which 47% was methionine. DL-methionine was then titrated to the basal diets to obtain experimental diets containing digestible SAA on either side of the estimated requirement of 4.7 g/kg of the diet for the first experiment and 4.0 g/kg of the diet for the second experiment based on previous work (Boling and Firman, 1997). Methionine additions for the first experiment resulted in diets containing 3.5, 3.8, 4.2, 4.5, 4.9, 5.2, 5.5, and 5.9 g/kg digestible SAA, respectively. For the second experiment, methionine additions resulted in diets containing 3.0, 3.3, 3.6, 3.9, 4.2, 4.5, 4.7, and 5.0 g/kg digestible SAA, respectively. Glutamic acid was added reciprocally into all of the experimental diets to maintain similar nitrogen content. Male British United Turkeys of America (BUTA) poults were obtained from a commercial hatchery at 1 day of age. The poults were fed a corn, soybean meal, and meat meal diet based on NRC (1994) requirements until the start of the trials. At the start of both trials, birds were pulled from a pool of 2000 birds. In the first experiment, 192 birds were placed in 48 floor pens with floor area of 2.93 square meters. For the second experiment, 144 birds were used. The birds were weighed, banded and weight sorted by computer to provide both similar total pen weight and distribution of birds within pens. Lighting was maintained at 23 hours per day throughout the trial period. Feed and water were provided *ad libitum.*

The trials were designed as randomized blocks containing six replicates for each treatment. Each treatment was randomly allocated to six blocks of eight pens such that each titration level was allotted to each block one time except for the treatment with the highest level of methionine and the positive control. This treatment and the positive control each had three replicates per treatment due to the number of pens available. All treatments were randomized within each block. The experiments were conducted in a commercial type, curtain sided, 48 pen floor trial facility with litter floors. For the first and second experiments, the birds were placed on trial at 83 and 106 days of age and were taken off trial at 92 and 116 days of age, respectively. At the conclusion of the trial, feed was removed from the birds 4 hours prior to weighing. Birds were individually weighed and the feed of each pen was weighed to monitor feed disappearance. One bird per pen was processed for carcass yield data.

The data were analyzed by analysis of variance using windows based statistical analysis software (JMP ™; SAS Institute, 1990). Block effects were not significant and this error term was eliminated from the analysis. The growth and feed conversion requirements for digestible SAA were estimated using splined-regression analysis on replicates (Robbins, 1986) with SAS (SAS Institute, 1990) software. This procedure estimates the requirement based on the intersection of lines defining the sloped, linear portion of the growth curve and a line fitting the plateau (point at which increasing SAA content does not result in improved performance) portion of the data. While this method of analysis has been criticized (Fisher *et al.*, 1973), more recent work based on computer modeled data has shown that the splined or segmented regression has a much higher probability of correctly estimating the requirement than do estimates based on quadratic response criteria at either 90 or 95% of the asymptote (Lamberson and Firman, 2002). Level of significance was set at $p < 0.05$.

Results and Discussion

Results from the first trial are shown in Table 3. Weight gain ranged from 624 g gained per bird to 1383 g. Gain appeared to plateau above the 4.2 g/kg SAA level although some variation existed above this level. Feed intake in the plateau region roughly followed body weight gain

Table 1: Composition (g/kg) of basal and NRC-based positive control diet for the 83 to 92 day period

Ingredients	Basal diet[1] g/kg	NRC diet g/kg
Corn	704.2	667.2
Soybean meal	62.9	217.4
Pork meal	10	20
Sucrose[2]	137.5	
Lard	55	78
Dicalcium Phosphate	11.6	7.34
Na Bicarbonate	5	
DL-Methionine		0.08
Limestone	8.06	4.5
Salt	20	2.5
Choline chloride	1.1	0.3
Avatek[5]	5	0.5
Baciferm[5]	5	0.5
Trace-mineral mix[3]	1.0	1.0
Vitamin premix[4]	0.75	0.75
Selenium premix[3]	0.3	0.3
$CuSO_4$	0.13	0.13
Calculated Analysis		
Crude Protein (g/kg)	89.2	165
ME (MJ/kg)	16.85	16.85
Calcium (g/kg)	7.5	605
Phosphorus (g/kg)	3.3	3.2
Methionine (g/kg)	1.7	3.7
Cystine (g/kg)	1.8	2.8
Lysine (g/kg)	3.7	9.2
Threonine (g/kg)	2.4	6.2
Valine (g/kg)	3.8	8.8
Arginine (g/kg)	5.3	11.2
Histidine (g/kg)	2.4	4.8
Isoleucine (g/kg)	3.1	7.5
Leucine (g/kg)	9.1	15.7
Phenylalanine + Tyrosine (g/kg)	7.1	14.3
Tryptophan (g/kg)	0.9	2.2

[1]Synthetic amino acids were added so the basal diet would contain the total digestible amount of the following essential amino acids: lysine, 0.76%; threonine, 0.58%; valine, 0.70%; arginine, 0.79%; histidine, 0.33%; isoleucine, 0.55%; leucine, 0.92%; phenylalanine + tyrosine, 0.79%; tryptophan, 0.18%. The amino acids in the basal diet are on a digestible basis while amino acids in the NRC diet are on a total basis. Protein is on a total basis in both diets. [2]Synthetic amino acids and glutamic acid were added back at the expense of sucrose to obtain 13% protein equivalent. [3]The mineral premixes provided the following amounts per kilogram of diet: manganese, 110 mg; zinc, 110 mg; iron, 60 mg; iodine, 2 mg; magnesium, 27 mg; selenium, 0.18 mg. [4]The vitamin premix provided the following amounts per kilogram of diet: vitamin A, 13,200 mg; vitamin D_3, 5,775 mg; vitamin E, 21 mg; niacin, 82.5 mg; d-pantothenic acid, 25 mg; riboflavin, 10 mg; vitamin B_6, 3.3 mg; menadione, 2.5 mg; folic acid, 2.1 mg; thiamin, 1.7 mg; biotin, 0.33 mg; vitamin B_{12}, 0.02 mg. [5]Avatec (lasalocid) is provided to prevent coccidiosis; Baciferm (bacitracin methylenedisalicylate) is provided for increased feed efficiency.

Table 2: Composition (g/kg) of basal and NRC-based positive control diet for the 106 to 116 day period.

Ingredients	Basal diet[1] g/kg	NRC diet g/kg
Corn	546.6	706.3
Soybean meal	69	180.4
Pork meal	10	
Sucrose[2]	275.7	
Lard	67.8	92
Dicalcium Phosphate	12.2	9.73
Na Bicarbonate	5	
Limestone	7.73	
Salt	5.81	2.5
Choline chloride	1.26	0.52
Avatek[5]	0.5	0.5
Baciferm[5]	0.5	0.5
Trace-mineral mix[3]	1	1
Vitamin premix[4]	0.75	0.75
Selenium premix[3]	0.3	0.3
$CuSO_4$	0.13	0.13
Calculated Analysis		
Crude Protein %	80	140
ME (MJ/kg)	15.06	15.06
Calcium (g/kg)	7.5	5.5
Phosphorus (g/kg)	3.3	2.8
Methionine (g/kg)	1.4	2.8
Cystine (g/kg)	1.6	2.7
Lysine (g/kg)	3.5	7.6
Threonine (g/kg)	2.2	5.2
Valine (g/kg)	3.4	7.6
Arginine (g/kg)	4.9	9.2
Histidine (g/kg)	2.2	4.2
Isoleucine (g/kg)	2.8	6.5
Leucine (g/kg)	7.8	14
Phenylalanine + Tyrosine (g/kg)	6.4	12.3
Tryptophan (g/kg)	0.8	1.8

[1]Synthetic amino acids were added so the basal diet would contain the total digestible amount of the following essential amino acids: lysine, 0.76%; threonine, 0.58%; valine, 0.70%; arginine, 0.79%; histidine, 0.33%; isoleucine, 0.55%; leucine, 0.92%; phenylalanine + tyrosine, 0.79%; tryptophan, 0.18%. The amino acids in the basal diet are on a digestible basis while amino acids in the NRC diet are on a total basis. Protein is on a total basis in both diets. [2]Synthetic amino acids and glutamic acid were added back at the expense of sucrose to obtain 12% protein equivalent. [3]The mineral premixes provided the following amounts per kilogram of diet: manganese, 110 mg; zinc, 110 mg; iron, 60 mg;iodine, 2 mg; magnesium, 27 mg; selenium, 0.18 mg. [4]The vitamin premix provided the following amounts per kilogram of diet: vitamin A, 13,200 mg; vitamin D_3, 5,775 mg; vitamin E, 21 mg; niacin, 82.5 mg; d-pantothenic acid, 25 mg; riboflavin, 10 mg; vitamin B_6, 3.3 mg; menadione, 2.5 mg;folic acid, 2.1 mg; thiamin, 1.7 mg; biotin, 0.33 mg; vitamin B_{12}, 0.02 mg. [5]Avatec (lasalocid) is provided to prevent coccidiosis; Baciferm (bacitracin methylenedisalicylate) is provided for increased feed efficiency.

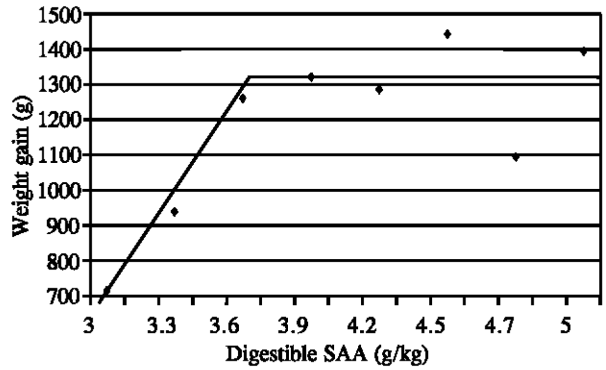


Fig. 1: Gain of tom turkeys fed graded levels of digestible SAA 12 to 15 weeks of age. Requirement determined using splined regression with 95% confidence intervals was found to be 3.9 g/kg +/- 0.5 mg/kg.

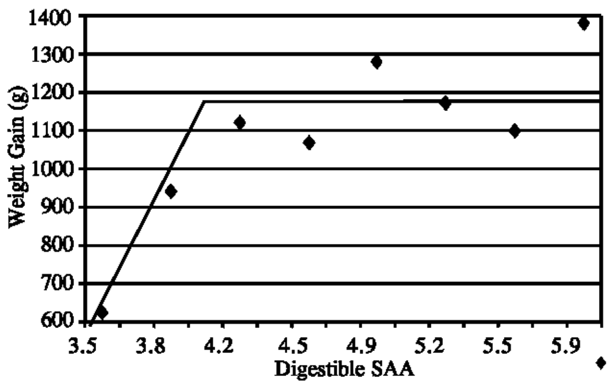


Fig. 2: Gain of tom turkeys fed graded levels of digestible SAA 106 to 116 days of age. Requirement determined using splined regression with 95% confidence intervals was found to be 3.7 g/kg +/- 0.6 mg/kg.

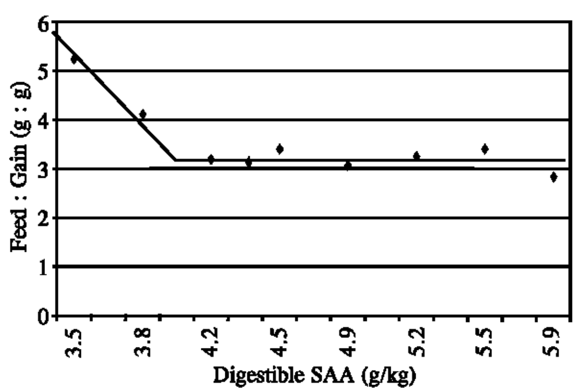


Fig. 3: Feed: gain of tom turkeys fed graded levels of digestible SAA 83 to 93 days of age. Requirement determined using splined regression with 95% confidence intervals was found to be 4.0 g/kg +/- 0.3 mg/kg.

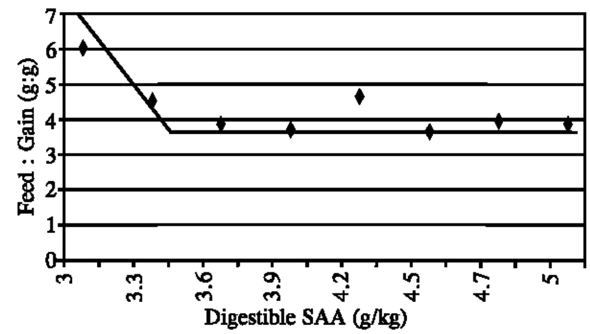


Fig. 4: Feed:gain of tom turkeys fed graded levels of digestible SAA from 106 to 116 days of age. Requirement determined using splined regression with 95% confidence intervals was found to be 4.0 g/kg +/- 0.3 mg/kg.

Table 3: Growth performance of tom turkeys fed titrated levels of digestible sulphur amino acids (SAA) from 83 to 92 days of age

Digestible SAA (g/kg)	Weight Gain (g)	Adjusted Feed:Gain
3.5	624^{a}	5.27^{c}
3.8	944^{b}	4.13^{b}
4.2	1121^{cd}	3.21^{a}
4.5	1071^{bc}	3.41^{a}
4.9	1283^{ef}	3.08^{a}
5.2	1175^{cde}	3.27^{a}
5.5	1104^{c}	3.42^{a}
5.9	1383^{f*}	2.84^{*a}
PC**	1322^{ef*}	3.01^{*a}
Pooled SEM	66	0.21
Pooled SEM*	94	0.29

SEM* has only three replicates, but SEM has six replicates.**NRC based positive control diet.

Table 4: Growth performance of tom turkeys fed titrated levels of digestible SAA from 106 to 116 days of age

Digestible SAA (g/kg)	Weight Gain (g)	Adjusted Feed:Gain
3.0	717^{a}	6.05^{b}
3.3	942^{ab}	4.55^{a}
3.6	1264^{bcd}	3.89^{a}
3.9	1322^{cde}	3.74^{a}
4.2	1289^{cde}	4.71^{a}
4.5	1444^{de}	3.69^{a}
4.7	1097^{bc}	4.00^{a}
5.0	1397^{cde*}	3.88a*
PC**	1556^{de*}	3.94a*
Pooled SEM	127	0.64
Pooled SEM*	179	0.9

SEM* has only three replicates, but SEM has six replicates.**NRC based positive control diet.

Table 5: Carcass data for tom turkeys fed titrated levels of SAA from 106 to 116 days of age[1]

Digestible SAA (%)	Dressing %	Fat Pad %	Pectoralis Major %	Pectoralis Minor %	Leg %	Thigh %	Wing %
0.3	74	2.4	19.6	5.7	14.5	13.9	13.3
0.33	74.4	2.4	20.7	5.9	13.6	14.4	12.7
0.36	74.6	1.6	19.8	5.5	14.1	14.5	12.8
0.39	75.6	2.1	20.2	5.4	14.3	14.4	12.3
0.42	73.9	2.6	20.4	5.8	14.5	13.9	12.9
0.45	74.1	2	19.9	5.6	14.6	15.1	12.6
0.47	74	1.9	20.2	5.6	14.4	14.5	12.9
0.5	74.8*	1.7*	18.7*	5*	14.9*	14.6*	13.0*
PC**	74.5*	2.1*	22.3*	5.9*	13.7*	13.9*	12.8*
Pooled SEM	0.72	0.28	0.55	0.19	0.29	0.37	0.33
Pooled SEM*	1.01	0.39	0.77	0.27	0.41	0.53	0.47

SEM* has only three replicates, but SEM has six replicates. [1]No significant differences were noted in any parameter. **NRC based positive control diet.

yielding similar feed efficiency values in this portion of the curve. Analysis of variance was used to determine the level of significance between treatments and the positive control diet, and through the use of splined regression analysis the digestible SAA requirement for the 82 to 93 day tom turkey was determined to be 3.9 and 4.0 g/kg for gain and feed conversion, respectively (Fig. 1 and 3). The NRC (1994) corn and soybean meal-based diet has an approximate SAA digestibility of 85% (Firman, 1992; Firman and Remus, 1993). Using this number, the estimated SAA requirement of the NRC diet would be approximately 4.7 g/kg expressed on a digestible basis. The requirement determined in this experiment was somewhat lower than this level. The difference in requirement may mean an overfeeding of SAA to male turkeys during this period. The percent of the total methionine SAA in the sufficient diet was 54% methionine and 46% cystine, respectively. This is below the maximum level of cystine as a percent of total SAA found by Behrends and Waibel (1980) to be acceptable.

Conversion of methionine to cysteine is not 100% based on differing molecular weights. However, if a 50:50 relationship is considered ideal, then the potential difference in the determined requirement of the total SAA in this study would be less than 1%.

Results from the second trial are shown in Table 4. Weight gain ranged from 717 g gained per bird to 1444 g. The plateau in gain appeared to be above the 3.6 g/kg SAA level although variation occurred above this level. Feed intake in the plateau region again roughly followed body weight gain yielding similar feed efficiency values in this portion of the curve. Analysis of variance was used to determine the level of significance between treatments and the positive control diet, and through the use of splined regression analysis, the digestible SAA requirement for the 106 to 116 day male turkey was determined to be 3.7 and 3.4 g/kg for gain and feed conversion, respectively (Fig. 2 and 4). Using 85% digestibility, the estimated digestible SAA requirement of the NRC diet is 3.8 g/kg. This number is very similar to the findings of this experiment. The percent of the SAA in the sufficient diet was 57% methionine and 43% cystine, respectively. Again, if a 50:50 relationship is considered ideal, then the potential difference in the determined requirement of the total SAA in this study would be approximately 1.6%. It should be noted however, that most practical diets include the addition of a methionine source which would then be included in the calculations for total SAA. While the ratios of methionine:cysteine are constantly changing in the experimental diets, the level of methionine that would have been added to a diet at the determined requirement is only slightly above those levels seen in a practical formulation.

Part of the importance of determining digestible amino acid requirements is to develop an ideal amino acid ratio for turkeys. This would allow diets to be formulated on a digestible basis using various feedstuffs under variable conditions. Ideal proteins express each essential amino acid based on a percent relative to lysine, due to the ease of determining the lysine content in feedstuffs and its overall importance in poultry nutrition. Using previous lysine data (Baker *et al.*, unpublished), the percent digestible SAA to lysine was determined to be 59% in the first trial and 68% in the second trial period. In the field of turkey nutrition an ideal ratio has been estimated (Firman and Boling, 1998) with the SAA:lysine ratio at 59% during the starter period. Work done by Chung and Baker (1992) indicated that the percent digestible SAA to lysine was 60% for swine. The SAA to lysine ratio was found to be 72% for the broiler chicken by Baker and Han (1994), although this is difficult to compare due to differing growth periods. The increased relative requirement of the SAA is probably due to the increased maintenance costs associated with the older bird.

The ability of the industry to feed lower protein diets is also indicated by this study when synthetic amino acids are added back to the diet in the proper amount. For example, the test diet in the second experiment contained 80 g/kg intact crude protein and the synthetic methionine at the digestible requirement level performed as well as the control diet based on the NRC (1994) requirements containing 140 g/kg crude protein (Table 2). This result is similar to other research that has indicated turkeys can exhibit satisfactory growth with a low protein diet by adding back the essential amino acids (Baldini *et al.*, 1954; Firman, 1994; Sell *et al.*, 1994; Waibel *et al.*, 1995).

The carcass data of the final experiment showed no significant differences between birds fed the required levels of digestible SAA and birds fed the industry standard positive control diet (Table 5). Further work in the area needs to be performed as these birds were on an industry standard diet until 106 days so changes in parts yield had little time to manifest themselves.

Acknowledgements

This work was supported by the Missouri Soybean Merchandising Council and the Missouri Agricultural Experiment Station.

References

Almquist, H. S., 1952. Amino acid requirement of chickens and turkeys-a review. Poult. Sci., 31: 966-981.

AOAC., 1990. Official methods of analysis. 15th ed. Association of Analytical Chemists, Arlington, VA.

Baker, D. H. and Y. Han, 1994. Ideal amino acid profile for chicks during the first three weeks posthatching. Poult. Sci., 73: 1441-1447.

Baker, D. H., C. M. Parsons, S. Aoyagi and Y. Han, 1993. Digestible amino acid requirements of broiler chickens based upon ideal protein considerations. Proceedings of the Arkansas Nutrition Conference, pp: 22-32.

Baldini, J. T., H. R. Rosenberg and J. Waddell, 1954. The protein requirement of the turkey poult. Poult. Sci., 33: 539-543.

Behrends, B. R. and P. E. Waibel, 1980. Methionine and cystine requirements of growing turkeys. Poult. Sci., 59: 849-859.

Boling, S. D. and J. D. Firman, 1997. Digestible sulfur amino acid requirement of starting turkeys. Poult. Sci., 76: 873-877.

Chung, T. K. and D. H. Baker, 1992. Ideal amino acid pattern for 10-kilogram pigs. J. Anim. Sci., 70: 3102-3111.

D'mello, J. P. F., 1976. Requirements of the young turkey for sulphur amino acids and threonine: Comparison with other species. Br. Poult. Sci., 17: 157-162.

Fernandez, S. R., S. Aoyagi, Y. Han, C. M. Parsons and D. H. Baker, 1994. Limiting order of amino acids in corn and soybean meal for growth of the chick. Poult. Sci., 73: 1887-1896.

Firman, J. D., 1997. Early stage turkey nutrition and ideal protein: Implications for all aspects of poultry production. Proceedings of Alltech's 13th Annual Symposium, pp: 357-378.

Firman, J. D., 1994. Utilization of low protein diets for turkeys. BioKyowa Technical Review-7.

Firman, J. D., 1992. Amino acid digestibility of soybean meal and meat meal in male and female turkeys of different ages. J. Appl. Poult. Res., 1: 350-354.

Firman, J. D. and S. D. Boling, 1998. Ideal protein in turkeys. Poult. Sci., 77: 105-110.

Firman, J. D. and J. C. Remus, 1993. Amino acid digestibility of feedstuffs in female turkeys. J. Appl. Poult. Res., 2: 171-175.

Fisher, C., T. R. Morris and R. C. Jennings, 1973. A model for the description and prediction of the response of laying hens to amino acid intake. Br. Poult. Sci., 14: 469-484.

Graber, G. and D. H. Baker, 1971. Sulfur amino acid nutrition of the growing chick: Quantitative aspects concerning the efficacy of dietary methionine, cysteine and cystine. J. Anim. Sci., 33: 1005-1011.

Hurwitz, S., Y. Frish, A. Bar, U. Eisner, I. Bengal and M. Pines, 1983. The amino acid requirements of growing turkeys. 1. Model construction and parameter estimation. Poult. Sci., 62: 2208-2217.

Kummero, V. E., J. E. Jones and C. B. Loadholt, 1971. Lysine and total sulfur amino acid requirements of turkey poults, one day to three weeks. Poult. Sci., 50: 752-758.

Lamberson, W. R. and J. D. Firman, 2002. A comparison of quadratic versus segmented regression procedures for estimating nutrient requirements. Poult. Sci., 82: 481-484.

Murillo, M. G. and L. S. Jensen, 1976 Methionine requirement of developing turkeys from 8-12 weeks of age. Poult. Sci., 55: 1414-1418.

National Research Council, 1994. Nutrient Requirements of Poultry. 9th Revised edition. National Academy Press, Washington, D.C.

Potter, L. M. and J. R. Shelton, 1979. Methionine and protein requirements of young turkeys. Poult. Sci., 58: 609-615.

Potter, L. M. and J. R. Shelton, 1980. Methionine and protein requirements of turkeys 8 to 16 weeks of age. Poult. Sci., 59: 1268-1274.

Robbins, K. R., 1986. A method, SAS program, and example for fitting the broken-line to growth data. The University of Tennessee Agriculture Experiment Station. Research Report, 86-09.

SAS Institute, 1990. SAS User's Guide, Statistics, version 5 edition. SAS Institute Incorporated, Cary, NC.

Sell, J. L., M. J. Jeffrey and B. J. Kerr, 1994. Influence of amino acid supplementation of low-protein diets and metabolizable energy feeding sequence on performance and carcass composition of toms. Poult. Sci., 73: 1867-1880.

Waibel, P. E., C. W. Carlson, J. K. Liu, J. A. Brannon, and S. L. Noll, 1995. Replacing protein in corn-soybean turkey diets with methionine and lysine. Poult. Sci., 74: 1143-1158.

Warnick, R. E. and J. O. Anderson, 1973. Essential amino acid levels for starting turkey poults. Poult. Sci., 52: 445-452.

Warnick, R. E. and J. O. Anderson, 1968. Limiting essential amino acids in soybean meal for growing chickens and the effect of heat upon availability of the essential amino acids. Poult. Sci., 47: 281-287.