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A procedure to evaluate the efficiency of utilization of dietary amino acid for poultry

Edney Pereira da Silva[1], Nilva Kazue Sakomura[1*], Juliano Cesar de Paula Dorigam[1], Euclides Braga Malheiros[1], João Batista Kochenborger Fernandes[2] and José Anchieta de Araujo[1]

*[1]Faculdade de Ciências Agrárias e Veterinárias, Universidade Estadual Paulista "Júlio de Mesquita Filho", Via de Acesso Prof. Paulo Donato Castellane, s/n, 14884-900, Jaboticabal, São Paulo, Brazil. [2]Centro de Aquicultura, Universidade Estadual Paulista "Júlio de Mesquita Filho", Jaboticabal, São Paulo, Brazil. *Author for correspondence. E-mail: sakomura@fcav.unesp.br*

ABSTRACT. The aim of this study was to develop a procedure based on Gompertz function to determine the efficiency of utilization of amino acid. The procedure was applied to determine the efficiency of utilization of dietary lysine, methionine+cystine and threonine by growing pullets and based on the efficiencies were estimated the requirements for the growth phase of birds. The Gompertz function was fitted to the data of feed intake, body weight, feather-free body protein weight and feather protein weight of four strains of laying hens in the growth phase. The rates of consumption and daily protein deposition (PD) were calculated. The amino acid deposition was obtained by multiplying the PD by the amino acid concentration in feather protein and feather-free body protein. The results showed that the efficiency of utilization of amino acid decreased with maturity and, conversely, there was a proportional increase of the requirement per kg of weight gain. The procedure based on the Gompertz function to determine the efficiency of utilization of amino acid proved to be suitable to evaluate the efficiency of utilization of amino acid and can be a useful tool to diagnose the effectiveness of the nutritional management, aiding in decision-making on the nutritional management.

Keywords: growth curve, lysine, methionine+cystine, protein weight, pullets, threonine.

Um procedimento para avaliar a eficiência de utilização do aminoácido dietético para aves

RESUMO. O objetivo deste estudo foi desenvolver um procedimento baseado na função Gompertz para determinar a eficiência de utilização do aminoácido. O procedimento foi aplicado para determinar a eficiência de utilização da lisina, metionina+cistina e treonina da dieta de frangas de postura em crescimento, e com base nas eficiências foram estimadas as exigências para fase de crescimento das aves. A função Gompertz foi ajustada aos dados de consumo de ração, peso corporal, peso proteico do corpo depenado e peso de penas de quatro linhagens de aves de postura na fase de crescimento. As taxas de consumo e deposição diária de proteína (DP) foram calculadas. A deposição do aminoácido foi obtida multiplicando a DP pela concentração do aminoácido nas penas e corpo depenado. Os resultados obtidos demonstraram que as eficiências de utilização dos aminoácidos diminuíram com a maturidade e, inversamente, houve um aumento proporcional da exigência por kg de ganho de peso. O procedimento baseado na função Gompertz para determinar a eficiência de utilização do aminoácido mostrou ser adequado para avaliar a eficiência de utilização do aminoácido e pode ser uma ferramenta útil para diagnosticar a eficácia do manejo nutricional auxiliando na tomada de decisões sobre o manejo nutricional.

Palavras-chave: curva de crescimento, lisina, metionina+cistina, peso proteico, frangas, treonina.

Introduction

Among the functions used to describe the growth, the Gompertz function (GOMPERTZ, 1825) is the most used for poultry. This preference is partially due to the biological significance of its parameters as well as the ease of statistical adjustment and robustness in describing the trajectory of growth in birds (RIVERA-TORRES et al., 2011). This equation has also been applied on estimates of the efficiency of amino acid utilization. This application allows daily calculations of the deposition and nutrient intake during the whole production period, giving dynamism to the inferences. This approach makes it possible to diagnose the daily efficiency of amino acid utilization and, consequently, decision-making on the nutritional management to be adopted.

Nowadays, the feeding program for growing laying hens has been based on three diets with nutritional levels established on the average requirement of each rearing phase (1-6, 7-12 and 13 to 18 weeks of age). Based on the average requirement of the phase, the animal receives restricted nutritional levels at the initial phase and excessive levels at the final phase. Therefore, techniques that assess the efficiency of utilization of nutrients are necessary (SILVA et al., 2013) to make decisions and optimize dietary levels, aiming to minimize the effects from limited and excess supply of nutrients. For birds, the amino acids methionine, lysine and threonine are the major limiting amino acids in corn and soybean meal based diets. Considering this, this study aimed to develop a procedure based on the Gompertz function to determine the efficiency of amino acid utilization. The procedure was applied to determine the efficiency of utilization of dietary lysine (Lys), methionine+cystine (Met+Cys) and threonine (Thr) for growing pullets and based on the efficiencies were estimated the requirements for the growth phase of the birds.

Material and methods

The study was conducted in the Laboratory of Poultry Science, Faculty of Agricultural and Veterinary Sciences, UNESP - FCAV (Lavinesp), Jaboticabal-SP, Brazil. The genetic parameters were determined from four laying hen strains, Hy-Line Brown (HLB), Hisex Brown (HSB), Hy-Line W-36 White (HLW) and Hisex White (HSW). Birds were distributed into four groups with four replicates of 75 birds, amounting to 16 experimental units. The experimental period was 126 days. Pullets of each strain were housed in breeding (1st to 6th week) and rearing (7th to 18th week) cages.

Birds fed diets based on corn, soybean meal and wheat bran, to meet their nutritional requirements, in accordance with the recommendation of Rostagno et al. (2000) for each phase of raising. For white strains, the content of metabolizable energy (AMEn) and crude protein (CP) were: 2,950 kcal AMEn kg^{-1} and 21% CP, 1st to 6th week; 2,850 kcal AMEn kg^{-1} and 18% CP from the 7th to 12th week; 2,800 kcal AMEn kg^{-1} and 16% CP from the 13rd to 18th weeks. For brown strains were used: 2,950 kcal AMEn kg^{-1} and 21% CP from the 1st to 6th week; 2,850 kcal AMEn kg^{-1} and 17% CP from the 7th to 12sd week; 2,750 kcal AMEn kg^{-1} and 16% CP from the 13rd to 18th week.

The birds and feed leftovers were weighed weekly. Based on the average body weight of the birds, we selected a sample of each experimental unit for slaughtering. After fasting for 24 hours, birds were individually weighed and killed using CO_2. A sample of feathers was collected for later analysis. The weight of feathers was obtained by difference between the weight of the fasting bird and the weight of the feather-free carcass. Samples of feather-free carcass and feathers were analyzed for dry matter (in oven at 105ºC for 16 hours), and for total nitrogen content by the Kjeldahl method (2001.11) according to AOAC (2002). The factor 6.25 was used to convert the nitrogen content into crude protein. The variables analyzed were daily feed intake, feather-free protein weight and feather protein weight. For the relationship of these variables over time we used the Gompertz equation (1):

$$Wt = Wm \times e^{\left[-e^{((ln(-lnWi/Wm))-(B\times t))}\right]} \quad (1)$$

where:

t is the age (days), Wt is the weight or feed intake at each time t, Wi is the weight at birth or initial feed intake (kg) diet, Wm is the weight or feed intake at maturity (kg), B is the maturity rate (day^{-1}), 'e' is the numerical base of 'Euler' and 'ln' is the natural log.

The daily protein deposition (dPD, g day^{-1}) was calculated by the equation (2) (GOUS et al., 1999), applied to the protein weight of the feather-free body (BP) and feather protein weight (FP):

$$dPD = B \times Wt \times ln(Wm/Wt) \quad (2)$$

The deposition of Lys (dLys), Met+Cys (dMet+Cys) and Thr (dThr) in the body was obtained by summing the deposition of these amino acids in BP and FP as follows:

$$dLys = dPD_c \times AA_c + dPDf \times AA_f$$
$$dMet{+}Cys = dPD_c \times AA_c + dPDf \times AA_f$$
$$dThr = dPD_c \times AA_c + dPDf \times AA_f$$

where:

dPD_c (g day^{-1}) and $dPDf$ (g day^{-1}) are respectively the protein deposition in BP and FP, obtained by equation (2). AAc is the amino acid content in BP, considered in this study as Lys = 75 mg g^{-1}, Met+Cys = 36 mg g^{-1} and Thr = 42 mg g^{-1}. AAf is the amino acid content in the FP, considered in this study as Lys = 18 mg g^{-1}, Met+Cys = 76 mg g^{-1} and Thr, = 44 mg g^{-1}, obtained from Emmans (1989).

The daily intakes of Lys (iLys), Met+Cys (iMet+Cys) and Thr (iThr) were obtained by multiplying the daily feed intake (dFI) by the concentration of digestible Lys (ccLys), Met+Cys (ccMet+Cys) and Thr (ccThr) in the diet.

The ccLys in the diet were: 10.09, 8.11 and 7.24 g kg^{-1} in the initial, breeding and rearing phases for white strains and 10.09, 8.16 and 6.67 g kg^{-1}, for brown strains. The ccMet+Cys in diets were, respectively: 6.37, 5.63, 5.03 g kg^{-1} for initial, breeding and rearing phases for white strains and 6.37, 5.76, 5.04 g kg^{-1} for brown strains. The ccThr in diets were, respectively: 7.07, 5.99, 5.24 g kg^{-1} for initial, breeding and rearing phases for white strains and 7.07, 5.59, 5.25 g kg^{-1}, for brown strains.

The efficiency of utilization of amino acid was obtained by the ratio between the deposition (dLys, dMet+Cys and dThr) and the respective intake corrected for maintenance of Lys (icLys), Met+Cys (icMet+Cys) and Thr (icThr).

$$kLys = dLys/icLys \times 100$$
$$kMet+Cys = dMet+Cys/icMet+Cys \times 100$$
$$kThr = dThr/icThr \times 100$$

In this calculation, the values of icLys, icMet+Cys and icThr were obtained by subtracting the daily intake of the amino acid by the amino acid requirement for maintenance, expressed as protein metabolic weight of the bird. The intakes corrected for maintenance were calculated as follows:

$$icLys = iLys - mLys \times BPm^{0.73} \times u$$
$$icMet+Cys = iMet+Cys - mMet+Cys \times BPm^{0.73} \times u$$
$$icThr = iThr - mThr \times BPm^{0.73} \times u$$

where:

BPm is the protein weight at maturity; $BPm^{0.73}$ is the protein metabolic weight; u is the degree of maturity of the protein weight, derived from the relationship BP BPm^{-1}. For the calculations were considered, respectively, the values of 152 (SIQUEIRA et al., 2011), 87.3 and 75.6 mg $BPm^{0.73} \times u$ (BONATO et al., 2011) as the requirements for maintenance of Lys (mLys), Met+Cys (mMet+Cys) and Thr (mThr).

The requirements of Lys (rLys), Met+Cys (rMet+Cys) and Thr (rThr) per kg of weight gain (WG, kg day^{-1}) were daily estimated from the equations:

$$rLys = [dLys/kLys]/WG$$
$$rMet+Cys = [dMet+Cys/kMet+Cys]/WG$$
$$rThr = [dThr/kThr]/WG$$

where rLys, rMet+Cys and rThr correspond to the amounts (g) of these amino acids required for a gain of 1 kg body weight.

Results and discussion

The feed intake at maturity (W*m*) of the brown strains was 30% higher compared to white strains, however, the rate (*B*) was 35% higher for white strains. These parameters, together, indicate the increased physical intake capacity of the bird. In general, the parameters of the Gompertz function fitted to the growth of body weight (BW), showed similarity between the strains of the same category, brown or white. The differences between the strains were observed when comparing the parameters fitted for BP and FP. The W*i*, W*m* and *B* parameters (Table 1) indicated that the growth profiles of the four strains are specific, especially for the Hy-line White that showed only 70% body weight of the brown strains, and similar values of feather protein weight at maturity.

Table 1. Estimates of parameters that describe the growth of body weight (BW), the protein weight of feather-free body protein (BP), feather protein weight (FP) and feed intake (FI) for four genotypes of pullets.

Parameters	Hisex Brown	Hy-Line Brown	Hisex White	Hy-Line White
		Body weight (BW)		
W*i*	0.0274	0.0267	0.0296	0.0269
W*m*	1.765	1.770	1.346	1.261
B	0.0238	0.0238	0.0241	0.0263
		Feather-free body protein (BP)		
W*i*	0.0041	0.0040	0.0051	0.0040
W*m*	0.329	0.365	0.253	0.284
B	0.0255	0.0261	0.0254	0.0276
		Feather protein weight (FP)		
W*i*	0.0011	0.0016	0.0014	0.0014
W*m*	0.144	0.155	0.119	0.144
B	0.0290	0.0271	0.0290	0.0277
		Feed intake (FI)		
W*i*	0.003	0.003	0.002	0.003
W*m*	0.078	0.080	0.059	0.055
B	0.0399	0.0378	0.0504	0.0545

Wi is the weight at birth or initial feed intake (kg); Wm is the weight or feed intake at maturity (kg), B is the maturity rate (day^{-1}).

The difference in the physical composition is reflected in the chemical composition. The total amount deposited in body protein (BP+FP), in relation to the body weight, showed that at maturity (W*m*) the strains Hisex Brown, Hy-Line Brown, Hisex White and Hy-Line White had average values of 270, 290, 280 and 340 g of protein kg^{-1} of body weight, being that 70, 70, 68 and 66% corresponded to feather-free body protein and the other 30, 30, 32 and 34% to the protein of the feathers, respectively.

The W*m* and *B* parameters fitted for BP and FP determine the daily amount of protein deposited by the strains. Due to the differences between the values of *B* for BP and FP, the protein deposition in each component has to be calculated separately, since the maximum protein deposition in the feather-free body and in feathers occur in different ages.

Considering the average value of the four strains for BP (W*i* = 0.005 kg, W*m* = 0.308 and *B* = 0.026) and FP (Wi = 0.001 kg, Wm = 0.141 and B = 0.028) the maximum protein deposition in feathers calculated ($ln[-ln(Wi/Wm)]/B$) occurs approximately one week earlier from the maximum deposition of the feather-free body and at this moment the bird should receive specific quantities of the amino acids to synthesize the protein profile demanded. The results obtained for feed intake indicated that the maximum body growth rate occurs 29 days after the maximum rate of feed intake, which is around 26 days old.

In order to use the procedure, it is necessary information about the protein deposition and feed intake, which can be obtained based on the parameters of the Gompertz function. These information were generated daily and the weekly average feed intake, weight gain, protein deposition in the feather-free body and in feathers from 1 to 18 weeks of age are presented in Table 2.

Based on this procedure is possible to verify that the parameters of the Gompertz function for BP, FP and FI can be interpreted with practical nutritional implications. The protein deposition and feed intake listed in Table 2 were used to calculate amino acid intake and amino acid deposition, and estimate thus the efficiency of utilization and the requirement per kg of weight gain of birds.

Table 2. Estimation of feed intake (FI, g day^{-1}), weight gain (WG, g day^{-1}), protein deposition in the feather-free body (dPDc, g day^{-1}) and protein deposition in feathers (dPDf, g day^{-1}) based on the equations shown in Table 1 for the four genotypes of pullets.

Age	FI				WG				dPD$_c$				dPD*f*			
	B		W		B		W		B		W		B		W	
	HS	HL	HS	HL	HS	HL	HS	HL	HS	HL	HS	HL	HS	HL	HS	HL
1	5	5	3	5	4	4	4	4	0.7	0.7	0.7	0.7	0.2	0.3	0.3	0.3
2	9	10	8	10	5	5	5	5	1.1	1.1	1.0	1.1	0.4	0.5	0.4	0.4
3	16	16	14	17	8	7	7	7	1.6	1.6	1.3	1.5	0.7	0.7	0.7	0.7
4	23	23	22	25	10	10	8	9	2.0	2.1	1.7	2.0	0.9	1.0	0.9	0.9
5	31	31	29	32	12	12	10	10	2.4	2.6	2.0	2.4	1.2	1.2	1.0	1.1
6	39	39	36	38	13	13	11	11	2.8	3.0	2.2	2.7	1.4	1.4	1.2	1.3
7	46	46	42	43	15	15	12	12	3.0	3.3	2.3	2.8	1.5	1.5	1.2	1.4
8	52	52	46	46	15	15	12	12	3.1	3.5	2.4	2.9	1.5	1.5	1.3	1.5
9	58	58	50	49	15	15	12	12	3.1	3.5	2.3	2.8	1.5	1.5	1.2	1.5
10	62	62	52	51	15	15	12	11	3.0	3.4	2.2	2.7	1.4	1.5	1.2	1.4
11	66	66	54	52	15	15	11	11	2.8	3.2	2.1	2.5	1.3	1.4	1.1	1.3
12	68	69	56	53	14	14	10	10	2.6	3.0	1.9	2.3	1.2	1.3	1.0	1.2
13	71	71	57	54	13	13	9	9	2.4	2.7	1.8	2.0	1.1	1.2	0.8	1.1
14	72	73	57	54	12	12	9	8	2.1	2.5	1.6	1.8	0.9	1.0	0.7	1.0
15	74	75	58	54	11	11	8	7	1.9	2.2	1.4	1.6	0.8	0.9	0.6	0.8
16	75	76	58	55	10	10	7	6	1.7	1.9	1.2	1.3	0.7	0.8	0.5	0.7
17	76	77	59	55	9	9	6	5	1.5	1.7	1.1	1.1	0.6	0.7	0.5	0.6
18	76	78	59	55	7	8	5	4	1.3	1.4	0.9	1.0	0.5	0.6	0.4	0.5
Mean	51	51	42	42	11	11	9	8	2.2	2.4	1.7	1.9	1.0	1.0	0.8	1.0

B, Brown; W, White; HS, Hisex; HL, Hy Line.

The results for Lys, Met+Cys and Thr are shown in Tables 3, 4 and 5. In general, the weekly average results for Lys, Met+Cys and Thr demonstrated that the intake in the first week of life was lower in relation to its body content, providing values of efficiency greater than 1 or 100%.

Table 3. Intake (iLys, mg bird^{-1}), deposition (dLys mg bird^{-1}), efficiency of utilization (kLys, %) and lysine requirement (rLys, g kg^{-1} gain) for the four genotypes of pullets.

Age	iLys				dLys				kLys				rLys			
	B		W		B		W		B		W		B		W	
	HS	HL	HS	HL	HS	HL	HS	HL	HS	HL	HS	HL	HS	HL	HS	HL
1	47	53	35	48	60	55	55	54	128	105	166	117	13	15	10	13
2	93	100	80	104	93	91	82	88	101	92	105	86	17	18	16	19
3	157	162	145	176	131	133	112	126	85	83	79	72	21	21	21	24
4	232	235	220	253	170	177	141	164	74	76	65	66	24	24	26	28
5	312	313	296	324	205	218	166	198	66	70	57	62	26	27	30	31
6	391	390	365	384	232	252	185	223	60	66	51	59	29	29	33	33
7	375	373	339	347	250	276	196	238	68	75	59	70	25	25	29	28
8	426	425	376	376	258	288	200	242	62	69	55	66	27	27	31	30
9	470	469	404	397	258	289	197	238	57	64	50	62	30	29	33	32
10	506	507	426	412	250	282	189	227	51	58	46	58	32	32	36	35
11	535	537	441	422	236	268	178	211	46	52	42	53	35	35	38	38
12	558	562	452	430	218	249	163	191	41	47	38	48	38	38	42	42
13	471	476	411	388	199	227	148	171	45	51	39	48	34	34	41	41
14	483	489	416	391	178	204	132	151	40	45	34	42	38	38	45	47
15	492	499	420	393	158	180	117	131	35	40	30	37	42	42	51	53
16	498	507	422	395	139	158	102	113	30	34	27	32	48	48	57	61
17	504	513	424	396	121	138	89	97	26	30	23	28	54	54	64	70
18	508	518	426	397	104	119	77	82	23	26	20	24	61	62	73	81
Mean	392	396	339	335	181	200	141	164	58	60	55	57	33	33	38	39

B, Brown; W, White; HS, Hisex; HL, Hy Line.

Some authors recommend an efficiency of amino acid utilization for birds around 80% (MARTIN et al., 1994). Based on this, the average efficiency of utilization of Lys and Thr of the four genotypes was normalized (80%) in the third week of age. The results for Met+Cys showed that dietary limitation for these amino acids persisted until the sixth week of age, when the average efficiency of utilization of the four genotypes reached 80%. In this approach, the experimental diet was formulated to contain ccLys, ccMet+Cys and ccThr close to a practical diet and this positive because it allows an approximation to the actual conditions of raising (ZELENKA et al., 2011).

Table 4. Intake (iMet+Cys, mg bird^{-1}), deposition (dMet+Cys, mg bird^{-1}), efficiency of utilization (kMet+Cys, %) and methionine+cystine requirement (rMet+Cys, g kg^{-1} of gain) for four genotypes of pullets.

Age	iMet+Cys				dMet+Cys				kMet+Cys				rMet+Cys			
	B		W		B		W		B		W		B		W	
	HS	HL	HS	HL	HS	HL	HS	HL	HS	HL	HS	HL	HS	HL	HS	HL
1	30	34	22	30	45	46	44	44	152	138	211	149	8	9	6	8
2	59	63	51	66	74	76	69	72	126	121	140	112	11	12	10	12
3	99	102	91	111	108	112	98	106	110	110	108	96	13	14	13	15
4	146	148	139	160	144	149	126	140	99	102	91	89	15	15	16	18
5	197	197	187	205	177	184	150	171	91	94	81	84	17	17	19	19
6	247	246	230	243	203	213	168	195	83	88	74	81	18	18	21	21
7	264	263	236	241	220	232	178	210	85	90	77	89	18	18	20	20
8	301	300	261	261	227	242	181	215	77	82	71	85	19	19	21	21
9	332	331	281	275	226	243	178	213	70	75	65	80	21	21	23	22
10	357	358	295	286	217	236	169	203	63	68	59	74	23	23	25	24
11	378	379	306	293	204	223	157	190	56	61	53	68	25	25	27	27
12	394	397	314	298	187	206	143	173	49	54	48	61	27	27	29	29
13	356	360	286	270	168	187	128	155	50	55	47	62	26	26	29	29
14	365	369	289	272	149	167	113	137	43	48	42	54	29	29	32	33
15	371	377	292	273	131	148	99	119	38	42	36	48	33	33	36	37
16	377	383	293	274	114	129	85	103	32	36	31	41	37	37	40	43
17	381	387	295	275	98	112	73	88	28	31	27	35	42	42	45	50
18	384	391	296	276	84	96	63	75	24	27	23	30	47	48	52	58
Mean	280	283	231	228	154	167	123	145	71	73	71	74	24	24	26	27

B, Brown; W, White; HS, Hisex; HL, Hy Line.

Table 5. Intake (iThr, mg bird^{-1}), deposition (dThr, mg bird^{-1}), efficiency of utilization (kThr, %) and threonine requirement (rThr, g kg^{-1} of gain) for the four genotypes of pullets.

Age	iThr				dThr				kThr				rThr			
	B		W		B		W		B		W		B		W	
	HS	HL	HS	HL	HS	HL	HS	HL	HS	HL	HS	HL	HS	HL	HS	HL
1	33	37	24	34	41	41	40	39	127	110	171	120	9	10	7	9
2	65	70	56	73	67	67	61	64	103	97	111	90	12	13	11	13
3	110	113	102	123	96	99	85	94	88	87	85	76	14	15	15	17
4	162	164	154	177	127	132	108	123	79	80	71	70	17	17	18	20
5	219	219	207	227	154	162	129	149	71	75	63	66	19	19	21	22
6	274	273	255	269	176	187	144	169	65	69	57	63	20	20	23	23
7	257	256	251	256	190	205	152	181	75	81	62	72	17	17	21	21
8	292	291	278	277	197	213	155	185	69	75	57	68	19	19	23	22
9	322	322	299	293	196	214	152	183	62	68	52	64	20	20	25	24
10	347	347	314	304	189	208	145	175	56	62	47	59	22	22	27	26
11	367	368	326	312	178	197	136	162	50	55	43	54	24	24	29	29
12	382	385	334	317	164	183	124	148	44	49	38	49	27	27	32	32
13	371	375	297	281	148	166	111	133	42	46	39	50	28	28	30	31
14	380	385	301	283	132	149	99	117	36	41	35	44	31	31	34	35
15	387	393	304	285	116	132	87	102	32	36	30	38	34	35	38	40
16	392	399	306	286	101	116	76	88	27	31	26	33	39	39	42	45
17	396	404	307	287	88	100	65	75	24	26	23	29	44	44	48	53
18	400	407	308	287	75	86	56	64	20	23	19	24	50	50	55	61
Mean	286	289	246	243	135	148	107	125	59	62	57	59	25	25	28	29

B, Brown; W, White; HS, Hisex; HL, Hy Line.

This methodology is interesting for diagnosing the effectiveness of nutritional management. The simulation performed considering the practical conditions of the study, which used three feeding programs (initial phase 0-6 weeks; breeding 7-12 weeks and rearing 13-18 weeks old) and diets with dietary concentrations of Lys, Met+Cys and Thr established based on the average age of each phase, showed that there was a restricted supply of these amino acids and, inevitably, this period provided a limitation in the maximum potential expression of protein deposition by the bird.

According to the results of the efficiency of amino acids utilization obtained by this procedure, the first three weeks of life must be considered separately from the feeding program to avoid restriction of supply of the major limiting amino acids (Met+Cys, Lys and Thr).

Another finding is the low efficiency of amino acid utilization the from the 10th week of age, especially for the last phase, from 13 to 18 weeks, indicating the excessive supply for the three amino acids studied. The low efficiency in the final weeks of the growth phase may be related to a combination of the excess of amino acids in the moment at which the potential for protein deposition of the bird substantially is reduced. Moreover, according to Silva et al. (2013) the maintenance requirement at this phase took the higher proportion in relation to the other phases. By setting the feed intake value of the present study, it is possible to suggest that the concentrations of dietary Lys, Met + Cys and Thr may be reduced.

The results obtained evidenced that the efficiencies varied between the genotypes. Considering the three amino acids, the major differences in the efficiency of utilization were observed between the brown and white strains. Furthermore, the values were higher for the brown strains, indicating that dietary levels (ccLys, ccMet + Cys and ccThr) were more suited to the growth of these birds compared to the white strains that were, on average, 10% less efficient in the use of dietary amino acids.

Information about the individual utilization of amino acids are scarce in the literature. To compare the efficiency of utilization of Lys, Met + Cys and Thr of the present study, the values above 80% obtained in the first weeks of age were overlooked. Thus, the efficiencies were 49, 57 and 51% for Lys, Met+Cys and Thr respectively. Similar results for efficiency were found by Zelenka et al. (2011) for Lys (49%), Met+Cys (52%) and Thr (45%) using a similar procedure to that applied in the present study for slow-growing broilers.

Some authors advocate that the efficiency of utilization should be obtained with increasing levels of the studied amino acid in the diet to obtain a well-defined response curve, and thus regress the responses of deposition to the amino acid intake (BAKER, 1986). Therefore, the present procedure can be applied to determine the efficacy of the nutritional management by relating the growth curve of the bird with its intake curve.

The daily requirement (r, mg bird$^{-1}\times$day) for growth was obtained considering the division of the deposition by the efficiency of amino acid and, to make it dynamic, its value was related to the kg weight gain of the bird (*a*, mg kg^{-1}). In this way, nutritionists may associate this requirement to a maintenance coefficient (*b*, g kg^{-1}) and calculate the requirement for any bird by the factorial method from the desirable weight gain (WG) and body weight (BW):

$$r = a \times WG + b \times BW.$$

In this approach, the calculated requirement is related to the potential for protein deposition, so, the higher the protein deposition the higher the requirement. The total required by the bird and the increase rate of requirement are correlated with the growth parameters W*m* and *B* of the Gompertz function.

However, by changing the basis of requirement from g bird^{-1} to g kg^{-1} promotes a dilution of the requirement by the total weight gain, especially for birds of the brown strain. Therefore, the overall mean requirement (g kg^{-1}) of rLys, rMet+Cys and rThr were higher for the white strain, once their weight gain is lower.

It is observed that within each phase, rLys (Table 3), rMet+Cys (Table 4) and rThr (Table 5) tend to increase. When the diet was changed to adjust the levels of dietary amino acids (ccLys, ccMet + Cys and ccThr) to the next phase, the efficiency of utilization at this time increased and then decreased by repeating the same pattern.

The results obtained showed high values for rLys (Table 3), rMet + Cys (Table 4) and rThr (Table 5) particularly during the phase from the 13rd to 18th weeks of age. The maximum, minimum and average values were, for rLys: 81, 35 and 8; for rMet+Cys: 58, 25 and 5 and for rThr: 61, 26 and 6 g of the amino acid per kg weight gain, respectively. The presented values for rLys, rMet+Cys and rThr are in agreement with the efficiency of utilization and reflect the nutritional management used, indicating that adjustments can be made to improve the utilization of the amino acids of the diet. The requirements were recalculated considering a constant efficiency for all ages (Table 6). The requirement adjusted of Lys (radjLys), Met+Cys (radjMet+Cys) and Thr (radjThr) for 80% efficiency were 25, 21 and 17 for radjLys; 23, 18 and 14 for radjMet+Cys and 19, 16 and 13 for radjThr, respectively. By adjusting the efficiency of utilization, the values are in agreement with the literature. For Lys, Rostagno et al. (2011) considered that the requirement is 20 g of Lys per kg weight gain for growing pullets. Applying the relationship Met+Cys:Lys and Thr:Lys of Rostagno et al. (2011), for the coefficient of 20 g of Lys kg^{-1} weight gain of Rostagno et al. (2011), it is obtained an average requirement of 15.7 g of Met+Cys and 13.6 g of Thr per kg weight gain, respectively. The values of Met+Cys and Thr obtained by Rostagno et al. (2011) were 12.7 and 15 %, lower than those found in the present study, considering the efficiency of utilization of 80 % for both amino acids.

Besides that, Nascimento et al. (2009a) found values of 21.6 g of Lys per kg body weight for female slow-growing broilers (ISA Label Ja57). These values were similar to the values found in the simulation presented in Table 6.

Table 6. Adjusted lysine requirement (radjLys, g kg^{-1} of gain), methionine + cystine (radjMet+Cys, g kg^{-1} of gain) and threonine (radjThr, g kg^{-1} of gain) to 80% of efficiency of amino acid utilization and the ideal ratio amino acid:lysine for methionine+cystine (Met+Cys Lys^{-1}) and threonine (Thr Lys^{-1}).

Age	radjLys				radjMet+Cys				radjThr				Met+Cys Lys^{-1}				Thr Lys^{-1}			
	B		W		B		W		B		W		B		W		B		W	
	HS	HL	HS	HL	HS	HL	HS	HL	HS	HL	HS	HL	HS	HL	HS	HL	HS	HL	HS	HL
1	21	19	19	19	15	16	16	15	14	14	14	14	75	83	80	81	70	74	72	21
2	21	21	20	20	17	18	17	17	15	15	15	15	79	84	84	82	72	74	74	21
3	22	22	21	22	18	19	18	18	16	16	16	16	82	84	87	84	73	74	76	22
4	22	23	21	23	19	19	19	19	16	17	16	17	85	84	89	85	75	74	77	22
5	22	23	21	24	19	20	19	20	17	17	16	18	86	84	90	86	75	74	77	22
6	22	24	21	24	19	20	19	21	17	18	16	18	87	84	91	87	76	74	78	22
7	22	24	21	25	19	20	19	22	16	18	16	19	88	84	91	88	76	74	78	22
8	21	24	21	25	19	20	19	22	16	18	16	19	88	84	91	89	76	74	77	21
9	21	23	21	25	18	20	19	22	16	17	16	19	88	84	90	89	76	74	77	21
10	20	23	21	25	18	19	18	22	15	17	16	19	87	84	89	90	76	74	77	20
11	20	23	20	25	17	19	18	23	15	17	15	19	86	83	88	90	75	74	76	20
12	20	22	20	25	17	18	17	23	15	16	15	19	86	83	87	90	75	74	76	20
13	19	22	20	25	16	18	17	22	14	16	15	19	85	83	86	91	75	73	75	19
14	19	21	19	25	16	18	17	22	14	16	15	19	84	82	85	91	74	73	75	19
15	18	21	19	24	15	17	16	22	14	15	14	19	83	82	84	91	74	73	74	18
16	18	21	19	24	15	17	16	22	13	15	14	19	82	82	83	91	73	73	74	18
17	18	20	19	24	14	16	15	22	13	15	14	19	81	81	82	91	73	73	73	18
18	17	20	18	24	14	16	15	22	13	14	13	19	80	81	82	91	72	73	73	17
Mean Lin	20	22	20	24	17	18	17	21	15	16	15	18	84	83	87	88	74	74	76	20
Mean AA	21				18				16				86				75			

B, Brown; W, White; HS, Hisex; HL, Hy Line; Lin, lineage; AA, amino acid.

The ideal ratio Met+Cys: Lys in this study ranged from 75 to 91 %. These values were close to those found for females by Silva Junior et al. (2006) and Nascimento et al. (2009b) with female slow-growing broilers, which obtained values from 77 to 82 %, respectively. For the ratio Thr: Lys, the results were similar to those registered in recent studies (BERNARDINO et al., 2011; DUARTE et al., 2012). Thus, the methodology employed shown to be applicable to assess the efficiency of amino acid utilization, since it allowed obtaining results that were supported by recent findings in the literature. Moreover, it can be a useful tool to diagnose the effectiveness of nutritional management, aiding in decision-making on the nutritional management.

Conclusion

The procedure based on the Gompertz function to determine the efficiency of amino acid utilization proved to be suitable for evaluating the efficiency of amino acid utilization and can be a useful tool to diagnose the effectiveness of nutritional management, aiding in decision-making on the nutritional management.

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