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Digestible lysine supplementation influences weight gain in 21-day-old broiler chickens

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Additional keywords

Digestible amino acids.
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SUMMARY

This study analysed the effects of digestible lysine on the performance parameters, morphometry and quality of the breast muscle (Pectoralis major) of Cobb 500 broiler chickens aged 21 and 42 days. Two completely randomized experiments were performed, with five treatments and eight replications of 30 birds per treatment. The diets were adjusted according to the nutritional requirements for each phase of poultry development, with digestible lysine levels during the initial phase (birds aged 1 to 21 days) at 1.12, 1.19, 1.25, 1.31, and 1.37% and during the final phase (22 to 42 days) at 0.97, 1.02, 1.08, 1.13, and 1.19%. During the initial phase, lysine supplementation had a significant effect (P<0.05) on weight gain and red content in breast meat, with 1.24% and 1.29% digestible lysine resulting in maximum weight gain and red content, respectively. No significant difference (P>0.05) was observed in breast muscle morphometry, carcass yield, performance, or meat quality in birds aged 22-42 days for the different levels of lysine, suggesting that the lowest level of lysine tested did not have a negative impact on production characteristics even though it was below the recommended levels for this species. In conclusion, 1.24% digestible lysine is recommended for maximum weight gain at the initial phase of broiler chicken development (1-21 days) and 0.97% is sufficient to meet the nutritional requirements of birds at the final phase (22-42 days) without compromising production performance.

Suplementação de lisina digestível influencia o ganho de peso de frangos de corte aos 21 dias de idade

Palavras chave adicionais

Aminoácidos digestíveis.
Análise de regressão.
Desempenho.
Proteína ideal.

RESUMO

Este estudo analisou os efeitos da lisina digestível sobre os parâmetros de desempenho, morfometria e qualidade do músculo do peito (Pectoralis major) de frangos de corte com 21 e 42 dias de idade. Foram realizados dois experimentos em um delineamento inteiramente casualizado, com cinco tratamentos e oito repetições de 30 aves por parcela. As dietas foram formuladas de acordo com as exigências nutricionais para cada fase de desenvolvimento das aves, com diferentes níveis de lisina digestível durante a fase inicial (1 a 21 dias de idade) para o primeiro experimento: 1,12, 1,19, 1,25, 1,31 e 1,37% de lisina digestível e durante a fase final (22 a 42 dias) para o segundo experimento: 0,97, 1,02, 1,08, 1,13 e 1,19% de lisina digestível. Durante a fase inicial, a suplementação de lisina teve um efeito (P <0,05) sobre o ganho de peso e teor de vermelho na carne de peito. Estimaram-se os níveis de 1,24 e 1,29% de lisina digestível, como ideais para maximizar o ganho de peso das aves e o teor de vermelho da carne de peito aos 21 dias de idade. Não foi observada diferença entre os tratamentos (P>0,05) sobre a morfometria do músculo do peito, rendimento da carcaça, desempenho e qualidade da carne em aves de 22 a 42 dias para os diferentes níveis de lisina. Estes resultados sugerem que o menor nível de lisina testado não apresentou impacto negativo sobre as características analisadas, apesar de estar abaixo dos níveis recomendados. Em conclusão, recomenda-se 1,24% de lisina digestível para o ganho de peso máximo na fase inicial de desenvolvimento de frango de frango (1-21 dias) e 0,97% de lisina digestível é suficiente para atender aos requisitos nutricionais das aves na fase final de criação (22-42 dias) sem comprometer o desempenho.

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INTRODUCTION

To meet the growing global demand for animal proteins, broiler production is predicted to reach 131 million tons by 2025 (OECD/FAO 2016). To achieve and sustain such a substantial growth in production, producers must have management techniques which

make it possible to maximize the genetic potential of broiler lines.

Lysine is a synthetic amino acid that is often used as a reference in the formulation of feeds based on ideal protein, as its analysis in food is relatively simple, there is a lot of information on lysine digestibility in birds, and its absorption acts mainly by increasing body protein (Baker et al. 1994, pp. 1441-1447). Synthetic lysine supplementation can reduce the cost of feed by 7.07% while still maintaining adequate levels of this amino acid (Araújo et al. 2004, pp. 1197-1201). A reduction in crude protein in the diet, by decreasing the amount of soymeal and increasing that of corn, can lead to economic benefits and have husbandry and environmental advantages, as a better balance of digestible amino acids maximizes nitrogen and energy retention while reducing the loss of non-digested and non-metabolized nutrients (Araújo et al. 2004, pp. 1197-1201).

Lysine levels in the diet can be easily increased by synthetic lysine supplementation or by the addition of lysine-rich ingredients, such as soybean meal. However, it is essential to maintain an adequate arginine and lysine ratio (arg:lys) due to their antagonist relationship, as an imbalance between these amino acids in the diet can affect production, increase the incidence of locomotive disorders, promote feather malformation, and interfere with the immune system of broiler chickens (Kidd & Fancher 2001, pp. 385-393).

The carcass composition of broilers has evolved into leaner poultry and lines have been specially developed for greater breast yield. Additionally to genetics and sex, nutrition can influence the yield and quality of breast meat in broiler chickens (Zhai et al. 2015). The effect of lysine on breast yield occurs from the initial to the final phase of poultry development (Labadan et al. 2001, pp. 599-606). If lysine requirements are not met at the initial phase of development, loss in carcass yield and breast muscle will be noticed at slaughter even if the diet provided at the final phase had contained the required levels of this amino acid (Kidd & Fancher 2001, pp. 385-393).

Color, tenderness, succulence, and flavor are developed post-mortem and are influenced by the connective tissue composition of the skeletal muscles and preslaughter fibrilar (Sams 1999, pp. 798-803). This features that determine the consumer's choice for a particular meat.

Therefore, the aim of this study was to analyse the effects of digestible lysine on production performance, carcass and parts yield; and on the morphometry, composition, and quality of the breast muscle (*Pectoralis major*) of broiler chickens aged 21 and 42 days.

MATERIAL AND METHODS

This study was approved by the Ethics Committee on the Use of Animals of the UNESP – Univ Estadual Paulista, Campus Jaboticabal, Jaboticabal-SP, Brazil (protocol number 007753/11).

Husbandry and rearing conditions

Two experiments were conducted: the initial phase (birds aged 1 to 21 days) and the final phase of development (22 to 42 days old). For the initial phase experiment, 1,200 one-day-old Cobb 500 male chicks, with average initial weight of 48g, were housed in a conventional masonry shed with wood shavings bed at 1.2 kg of dry matter per bird housed per box. Infrared lamps of 250 watts were used to keep the room temperature between 28 and 30 °C during the first two weeks of life. At 22 days of age, and average weight of 905g, the birds were included in the final phase experiment.

Temperature and relative humidity were recorded daily using two digital thermo-hygrometers placed at the same height of the birds and at equidistant positions. The maximum and minimum temperatures recorded were 37.5 and 22.7 °C, respectively; and the maximum and minimum relative humidity 62 and 20.18%, respectively. During the first two weeks of age, small aluminium drinkers and juvenile tubular feeders were used and gradually replaced, after the first week of age, by 20kg-capacity tubular feeders and pendular drinkers. Food and water were replenished twice a day, allowing the birds free access to the experimental diets and water throughout the study period.

The chicks were vaccinated against Marek, Gumboro, and Bouba disease in the hatchery; against Gumboro disease at 5 and 21 days old; and against Newcastle Disease on the 8th day (via drinking water). Curtains and fans were used to ensure the thermal comfort of the birds.

Experimental treatments

To avoid other amino acids becoming limiting in the experimental diets, the remaining amino acids were added, as needed, to prevent their ratio to lysine to fall below those recommended by Rostagno et al. (2005) for the ideal protein. The total amino acid value of the ingredients used was obtained by high-performance liquid chromatography (HPLC) (**Table I**) at the Laboratory for Animal Nutrition Analysis (LANA) of the School of Agrarian Sciences and Veterinary Medicine, UNESP- Univversidade Estadual Paulista, Jaboticabal-SP, Brazil. These were subsequently converted into digestible amino acids using the digestibility coefficients from the Brazilian Tables for Poultry and Swine (Rostagno et al. 2005).

Five treatments were established for the initial phase of development, with diets containing 1.12 1.19, 1.25 1.31 and 1.37% digestible lysine (**Table II**). Five treatments were also established for the final phase, with diets containing 0.97, 1.02 1.08 1.13 and 1.19% digestible lysine (**Table III**). For both phases of development, the levels of the remaining amino acids were determined based on the values recommended by Rostagno et al. (2005).

Performance, carcass yield, and meat quality

Weight gain (g), feed intake, and feed conversion (g diet/weight gain) were evaluated as performance characteristic at the initial and final phase of poultry development. Feed consumption and conversion values were corrected according to the mortality of the period. At 21 and 42 days of age, three birds per repetition were selected for slaughter, totalling 24 chicks per treatment. After eight hours of food withdrawal, the

Table I. Percentage of dry matter (DM), crude protein (CP), metabolizable energy (ME), ether extract (EE), crude fibre (CF), calcium (Ca), available phosphorus (Pd), and sodium (Na); and composition of total (TAA) and digestible amino acids (DAA) of the ingredients used in the experimental diets (Porcentagem de matéria seca (MS), proteína bruta (PB), energia metabolizável (EM), extrato etéreo (EE), fibra bruta (FB), cálcio (Ca) fósforo disponível (Pd) e sódio (Na) e composição dos aminoácidos totais (AAT) e dos aminoácidos digestíveis (AAD) nos ingredients utilizados nas dietas experimentais).

	Corn		Soybean meal	
DM	88.90		89.10	
CP	8.11		44.40	
ME(kcal/kg)	3381		2256	
EE	3.61		1.66	
CF	1.73		5.41	
Ca	0.03		0.24	
Pd	0.08		0.18	
Na	0.02		0.02	
	AAT[1]	AAD[2]	AAT[1]	AAD[2]
Alanine	0.59	0.55	1.94	1.90
Arginine	0.36	0.33	3.19	3.06
Glycine	0.31	0.30	1.89	1.88
Isoleucine	0.27	0.24	2.01	1.83
Leucine	0.97	0.92	3.42	3.12
Lysine	0.23	0.20	2.72	2.50
Cistine	0.18	0.16	0.62	0.60
Methionine	0.17	0.16	0.60	0.54
Meth + Cis	0.35	0.32	1.22	1.06
Phenylalanine	0.39	0.35	2.32	2.15
Tyrosine	0.24	0.21	1.50	1.47
Threonine	0.29	0.24	1.74	1.53
Tryptophan	0.06	0.05	0.58	0.52
Valine	0.39	0.34	2.13	1.90
Histidine	0.24	0.22	1.16	1.10
Serine	0.39	0.34	2.29	2.24

[1]Total amino acids and [2]digestible amino acids calculated based on the digestibility coefficients from the Brazilian Tables for Poultry and Swine (Rostagno et al., 2005).

birds were killed by electrosensitization followed by bleeding. The weight of the breast, thighs, drumsticks, back, and wings in relation to the weight of the carcass was used to calculate the carcass and parts yield from each bird, according to the methodology by Mendes et al. (1993, pp. 466-472).

Quality analyses of the breast (*Pectoralis major)* were conducted 24 h post-mortem, according to the methodology described by Ferreira et al. (2015). The pH was determined by directly inserting an electrode into the muscles using a digital pH meter (Testo, model Testo-106, Lenzkirch, Germany). Meat color was measured from the inner portion of the breast using Chrome Meter CR-300 equipment (Konica Minolta Sensing, Osaka, Japan) and the CIELAB trichromatic system, which determines lightness (L*), redness (a*), and yellowness (b*) values. The water-holding capacity was measured by press loss: 1 g from each meat sample was pressed with a 10-kg weight for 5 minutes at 25ºC; each sample was subsequently reweighed to calculate water-holding capacity, and this value was expressed as a percentage of the initial weight. To determine cooking losses, samples were placed in plastic bags and cooked in a water bath at 85°C for 30 minutes at a final internal temperature of 75 to 80°C. After releasing the exuded water and cooling to reach room temperature, they were again weighed and compared to the initial weight (Cason et al. 1997). Warner–Bratzler shear force was measured on the cooked samples previously used in the cooking loss analysis using a Texture Analyzer TAXT2i (Godalming, Surrey, United Kingdom) and expressed as kilograms per square centimeter (Lyon et al. 1998, pp. 53-60).

Muscle histology and morphometry

Muscle morphometry consisted in analysis diameter and the number of muscle fibres at both phases (initial and final) of poultry development was perfor-

Table II. Composition (%) of experimental diets used during the initial phase of the development of broiler chickens aged 1 to 21 days (Composição (%) da dieta experimental utilizada durante a fase incial (1 a 21 dias de idade) para frangos de corte).

Ingredients	Lysine levels (%)				
	1.125	1.185	1.247**	1.309	1.375
Corn grain	56.48	56.25	56.01	55.76	55.49
Soybean meal (45%)	36.44	36.47	36.50	36.53	36.56
Soy oil	2.90	2.96	3.01	3.07	3.13
Dicalcium phosphate	1.94	1.95	1.95	1.95	1.95
Limestone	0.81	0.81	0.81	0.81	0.81
Salt	0.49	0.49	0.49	0.49	0.49
Vit. + Min Supplement*	0.20	0.20	0.20	0.20	0.20
DL – Methionine	0.31	0.30	0.30	0.30	0.30
L – Threonine	0.08	0.08	0.08	0.08	0.08
L – Lysine HCL	0.11	0.18	0.26	0.34	0.43
Choline hydrochloride	0.08	0.08	0.08	0.08	0.08
Coccidicidal	0.05	0.05	0.05	0.05	0.05
Inert (washed sand)	0.11	0.18	0.26	0.34	0.43
Total	100.00	100.00	100.00	100.00	100.00
	Calculated levels				
Metabolizable energy (kcal/kg)	3.020	3.020	3.020	3.020	3.020
Crude protein (%)	21.46	21.46	21.46	21.46	21.46
Calcium (%)	0.913	0.913	0.913	0.913	0.913
Choline (%)	0.056	0.056	0.056	0.056	0.056
Available phosphorus (%)	0.470	0.470	0.470	0.470	0.470
Total phosphorous (%)	0.732	0.732	0.732	0.732	0.731
Sodium (%)	0.220	0.220	0.220	0.220	0.220
Dig. Lysine (%)	1.125	1.185	1.247	1.309	1.372
Dig. Methionine (%)	0.604	0.604	0.604	0.604	0.604
Dig. Met.+Cist. (%)	0.890	0.890	0.890	0.890	0.890
Dig. Threonine (%)	0.811	0.811	0.811	0.811	0.811
Dig. Tryptophan (%)	0.249	0.249	0.249	0.249	0.249
Dig. Valine (%)	0.935	0.935	0.935	0.935	0.935
Dig. Arginine (%)	1.309	1.309	1.309	1.309	1.309
Dig. Isoleucine (%)	0.811	0.811	0.811	0.811	0.811

* Vitamin and Mineral Supplement. Enriched per kilogram of feed: Vit. A 1500 IU / kg, Vit E 20 mg, Vit. K 0.5 mg, Vit. B1 2mg, Vit B2 3.6 mg, Vit. B12 20 mcg, calcium pantothenate 10 mg, folic acid 0.5 mg, growth promoter 50 mg, Niacin 100 mg, copper 75 mg, iodine 1.25 mg, selenium 0.25 mg, manganese 120 mg, zinc 100 mg, iron 50 mg, antioxidant 0.5 mg, coccidicidal 110 mg.
** Recommended digestible lysine level for broiler chickens aged 1 to 21 days by Rostagno et al. (2005).

med at the Department of Morphology and Physiology of the School of Agricultural Sciences and Veterinary Medicine, UNESP- Universidade Estadual Paulista, Jaboticabal-SP, Brazil. After slaughter, the breast muscle (*Pectoralis major)* was extracted and weighed (Bel S1002, 1000g x 0.01g, Piracicaba, SP, Brazil). A digital calliper (Toledo –Adventure ARD 110, São Bernardo do Campo, Brazil) was used to measure muscle thickness (mm) and a ruler (cm) to determine the length and width of the muscle (breast fillets).

Breast tissue was sampled (approximately 2 cm in length) from the *pars sternobranchialis* region and glass slides prepared for histological analysis. Samples were dehydrated, cleared, and paraffin embedded. Subsequently, muscle fibres were stained with haematoxylin-eosin (HE). Measurements of the fibres were obtained according to the technique by Dubowitz and Brooke (1973). A light microscope (BX50 Olympus) equipped with a digital image analysis system (Digital Image Processing And Analysis Software for Professional Microscopy- Qwin V3, Leica, Germany) and the software Optimus 4.0 were used to determine muscle fibre diameter (cross sectional area) and the concentration of fibres (number of fibres/μm^2) using a 40x objective.

Experimental design, treatments, and statistical analysis

This study used a completely randomized design for both phases of poultry development, with five concentrations of digestible lysine and eight repetitions

Table III. Composition (%) of experimental diets used during the final phase of the development of broiler chickens aged 22 to 42 days (Composição (%) da dieta experimental utilizada durante a fase final (22 a 42 dias de idade) para frangos de corte).

Ingredients	Lysine Levels (%)				
	0.97	1.02	1.08**	1.19	1.13
Corn grain	61.89	61.80	61.61	61.33	61.47
Soybean meal (45%)	30.30	30.30	30.30	30.30	30.30
Soy oil	4.100	4.100	4.100	4.100	4.100
Dicalcium phosphate	1.600	1.600	1.600	1.600	1.600
Limestone	0.800	0.800	0.800	0.800	0.800
Salt	0.500	0.500	0.500	0.500	0.500
Vit. + Min. Supplement*	0.200	0.200	0.200	0.200	0.200
DL – Methionine	0.220	0.220	0.220	0.220	0.220
L – Threonine	0.040	0.040	0.040	0.040	0.040
L – Lysine HCL	0.090	0.160	0.230	0.300	0.370
Choline hydrochloride	0.070	0.070	0.070	0.070	0.070
Coccidicidal	0.050	0.050	0.050	0.050	0.050
Inert (washed sand)	0.140	0.160	0.280	0.420	0.350
Total	100.00	100.00	100.00	100.00	100.00
	Calculated Levels				
Metabolizable energy (kcal/kg)	3.171	3.171	3.171	3.171	3.171
Crude protein (%)	19.11	19.11	19.11	19.11	19.11
Calcium (%)	0.82	0.82	0.82	0.82	0.82
Choline	0.05	0.05	0.05	0.05	0.05
Available phosphorus (%)	0.40	0.40	0.40	0.40	0.40
Total phosphorous (%)	0.65	0.65	0.65	0.65	0.65
Sodium (%)	0.22	0.22	0.22	0.22	0.22
Dig. Lysine (%)	0.97	1.02	1.08	1.19	1.13
Dig. Methionine (%)	0.51	0.51	0.51	0.51	0.51
Dig. Met.+Cist. (%)	0.77	0.77	0.77	0.77	0.77
Dig. Threonine (%)	0.69	0.69	0.69	0.69	0.69
Dig. Tryptophan (%)	0.22	0.22	0.22	0.22	0.22
Dig. Valine (%)	0.79	0.79	0.79	0.79	0.79
Dig. Arginine (%)	1.18	1.18	1.18	1.18	1.18
Dig. Isoleucine (%)	0.74	0.74	0.74	0.74	0.74

* Vitamin and Mineral Supplement. Enriched per kilogram of product: Vit. A 5,500,000 IU / kg; Vit D3 1,000,000 IU / kg; Vit. 6500 mg; Vit. K3 1250 mg; Vit. B1 500 mg.;Vit B2 2500 mg; Vit. B6 750 mg; Vit. B12 7500 mcg; calcium pantothenate 6500 mg; folic acid 250 mg; niacin 17,500 mg; biotin 25 mg; copper 3000 mg; cobalt 50 mg; iodine 500 mg; selenium 100 mg; manganese 32,500 mg; zinc 22,500 mg; iron 25,000 mg; antioxidant 2000mg.

** Recommended digestible lysine level for broiler chickens aged 22 to 42 days by Rostagno et al. (2005).

of 30 birds per treatment. The data were checked for normality by studentized test (Cramer-von-Misses) and homogeneity of variances (Levene test). The data were analysed by ANOVA, using the GLM procedure of SAS® statistical analysis program (SAS® developed at North Carolina State University, 2002). Means were compared by orthogonal contrasts and significance considered at $P<0.05$.

RESULTS

Performance, carcass yield, and meat quality

No significant difference ($P>0.05$) was observed in the performance parameters of birds at 42 days of age. However, in birds aged 21 days, there was a significant quadratic effect ($P<0.05$) on weight gain. An equation ($WG = -2104.6x^2 + 5230.4x - 2376.6$; $R^2 = 0.86$) was used to estimate 1.242% digestible lysine as the level required to obtain the maximum weight gain of 873g (**Figure 1**). There was no significant effect ($P>0.05$) on carcass and parts yield between the different levels of lysine used at both phases of the study. For meat quality parameters, there was a significant quadratic effect ($P<0.05$) on the red content in the breast muscle only in 21-day-old birds. An equation ($RC = -56.646x^2 + 146.25x - 90.639$; $R^2 = 0.83$) was used to estimate

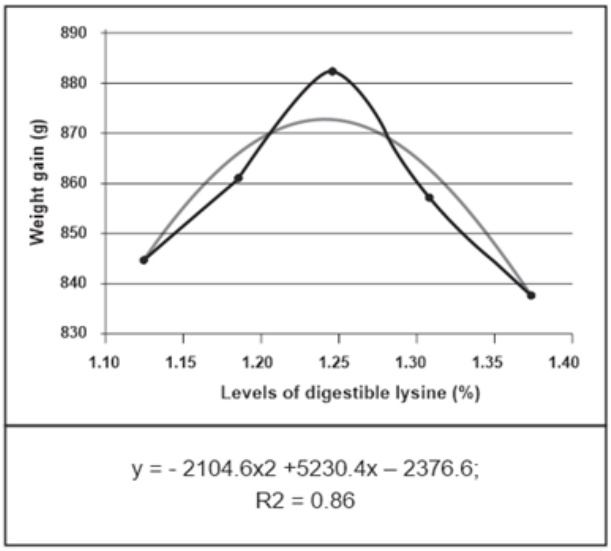

Figure 1. Effect of lysine levels (%) on the weight gain of broiler chickens aged 1 to 21 days (Efeito dos níveis de lisina (%) sobre o ganho de peso de frangos de corte de 1 a 21 dias de idade).

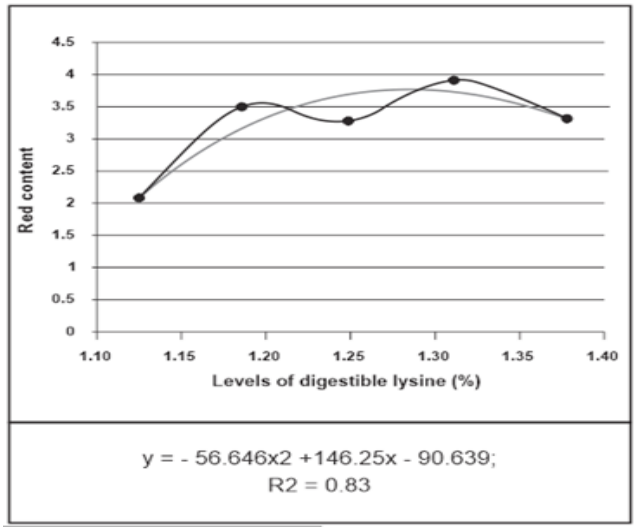

Figure 2. Effect of lysine levels (%) on the red content of the breast muscle of broiler chickens aged 21 days (Efeito dos níveis de lisina (%) sobre o teor de vermelho no músculo do peito de frangos de corte aos 21 dias de idade).

1.290% digestible lysine as the level required to obtain the maximum red content of 3.76 (**Figure 2**).

Muscle morphometry

There was no significant difference (P>0.05) between the different lysine levels on the length, width, or thickness of breast muscle fibres; or on the size and number of fibres present (P>0.05) at both stages of development analysed.

DISCUSSION

The digestible lysine levels used in this study were sufficient to promote significant weight gain and red content in the meat of broiler chickens at 21 days of age; however, no effect was observed on 42-day-old birds.

The increase in weight gain through the use of digestible lysine levels is related to the protein synthesis function of lysine (Rocha et al. 2009, p. 1726-1731). According to Leclercq (1998, pp. 118-123), lysine has specific effects on the body composition of animals and the requirements for this amino acid follows a hierarchy; with requirements for maximum weight gain being the lowest, followed by breast meat yield, feed conversion, and finally the reduction of abdominal fat deposition.

These performance results corroborate those by Bernal et al. (2014, pp. 49-54), who observed increase in weight gain when five diets with increasing levels of digestible lysine (1.06 to 1.30%) were fed to Cobb 500 male broilers aged 10 to 21 days. Furthermore, Cella et al. (2009, pp. 101-106) observed a quadratic effect on the weight gain of broiler chickens at the initial phase of development when diets containing lysine (1.14, 1.18, 1.22, and 1.26%) were used, with the best results obtained with 1.18% digestible lysine, similarly to the satisfactory response observed in this study for 1.24% lysine.

According to Rostagno et al. (2005), broilers aged 1 to 21 days had a nutritional requirement of crude protein of 21.46% and digestible lysine of 1.24%, according to the authors in 2011 (Rostagno et al. 2011) were updated to 21.60 and 1.25%, respectively. In the last update of the Brazilian Tables for Poultry and Swine in 2017 (Rostagno et al. 2017), requirements were higher when compared to previous years, being 24.64% crude protein and 1.32% digestible lysine. Therefore, the nutritional requirement of digestible lysine for broiler chickens needs to be constantly reviewed, mainly due to the genetic improvement of the birds.

The increased digestible lysine of 1.29% reduced a*, making the breast meat more red without altering the other parameters of meat quality. Considering that the pectoralis major muscle in broilers contains glycolytic fast-twitch fibers that grant the meat a white color (Alves et al. 2012, pp. 361-367) and present high metabolic plasticity, perhaps the redder coloring we observed in the present study could have been caused by the increased vascularity of the fibers associated to metabolic changes.

The length, width, thickness, and the number of fibres in the breast muscle in this study did not vary significantly in both stages of broiler development, even though it is known that lysine is required simply for protein deposition and an inverse relationship exists between muscle protein synthesis and lysine oxidation in the body (Bequette 2003). Protein synthesis is the main function of lysine and the data obtained in the present study for this parameter was satisfactory, as the lowest level of lysine tested did not compromise the production parameters analysed.

Changes in lysine supplementation in the feed alters the amino acid ratio of the diet, creating thus another source of variation that may influence results (Fernandes et al. 2011, pp. 151-155) and which may have been responsible for the lack of significant effect of the different levels of digestible lysine on carcass

and parts yield, and size and number of muscle fibres observed in the present study.

CONCLUSION

According to the results obtained in this study, 1.24% digestible lysine in the diet is recommended for maximum weight gain during the initial phase of development of broiler chickens. In birds aged 22 to 42 days, 0.97% digestible lysine is advocated for meeting the nutritional requirements of the birds and not compromising performance or meat quality parameters.

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BIBLIOGRAFY

Alves, M F R, Abe, F R, & Boleli, I C 2012, `Influence of enclosure size on growth of breast and leg muscle fibers in domestic fowl´. *International Journal of Poultry Science,* vol. 11, pp. 361–367.

Araújo, L F, Junqueira, O M & Araújo, C S S 2004, `Redução do nível proteico da dieta através da formulação baseada em aminoácidos digestíveis. *Ciência Rural,* vol. 34, no. 4, pp. 1197-1201.

Baker, D H & Han, Y 1994, `Ideal amino acid profile for chicks during the first three weeks posthatching. *Poultry Science*, vol. 73, pp. 1441-1447.

Bequette, B J 2003, Amino acid metabolism in animals: in the overview. In: D'Mello, J P F (ed.) `*Amino acids in animal nutrition´*. 2. New York, USA: CAB International.

Bernal, L E P, Tavernari, F C, Rostagno, H S & Albino, L F T 2014, `Digestible lysine requirements of broilers`.*Brazilian Journal of Poultry Science*, vol. 1, pp. 49-54.

Cason, J A, Lyon, C E & Papa, C M 1997. Effect of muscle opposition during rigor on development of broiler breast meat tenderness. *Poultry Science*, vol. 76, pp. 725-787.

Cella, P S, Murakami, A E & Franco, J R G 2009. Levels of digestible lysine in diets based on the ideal protein concept for broiler chickens in the initial phase. *Revista Brasileira de Zootecnia*, vol. 10, pp. 101-106.

Dubowitz, V & Brooke, M H 1973. `*Muscle biopsy-a modern approach´*. London, UK: Saunders.

Fernandes, J I M, Rosa, D D, Ribeiro, M V, Lima, E T & Fernandes, N L M 2011. `Assessment of arginine diet on the immune response of broilers immunized against Gumboro disease. *Acta Scientiarium. Animal Science*, vol. 33, pp. 151-155.

Ferreira, I B, Matos Junior, J B, Sgavioli, S, Vicentini, T I, Morita, V S & Boleli, I C. 2015. ´Vitamin C prevents the effects of high rearing temperatures on the quality of broiler thigh meat´. *Poultry Science*, vol. 94, pp. 8141-8151.

Kidd, M & Fancher, B I 2001. `Lysine needs of starting chicks and subsequent effect during the growing period´. *Journal of Applied Poultry Research*, vol. 10, pp. 385-393.

Labadan, M C, Hsu, K N & Austic, R E 2001, `Lysine and arginine requirements of broiler chickens at two-to-three week intervals to eight weeks of age´. *Poultry Science*, vol. 80, pp. 599-606.

Leclerq, B 1998. Specific effects of lysine on broiler production: comparison with threonine and valine. *Poultry Science*, vol. 77, pp. 118 - 123.

Lyon, C E, Lyon, B G &an Dickens, J A 1998, `Effects of stimulation, deboning time, and marination on color and texture of broiler breast meat. *Journal of Applied Poultry Research*, vol. 7, pp. 53-60.

Mendes, A A, Garcia, E A, Gonzalez, E & Varolli, J C 1993, `The effect of the strain and age of slaughter on carcass yield of broiler chickens´. *Revista Brasileira de Zootecnia*, vol. 22, pp. 466-472.

OECD/FAO (2016), OECD-FAO Agricultural Outlook 2016-2025, OECD Publishing, Paris. http://dx.doi.org/10.1787/agr_outlook-2016-en.

Rocha, T, Gomes, P C & Donzel, J L 2009, `Levels of digestible lysine in diets for laying hens in the period from 24 to 40 weeks of age´. *Revista Brasileira de Zootecnia*, vol. 38, pp. 1726-1731.

Rostagno, H S, Albino, L F T, Donzele, J L, Gomes, P C, Oliveira, R F, Lopes, D C, Ferreira, A S & Barreto, S L T 2005, *Brazilian tables for poultry and swine: composition of food and nutritional requirements*. 1th ed. UFV, Viçosa, MG.

Rostagno, H S, Albino, L F T, Donzele, J L, Gomes, P C, Oliveira, R F, Lopes, D C, Ferreira, A S & Barreto, S L T 2011, *Brazilian tables for poultry and swine: composition of food and nutritional requirements*. 2th ed. UFV, Viçosa, MG.

Rostagno, H S, Albino, L F T, Donzele, J L, Gomes, P C, Oliveira, R F, Lopes, D C, Ferreira, A S & Barreto, S L T 2017, *Brazilian tables for poultry and swine: composition of food and nutritional requirements*. 3th ed. UFV, Viçosa, MG.

Sams, A R 1999, `Meat quality during processing´. *Poultry Science*, vol. 78, pp. 798– 803.

SAS Institute 2002, SAS/STAT User's Guide: Statistics. Version 9.2. SAS Inst. Inc., Cary, NC.

Zhai, W, Peebles, E D, Wang, X, Gerard, P D, Olanrewaju, A H & Mercier, Y 2015, `Effects of dietary lysine and methionine supplementation on Ross 708 male broilers from 21 to 42 d of age (III): serum metabolites, hormones, and their relationship with growth performance´. *Journal of Applied Poultry Research*, vol. 25, pp. 223-231.