Efficiency of lysine utilization by growing meat quail

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ABSTRACT The objective of present study was to estimate the efficiency of lysine utilization by meat quail of 21 to 35 d of age. A total of 500 meat quails were distributed in a completely randomized design in a 2 × 5 factorial arrangement, with 2 sexes (male and female) and 5 digestible lysine levels (0.714, 0.816, 0.918, 1.020, and 1.122%) and 5 replications of 10 birds each. The variables studied were feather-free body weight (**FFBW**), feed intake (**FI**), lysine intake (**LysI**), feather-free body protein deposition (**FFBPD**), feather-free body lysine deposition (**FFBLysD**), feather-free body fat deposition (**FFBFatD**), feather weight (**FW**), feather protein deposition, feather lysine deposition, and feather fat deposition. The FFBW, FFBPD, FFBLysD, and FFBFatD were regressed as a function of LysI for each sex to estimate the efficiency of lysine utilization in the feather-free body (**ELysFFB**), and the individual equations were compared. In addition, a multiple regression without intercept was also used to estimate the ELysFFB and in feathers (**ELysF**) individually. To compare the ELysFFB obtained by the different methods, the t-statistic was used. There was no effect on sex × lysine level interactions for any variable. The females showed higher FFBW (5.07%) and FFBFatD (26.23%) than males. All variables increased with the level of dietary lysine, with the exception of FI, FW, and the deposition of nutrients within them. The ELysFFB values obtained by simple linear regression and multiple linear regression were 48.0 and 44.6%, respectively. As there was no difference in the efficiencies estimated by the different methodologies, the best estimate of ELysFFB was 46.3%, that is, the average. The best estimate of ELysF was 18.1%, obtained by multiple linear regression.

Key words: efficiency of lysine utilization, lysine, meat quail

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INTRODUCTION

Growth performance and muscle development of birds are highly dependent on adequate dietary supply, especially of lysine (**Lys**). Lys is considered the second limiting amino acid (**AA**) when corn-soybean meal diets are used (Edwards et al., 1999; Dozier and Payne, 2012), probably having the most specific effect on carcass composition and muscle growth of all AAs (Hocquette et al., 2007). Studies have shown that Lys supplementation at levels above the requirement for weight gain positively influences breast meat yield, in the same sense that some authors have shown that Lys deficiency specifically reduces muscle development (Leclercq, 1998; Tesseraud et al., 2001; Dozier et al., 2010).

Owing to its importance in body protein deposition, plus its broad commercial availability and easy laboratory analysis, Lys has become the reference AA for application of the concept of ideal protein, in which the concentrations of other AAs in diet are proportional to the amount of Lys (Baker, 1997; Corzo et al., 2002).

The Lys requirements of birds are determined using 2 main methods (D'Mello, 2003): dose-response, in which nutritional requirements are considered to be the amount of AA required to maximize bird performance (Silva et al., 2014), and factorial, in which the requirements are estimated based on the assumption that birds need AAs to maintain vital processes, growth, and production, which allows more flexible and accurate estimates of requirements (Sakomura et al., 2015; Reis et al., 2018; Melaré et al., 2019). However, so that factorial models for the prediction of Lys requirements can be developed, specific coefficients are needed: among them,

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the efficiency of Lys utilization (**ELysU**), obtained from dose-response studies designed specifically to obtain this parameter.

Unfortunately, ELysU studies with meat quail (*Coturnix coturnix coturnix*) are lacking in the literature, which makes it impossible to elaborate factorial models to predict the requirements for these birds. According to Moughan (2003), the lack of data that describe the efficiency of utilization of first-limiting essential AAs is a major weakness in modeling AA needs.

The ELysU for growth has been estimated in studies on laying hens (Zelenka et al., 2011; Silva et al., 2015) and broilers (Edwards et al., 1999; Fatufe et al., 2004; Sklan and Noy, 2004; Siqueira et al., 2013; Reis et al., 2018). However, applying the nutritional parameters for these birds to quail may not precisely maximize quail performance because there are several anatomical and physiological differences between meat quail and laying hens or broilers.

The importance of nutrition to performance, carcass composition, meat quality, and productive costs is known; however, the lack of information that could be used in modeling to determine optimal nutrient levels compromises the evolution of production systems. In this sense, the aim of our study was to estimate the ELysU for growing male and female meat quail.

MATERIALS AND METHODS

The experiment was conducted at the Center of Agrarian and Environmental Sciences of the Federal University of Maranhão, located in the municipality of Chapadinha, Maranhão (03°44′30″S; 43°21′33″W), Brazil, with an average altitude of 105 m.

The ethics committee of the Federal University of Maranhão has approved all procedures on animal care (record 23,115.004145/2017-44).

Birds, Housing, Experimental Design, and Husbandry

In total, five hundred 21-day-old meat quails (*Coturnix coturnix coturnix*), males and females, with an average body weight of 119.23 ± 1.92 g (male = 117.48 ± 0.68 g; female = 120.97 ± 1.08 g) were used. The birds were housed in cages (0.5 m × 0.75 m) located in masonry rooms (5.0 m × 7.7 m) with side windows.

From the first day until 20 d of age, the birds were reared receiving the same diet, under the same management and suitable environmental conditions. On day 21, the birds were individually weighed and placed into 50 cages (10 birds per cage). A factorial arrangement was used with 2 sexes and 5 levels of digestible Lys (**dig. Lys**), each combination being replicated 5 times, during the period 21 to 35 d of age.

The birds were subjected to 22 h of light per day and received water and feed ad libitum. Environmental temperature and relative humidity were measured daily using a thermohygrometer (MT-241; Minipa Brazil Ltd., Joinville, SC, Brazil) located at the geometric centre of the room, and the mean, minimum, and maximum temperatures and average relative humidity during the experimental period were 29.81 ± 0.97, 27.74, and 31.82°C and 68.15 ± 3.56%, respectively.

Experimental Diets

Diets were formulated by a dilution technique to obtain increasing levels of dig. Lys (Fisher and Morris, 1970).

A summit diet was formulated with 21.76% of crude protein (**CP**) and 1.122% dig. Lys, with the other AAs exceeding by at least 6 percentage points the ideal protein ratios recommended by Silva and Costa (2009), so that another AA did not become limiting. This summit diet was diluted sequentially with another CP-free diet containing the same energy, vitamin, and mineral levels to obtain diets with increasing levels of dig. Lys (0.714, 0.816, 0.918, 1.020, and 1.122%), these being established so that linear responses were obtained, so enabling the estimation of efficiencies (Tables 1 and 2).

CP levels ranged from 13.84 to 21.76% because the diets were formulated by dilution technique. To confirm that Lys really was the first-limiting nutrient and that the responses obtained were a function of Lys and not CP in the diet, a sixth (control) diet was used for each sex. The control diet was obtained by adding 1.3 g/kg L-Lys HCl (78.5%) to the diet containing 0.714% dig. Lys, so that it reached the concentration of 0.816% corresponding to the second level tested, as proposed by Nonis and Gous (2008). Thus, 8 experimental units (4 per sex) made up the experiment.

The total AA contents of corn and soybean meal used in the experimental diets were obtained by high-

Table 1. Diets formulated to obtain increasing levels of digestible lysine by the dilution technique for 21- to 35-day-old meat quail.

	Diets	
Ingredients (%)	CP free	Summit diet (1.122% Lys)
Corn	-	55.918
Soybean meal	-	37.565
Dicalcium phosphate	1.459	0.730
Limestone	0.537	1.034
Soybean oil	2.280	3.374
Salt	0.335	0.336
Mineral supplement[1]	0.200	0.200
Vitamin supplement[2]	0.200	0.200
L-Lys HCl (78.5%)	-	0.019
DL-Met (99%)	-	0.450
L-Thr (99%)	-	0.174
Corn starch	79.449	-
Potassium bicarbonate (38,9%)	0.359	-
Rice husk[3]	15.181	-
Total	100.00	100.00

[1]Composition/kg of feed: Mn, 160 g; Fe, 100 g; Zn, 100 g; Cu, 20 g; Co, 2 g; I, 2 g; vehicle q.s.p. content per kg.

[2]Composition/kg of feed: vitamin A, 12,000,000 IU; vitamin D3, 3,600,000 IU; vitamin E, 3,500 IU; vitamin B1, 2,500 mg; vitamin B2, 8,000 mg; vitamin B6, 5,000 mg; pantothenic acid, 12,000 mg; Biotin, 200 mg; vitamin K, 3,000 mg; folic acid, 1,500 mg; nicotinic acid, 40,000 mg; vitamin B12, 20,000 mg; Se, 150 mg; vehicle q.s.p.

[3]Used to add only fibers.

Table 2. Diets formulated by dilution method with increasing dig. Lys levels for 21- to 35-day-old meat quail.[1]

Ingredients (%)	Digestible lysine levels (%)									
	0.714		0.816		0.918		1.020		1.122	
CP free	36.36		27.27		18.18		9.09		-	
Summit diet	63.64		72.73		81.82		90.91		100.00	
Total	100.00		100.00		100.00		100.00		100.00	
Nutrient (%)		aa/Lys[2]		aa/Lys[2]		aa/Lys[2]		aa/Lys[2]		aa/Lys[2]
Crude protein	13.84	-	15.82	-	17.80	-	19.78	-	21.76	-
Lys (100)[3]	0.714	100	0.816	100	0.918	100	1.020	100	1.122	100
Met + Cys (78)[3]	0.596	84	0.681	84	0.766	84	0.851	84	0.936	84
Met (40)[3]	0.435	61	0.498	61	0.560	61	0.622	61	0.684	61
Thr (76)[3]	0.582	82	0.665	82	0.748	82	0.831	82	0.914	82
Val (74)[3]	0.623	87	0.712	87	0.801	87	0.890	87	0.979	87
Tryp (15)[3]	0.141	20	0.161	20	0.181	20	0.201	20	0.221	20
Crude fiber	4.771	-	4.573	-	4.376	-	4.178	-	3.981	-

[1]Calculated composition: metabolizable energy = 3050 kcal/kg; available P = 0.270%; Ca = 0.700%; Na = 0.150%; Cl = 0.244%; K = 0.925%; electrolyte balance = (mg/kg Na/22.99) + (mg/kg K/39.102) - (mg/kg CL/35.453) = 232.85 mEq/kg.
[2]Amino acid:Lys ratio.
[3]Ideal protein ratio recommended by Silva and Costa (2009).

performance liquid chromatography and later converted into digestible AAs using the digestibility coefficients of Silva and Costa (2009; Table 3).

Evaluated Parameters and Laboratory Analyses

The following parameters were evaluated in the experiment: feather-free body weight (**FFBW**; g/bird), feed intake (**FI**; g/bird/day), Lys intake (**LysI**; mg/bird/day), feather-free body protein deposition (**FFBPD**; mg/bird/day), feather-free body Lys deposition (**FFBLysD**; mg/bird/day), feather-free body fat deposition (**FFBFatD**; mg/bird/day), feather weight (**FW**; g/bird), feather protein deposition (**FPD**; mg/bird/day), feather Lys deposition (**FLysD**; mg/bird/day), and feather fat deposition (**FFatD**; mg/bird/day).

Fat, protein, and Lys deposition were determined by comparative slaughter at the beginning (reference groups) and the end of the experiment. The reference groups included 15 birds per sex weighing ±5% of initial average weight. At the end of the experiment, 3 birds per experimental unit, weighing ±5% of average final weight, were selected, making a total of 150 birds (75 birds per sex). In addition to these 150 birds, 24 birds were selected from the control treatment (12 birds per sex).

The selected birds were fasted for 12 h to allow complete emptying of the gastrointestinal tract, weighed, and slaughtered by cervical dislocation. The birds were then plucked manually and reweighed to estimate the FW by calculating the difference in body weight before and after plucking. The same procedure was followed for the reference-group birds.

The feather-free birds and their feathers were placed in a plastic bag, identified, and frozen at −20°C. The feather-free body of each replicate of each treatment was ground in an industrial meat grinder (98 STI model; C.A.F., São Paulo, SP, Brazil) to obtain homogeneous samples, which were freeze-dried (L108; Liotop, São Carlos, SP, Brazil) at −50°C for 72 h and ground again in a micromill (IKa A11 Basic; Ika Works Brazil Ltd., Taquara, RJ, Brazil). Feather samples were cut manually into small pieces with scissors until homogeneous samples were obtained.

Dried samples of feather-free body and feather were analyzed for CP by the Kjeldahl method (954.01) and lipids (method 920.39), according to the AOAC (1995) procedures.

The mean Lys concentrations in protein of the FFBW and feathers were 6.95 and 2.21 (%), respectively, determined by high-performance liquid chromatography at the Evonik Animal Nutrition Laboratory (São Paulo, Brazil). The FFBLysD and FLysD were obtained by the product of the FFBPD and FPD by the mean Lys concentrations in the feather-free body and feathers, respectively.

Table 3. Total and digestible amino acid composition of corn and soybean meal used in experimental diets.

	Corn		Soybean meal	
(%)	TAA[1]	DAA[2]	TAA[1]	DAA[2]
Lys	0.27	0.22	2.78	2.62
Met	0.13	0.12	0.51	0.47
Met + Cys	0.24	0.21	1.07	0.99
Thr	0.28	0.23	1.85	1.62
Val	0.37	0.33	2.27	2.17
Try	0.03	0.03	0.62	0.55
Crude protein	7.60		46.60	

[1]Total amino acids (TAA), determined by high performance liquid chromatography (HPLC) by the laboratory CBO, Valinhos, SP.
[2]AA digestibility calculated on the basis of the digestibility coefficients shown in the Silva and Costa (2009).

Statistical Analysis

The assumptions of normality and homoscedasticity were verified and met by the Cramer-Von Mises and

Levene tests, respectively. The data were then submitted to analysis of variance, according to the following statistical model:

$$Y_{ij(k)} = \mu + Lys_i + S_j + Lys * S_{ij} + e_{ij(k)} \tag{1}$$

where $Y_{ij(k)}$ is the observed value for each variable studied corresponding to the effect of the i^{th} dig. Lys level for the j^{th} sex and the k^{th} replicate; μ is the effect of the general mean; Lys_i is the effect of the i^{th} dig. Lys level (%); S_j is the effect of the j^{th} sex; $Lys*S_{ij}$ is the effect of interaction between dig. Lys levels and sex; and $e_{ij(k)}$ is the experimental error. Subsequently the means were compared by Tukey test.

The variables affected by Lys level (FFBW, FFBPD, FFBLysD, and FFBFatD) were regressed as a function of LysI, the individual equation for each sex being compared by parallelism tests using sex (S_i) as a categorical variable and LysI as a covariate according to the following model described by Kaps and Lamberson (2004):

$$Y_{ij} = \beta_0 + S_i + \beta_1 LysI_{ij} + \sum_i \beta_{2i}(S * LysI)_{ij} + e_{ij} \tag{2}$$

where Y_{ij} is the observed values for FFBW, FFBPD, FFBLysD, or FFBFatD; S_i is the effect of sex_i; LysIij is the effect of Lys intake on sex; and β_0, β_1, and β_{2i} are the parameters of regression.

The hypotheses are the following:

a) H_0: $S_i = 0$ for all i, there is no sex effect;
   H_1: $S_i \neq 0$ for at least one i, there is sex effect;
b) H_0: $\beta_1 = 0$, the overall slope is equal to zero, there is no regression;
   H_1: $\beta_1 \neq 0$, the overall slope is different from zero, there is regression;
c) H_0: $\beta_{2i} = 0$, the slope in sex_i is not different than the average slope;
   H_1: $\beta_{2i} \neq 0$, the slope in sex_i is different than the average slope;

By the linear regression method, the efficiency of Lys utilization for feather-free body (**ELysFFB**) was obtained by the common inclination coefficient of the equation.

Another methodology to estimate the ELysFFB and in feathers (**ELysF**), described by Reis et al. (2018), was used, which consisted of multiple regression without intercept according to the equation:

$$LysI(mg/bird/d) = (\beta_1' * FFBLysD) + (\beta_2' * FLysD) \tag{3}$$

where β_1' and β_2' are the regression coefficients and can be interpreted as the Lys conversion rate for FFB and feathers, respectively. Thus, the reciprocals of these values represent the efficiency of Lys utilization for depositions in feather-free body (ELysFFB = $1/\beta_1$') and feathers (ELysF = $1/\beta_2$'), given in mg of Lys deposited per mg of Lys intake.

To compare the ELysFFB obtained by linear and multiple regression, the t-statistic according to Kaps and Lamberson (2004) was used:

$$t = \frac{(y_1 - y_2) - 0}{\sqrt{\left(\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}\right)}} \tag{4}$$

the degrees of freedom (DF) being defined as:

$$DF = \frac{\left(s_1^2/n_1 + s_2^2/n_2\right)^2}{\frac{\left(s_1^2/n_1\right)^2}{n_1 - 1} + \frac{\left(s_2^2/n_2\right)^2}{n_2 - 1}} \tag{5}$$

where $y_1 = \beta_1$, estimated by linear regression; $y_2 = 1/\beta_1$', estimated by multiple regression; $s^2{}_1$ and $s^2{}_2$ are the estimates of the variances of β_1 and β_1', respectively; and n_1 and n_2 are the numbers of observations used to estimate β_1 and β_1', respectively.

All statistical analyses were performed using Statistical Analysis System 9.0 (SAS, 2002), considering a significance level of up to 5% ($P \leq 0.05$)

RESULTS AND DISCUSSION

The control diet showed superior responses ($P < 0.05$) than the diet containing 0.714% dig. Lys and was compatible with the diet containing 0.816% dig. Lys for FFBW, FFBPD, and FFBLysD, confirming that Lys was indeed the first-limiting nutrient in the experimental diets (Table 4).

Table 4 shows the effects of sex and dig. Lys levels on FFBW (g/bird), FI (g/bird/day), LysI (mg/bird/day), FFBPD (mg/bird/day), FFBLysD (mg/bird/day), FFBFatD (mg/bird/day), FW (g/bird), FPD (mg/bird/day), FLysD (mg/bird/day), and FFatD (mg/bird/day).

There was no effect on sex × dig. Lys level interactions for any evaluated variable (Table 4). Regarding the sex effect, the FFBW was 5.07% higher in female quail than in males ($P < 0.05$). Unlike most poultry species, female quails are usually heavier than males. These results are supported by Ojedapo and Amao (2014) and Abou-Kassem et al. (2019), who reported that body weight was higher in female quail than in males. The weight difference may be related to the fact that females mature earlier than males, showing a high development of reproductive organs as sexual maturity approaches (Choi et al., 2012) and, consequently, an increase in weight associated with this reproductive maturation.

Regardless of sex, the FFBW increased with the increasing level of dietary Lys. The increase in body weight provided by different dietary levels of dig. Lys has been documented over the years in broiler studies (Tesseraud et al., 2001; Scheuermann et al., 2003; Fatufe et al., 2004; Dozier et al., 2010) and more recently in quail studies (Ton et al., 2011; Mehri et al., 2013; Lima et al., 2016; Hasanvand et al., 2017). As muscle growth is influenced by the balance of dietary AAs, especially Lys,

Table 4. Feed intake, lysine intake, and **v**ariables evaluated in the feather-free body and feathers of 21- to 35-day-old meat quail.

Variable	Sex	Control diet (0.816)	Digestible lysine level (%)					General
			0.714	0.816	0.918	1.020	1.122	
FFBW (g/bird)	F	148.59 ± 5.62	148.54 ± 3.24	147.80 ± 3.57	155.30 ± 5.70	157.22 ± 3.86	162.67 ± 4.67	154.31 ± 1.53[A]
	M	145.45 ± 6.58	141.32 ± 2.24	142.24 ± 3.83	144.46 ± 2.94	151.03 ± 1.54	155.25 ± 1.14	146.86 ± 1.60[B]
	General	147.02 ± 5.90[b,c]	144.93 ± 1.95[c]	145.02 ± 2.54[c]	149.88 ± 3.40[b,c]	154.25 ± 1.97[a,b]	158.96 ± 2.58[a]	
FI (g/bird/day)	F	8.87 ± 0.13	8.99 ± 0.40	8.87 ± 0.41	8.68 ± 0.30	8.82 ± 0.21	9.00 ± 0.45	8.87 ± 0.15
	M	7.16 ± 0.47	8.42 ± 0.15	7.96 ± 0.25	8.28 ± 0.32	9.19 ± 0.28	8.99 ± 0.21	8.58 ± 0.14
	General	8.72 ± 0.39	8.70 ± 0.22	8.42 ± 0.27	8.50 ± 0.22	9.01 ± 0.18	8.99 ± 0.23	
LysI (mg/bird/day)	F	74.87 ± 4.87	64.16 ± 2.83	72.39 ± 3.38	79.70 ± 2.77	89.99 ± 2.17	100.98 ± 5.04	81.44 ± 2.98
	M	68.83 ± 3.72	60.12 ± 1.05	64.96 ± 2.00	75.97 ± 2.98	93.75 ± 2.86	100.83 ± 2.40	79.13 ± 3.50
	General	71.85 ± 4.09[c,d]	62.14 ± 1.57[d]	68.67 ± 2.23[d]	77.84 ± 2.01[c]	91.87 ± 1.81[b]	100.90 ± 2.63[a]	
FFBPD (mg/bird/day)	F	464.89 ± 45.28	372.27 ± 33.95	392.53 ± 34.10	485.55 ± 51.70	586.91 ± 29.16	578.81 ± 55.93	483.12 ± 25.54
	M	459.17 ± 28.12	358.39 ± 25.76	380.35 ± 22.74	442.15 ± 26.83	608.77 ± 22.76	615.70 ± 18.14	482.69 ± 24.84
	General	462.03 ± 20.32[b]	365.33 ± 16.40[c]	386.44 ± 19.43[c,b]	463.85 ± 28.18[b]	597.84 ± 17.81[a]	597.25 ± 28.39[a]	
FFBLysD (mg/bird/day)	F	32.31 ± 3.14	25.87 ± 2.36	27.28 ± 2.37	33.75 ± 3.59	40.79 ± 2.03	40.23 ± 3.89	33.58 ± 1.78
	M	31.91 ± 1.95	24.91 ± 1.40	26.44 ± 1.58	30.73 ± 1.86	42.31 ± 1.58	42.79 ± 1.26	33.55 ± 1.73
	General	32.11 ± 1.41[b]	25.39 ± 1.14[c]	26.86 ± 1.35[c,b]	32.24 ± 1.96[b]	41.55 ± 1.24[a]	41.51 ± 1.97[a]	
FFBFatD (mg/bird/day)	F	191.95 ± 22.58	92.77 ± 21.24	99.39 ± 17.41	123.12 ± 30.67	187.69 ± 21.85	213.68 ± 46.50	143.33 ± 14.95[A]
	M	150.48 ± 17.78	83.92 ± 8.48	58.27 ± 9.98	110.79 ± 16.37	161.35 ± 26.08	153.40 ± 13.76	113.55 ± 10.69[B]
	General	171.22 ± 20.88[a,b]	88.34 ± 10.88[c]	78.83 ± 11.68[c]	116.96 ± 17.63[b,c]	174.52 ± 16.63[a,b]	183.54 ± 22.92[a]	
FW (g/bird)	F	8.73 ± 0.44	9.58 ± 0.50	8.47 ± 0.29	9.27 ± 0.47	9.91 ± 0.42	9.49 ± 0.23	9.34 ± 0.19
	M	9.11 ± 0.31	8.50 ± 0.43	8.59 ± 0.16	9.48 ± 0.32	9.10 ± 0.28	8.97 ± 0.26	8.93 ± 0.15
	General	8.92 ± 0.38	9.04 ± 0.37	8.53 ± 0.16	9.38 ± 0.32	9.51 ± 0.27	9.22 ± 0.19	
FPD (mg/bird/day)	F	47.26 ± 13.33	44.28 ± 16.78	48.40 ± 12.68	43.07 ± 13.78	28.58 ± 6.66	51.51 ± 15.72	43.17 ± 6.01
	M	28.15 ± 9.11	25.32 ± 5.55	22.19 ± 5.03	33.52 ± 2.36	44.04 ± 9.27	41.68 ± 4.45	33.35 ± 3.06
	General	37.71 ± 11.12	34.80 ± 8.16	35.30 ± 7.78	38.30 ± 6.72	36.31 ± 6.59	46.60 ± 7.87	
FLysD (mg/bird/day)	F	1.04 ± 0.30	0.98 ± 0.37	1.07 ± 0.28	0.95 ± 0.30	0.63 ± 0.15	1.14 ± 0.35	0.95 ± 0.13
	M	0.62 ± 0.20	0.56 ± 0.12	0.49 ± 0.11	0.74 ± 0.05	0.97 ± 0.21	0.92 ± 0.10	0.74 ± 0.07
	General	0.83 ± 0.25	0.77 ± 0.18	0.78 ± 0.17	0.85 ± 0.15	0.80 ± 0.15	1.03 ± 0.17	
FFatD (mg/bird/day)	F	8.45 ± 2.44	11.91 ± 4.09	9.35 ± 0.44	6.75 ± 1.55	7.02 ± 3.39	6.18 ± 1.90	8.24 ± 1.16
	M	7.68 ± 1.33	8.38 ± 3.18	7.74 ± 0.13	6.59 ± 1.11	5.34 ± 1.08	6.06 ± 0.65	6.82 ± 0.71
	General	8.07 ± 2.12	10.14 ± 2.51	8.54 ± 0.34	6.67 ± 0.94	6.18 ± 1.70	6.12 ± 0.95	

Data presented with mean and standard error. Means followed by the same letter in columns (capital) or rows (lower case) do not differ by Tukey test ($P > 0.05$) for each variable.

Abbreviations: F, female; FFBW, feather-free body weight; FI, feed intake; LysI, Lysine intake; FFBPD, feather-free body protein deposition; FFBLysD, feather-free body lysine deposition; FFBFatD, feather-free body fat deposition; FW, feather weight; FPD, feather protein deposition; FLysD, feather lysine deposition; FFatD, feather fat deposition; M, male.

it could be expected that higher levels of dig. Lys would provide higher body weights (Tesseraud et al., 2001).

Unlike the FFBW, the FW was not influenced either by sex or dig. Lys level (Table 4). It is worth mentioning that the FW during growth is the net result of a continuous process of growth, loss, and regrowth in successive feathering stages (Gous et al., 2019), which is difficult to estimate in research. However, feathers comprise a considerable proportion of the total protein in the body, and a correct description of feather growth is necessary for calculating nutritional requirements, especially of AAs. Urdaneta-Rincon and Leeson (2004) in a study into the effect of dietary Lys on feather growth in chicks reported no differences in FW, suggesting that Lys apparently has more of an effect on feather pigmentation than on feather weight. According to Grau et al. (1989), Lys deficiency during the critical stages of growth in turkeys, chickens, and Japanese quail resulted in white feathers instead of the normal dark bronze.

The FI was not affected by sex or dig. Lys levels ($P > 0.05$), with the LysI being affected only by dig. Lys levels ($P < 0.05$) (Table 4). Similar to our study, studies with growing quail (Alagawany et al., 2014; Hasanvand et al., 2017) showed that diets with increasing levels of dig. Lys did not provide increases in FI, concluding that there was no compensatory feed intake by birds fed limiting levels of dig. Lys.

Regarding the deposition of nutrients (protein, Lys, and fat) in feather-free body and feathers, the only variable influenced by sex was FFBFatD, in which the females presented FFBFatD levels 26.23% higher than the males ($P < 0.05$) (Table 4). The females also showed greater FFBFatD in others quail studies (Raji et al., 2015; Abou-Kassem et al., 2019). According to Choi et al. (2012), owing to sexual maturity, female quails secrete oestrogen from the ovary, which could increase lipid deposition among myofibers.

The FFBW, FFBPD, FFBLysD, and FFBFatD were influenced by dig. Lys levels ($P < 0.001$) (Table 4). As the main focus of this study was to determine the ELysFFB by linear regression, the Lys levels tested ranged from 0.714 to 1.122%, allowing to obtain linear responses ($P < 0.05$) in variables the effects of Lys on which were observed.

It is well known that protein deposition depends on the dynamics of synthesis and degradation processes. Studies suggest that the increased protein deposition due to Lys supplementation, as showed in our study, may be a result of the increased synthesis and reduced breakdown of proteins (Orcutt and Young, 1982; Fuller et al., 1987).

In our study, the FFBFatD also increased because of Lys supplementation, corroborating that of Lima et al. (2016), who studied dig. Lys requirement for growing quails and showed that the increase in the levels of dig. Lys provided an increase of fat deposition.

Unlike the deposition of nutrients in the feather-free body, the FPD, FLysD, and FFatD were not influenced by Lys levels ($P > 0.05$) (Table 4). Studies with broilers (Urdaneta-Rincon and Leeson, 2004; Siqueira et al., 2013) and quail (Alagawany et al., 2014) fed diets containing increasing levels of Lys also showed no effect on feathers. In feather protein, the proportion of Lys is lower than that of sulfur-containing AAs, whereas the converse applies for feather-free body protein. In this sense, it would be expected that dietary Lys would have greater influence on body protein than on feather development and characteristics, as observed in our study.

It is acknowledged that a suitable statistical model is essential to estimate nutritional requirements; in view of this, one the main aims in research papers has been the evaluation of statistical methods and models to determine the nutritional requirements of poultry (Pesti, 2009; Reis et al., 2018). Most dose-response studies performed to determine Lys requirements for birds consider Lys (%) as an independent variable. However, more detailed information can be obtained by performing regressions using LysI (mg/bird/day) as an independent variable rather than Lys (%), as birds need to ingest daily amounts of nutrients (mg/bird/day). In addition, regressions performed as a function of LysI make it possible to calculate ELysFFB for growth. Thus, the variables FFBW, FFBPD, FFBLysD, and FFBFatD, which were affected by Lys levels, were subjected to regression analyses using LysI as an independent variable (Table 5).

The FFBW as a function of LysI increased of different way between males and females (Table 5 and Figure 1). In the females, there was an increase in FFBW of 0.57 g/mg of Lys intake, while in males, this increase was of 0.32 g/mg of Lys intake. Grieser et al. (2018) in a study with one meat-type and 2 laying-type quails reported that the female of 3 quail strains evaluated were heavier than males from 21 d of age, attributing the greater growth of females against males because of the development of female reproductive system and greater internal organ weights (liver, proventriculus, and gizzard), and body fat in females.

FFBPD and FFBLysD analyzed as a function of LysI showed no sex effect ($P > 0.05$) in parallelism tests, indicating the need for only one equation to describe the responses, regardless of sex (Table 5). The FFBPD increased 6.83 mg/bird/day per mg Lys intake, with a Lys intake of 0.146 mg/bird/day per mg of feather-free body protein deposition being required (Table 5 and Figure 2).

Protein depositions per mg Lys intake calculated for 10- to 20-day-old chicks (Edwards et al., 1999) and 37- to 49-day-old broilers (Trindade Neto et al., 2009) corresponded to approximately 10 mg/bird/day. From the data of Brito et al. (2016), it was possible to calculate a protein deposition of approximately 14 mg/bird/day for broilers 8 to 21 d old. In our meat quail study, the protein deposition per mg Lys intake was less than that found in broiler studies. This response is reasonable to expect, as broilers have been selected over many generations for maximum protein deposition, while meat quail are at the beginning of genetic selection for this purpose compared with broilers.

Table 5. Coefficients of linear regressions for feather-free body weight (FFBW; g/bird), feather-free body protein deposition (FFBPD), feather-free body Lys deposition (FFBLysD), and feather-free body fat deposition (FFBFatD; mg/bird/day) of 21- to 35-day-old meat quail as a function of Lys feed intake.

Variable	Sex	Parameters[1] β_0	β_1	r^2	P value
FFBW (g/bird)	F	105.13 ± 6.52	0.57 ± 0.08	0.69	<0.0001[2]
	M	121.64 ± 5.75	0.32 ± 0.07	0.50	<0.0001[2]
	M and F	-	-	-	0.0258[3]
FFBPD (mg/bird/day)	F	−95.29 ± 72.93	7.10 ± 0.88	0.75	<0.0001[2]
	M	−45.99 ± 41.92	6.67 ± 0.52	0.88	<0.0001[2]
	M and F	−65.81 ± 40.10	6.83 ± 0.49	0.81	0.6685[3]
					<0.0001[2]
FFBLysD (mg/bird/day)	F	−6.62 ± 5.07	0.49 ± 0.06	0.75	<0.0001[2]
	M	−3.20 ± 2.91	0.46 ± 0.04	0.88	<0.0001[2]
	M and F	−4.57 ± 2.79	0.48 ± 0.03	0.81	0.6685[3]
					<0.0001[2]
FFBFatD (mg/bird/day)	F	−172.71 ± 52.37	3.87 ± 0.64	0.63	<0.0001[2]
	M	−62.67 ± 36.16	2.22 ± 0.45	0.53	<0.0001[2]
	M and F	-	-	-	0.0374[3]

Abbreviations: F, female; M, male.
[1]Parameters of simple linear regression: $y = \beta_0 + \beta_1 x$.
[2]Significance level of test "t" for coefficient "β_1" of linear regression.
[3]Significance level for the parallelism test between sexes.

According to Millward (1995), the growth potential of an individual in height and shape is genetically determined. Muscle mass is determined by the number and size of muscle fibers; thus, broilers selected for faster weight gain have more muscle fibers than laying hens and also have a rate of muscle protein degradation between 1 and 9 times slower than birds selected for egg production (Harper et al., 1999).

Considering FFBLysD, we observed deposition rates of 0.49 mg/bird/day for females and 0.46 mg/bird/day for males per mg of LysI from the values of coefficient "β_1" of the individual equations (Table 5). As the sex-specific equations did not differ ($P > 0.05$) by the parallelism test, only one equation was needed to describe the responses of both sexes, an average efficiency of 0.48 mg/bird/day being estimated, which corresponds to an ELysFFB in meat quail of 48% regardless of sex (Table 5 and Figure 3).

The FFBFatD as a function of LysI differed between males and females, with the females showing greater fat deposition (Table 5 and Figure 4). The females deposited 3.87 mg of fat/per mg of Lys intake, while the males deposited 2.22 mg of fat/per mg of Lys intake. As previously discussed, the development of female reproductive system contributes to greater lipid accumulation in females owing to oestrogen secretion from the ovaries (Marks, 1993).

Using the methodology described by Reis et al. (2018), our study also estimated individually ELysFFB and the efficiency of deposition in feathers (Table 6). As described in the methodology, LysI was regressed as a function of the amount of Lys deposition in feather-free body and feathers, and from the reciprocal of coefficients of the multiple linear regression equation, the specific efficiency for feather-free body and feathers was estimated at 44.6% (ELysFFB = 1/2.242 * 100) and 18.1% (ELysF = 1/5.515 * 100), respectively, showing that Lys was used with different efficiencies in the different body components (Table 6).

Reis et al. (2018) worked with data obtained from growing broilers fed with increasing levels of dig. Lys, and they estimated efficiencies for feather-free body and feathers of 68 and 58%, respectively, with these values being higher than those observed in our study. Studies that determined the efficiency in different body tissues, as described previously, are scarce in the literature, and the individual determinations for feather-free body and feathers can influence positively the nutritional requirement prediction models developed from these estimates (Melaré et al., 2019) because the composition of these components are variable (Stilborn et al., 1997, 2010), and the proportion of feathers to body increases over time when growing birds are used (Fisher and Scougall, 1982).

It was observed in the present study that the value of ELysFFB obtained by simple linear regression was 48.0% (Table 5), and by multiple linear regression, 44.6% for both sexes (Table 6). To compare the

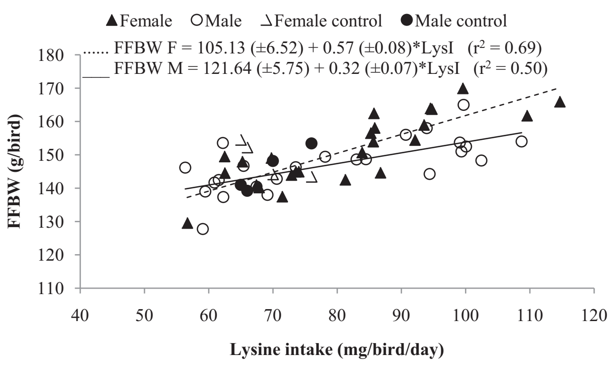

Figure 1. Feather-free body weight (FFBW) as a function of Lys intake (LysI) in diets for meat quail.

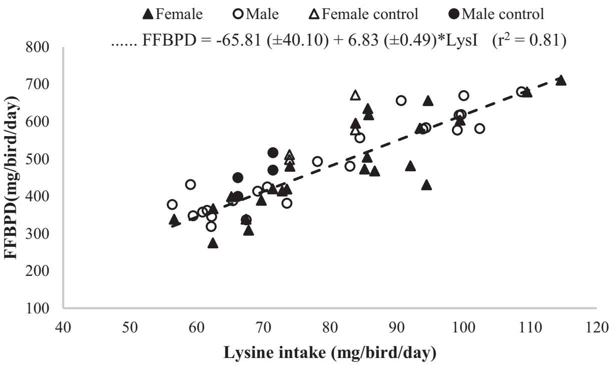

Figure 2. Feather-free body protein deposition (FFBPD) as a function of Lys intake (LysI) in diets for meat quail.

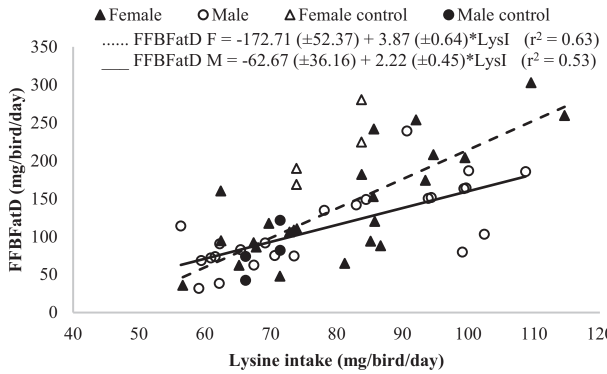

Figure 4. Feather-free body fat deposition (FFBFatD) as a function of Lys intake (LysI) in diets for meat quail.

efficiencies obtained by the use of different methodologies, the t-statistic proposed by Kaps and Lamberson (2004) was used, and no differences were observed ($t = 0.3763$; $P = 0.354$) between the efficiencies estimated by the different methodologies. Thus, the best estimate of ELysFFB was 46.3%, obtained from the average.

In broilers, the efficiencies found by Han and Baker (1991) for Hubbard broilers and New Hampshire × Columbian hybrids from 8 to 21 d of age were 69 and 67%, respectively. Siqueira et al. (2011) found a utilization efficiency of 76.9% in the period from 1 to 42 d. For Cobb 500 broilers, Siqueira et al. (2013) estimated the ELysU at 74.4% from 1 to 8 d of age and 79.04% from 8 to 22 d of age.

In laying hens, Silva et al. (2014) determined the efficiency at 49% for Hy-Line Brown, Hisex Brown, Hy-Line W-36 White, and Hisex White strains over the period of 1 to 126 d of age. Similarly, Zelenka et al. (2011) estimated the ELysFFB at 49.6% for Isa Brown hybrid pullets from 1 to 22 d of age. As previously described, the ELysFFB in our study was 46.3%, this being closer to the values found for laying hens than for broilers.

According to the study by Fatufe et al. (2004), the efficiency of AA utilization may depend on genotype, due perhaps to differences in the relative proportions of different protein fractions to whole-body protein and to differences in the ratio of synthesis to degradation of

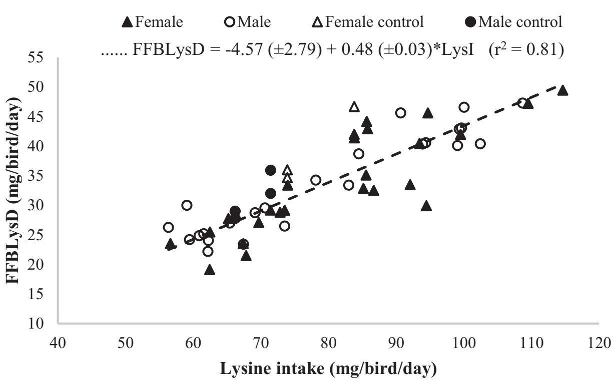

Figure 3. Feather-free body lysine deposition (FFBLysD) as a function of Lys intake (LysI) in diets for meat quail.

body proteins. Broiler strains have been subjected to intense selection pressures for decades to increase lean carcass deposition, making this species increasingly efficient over time (Maioran et al., 2011; Tavaniello et al., 2014).

It is interesting to note how genetic selection is able to modify the characteristics of birds. In a study of 2 quail lines, one selected and the other not, the authors showed that the heavyweight line developed by selection for 4-week body weight exhibited a higher number of type IIB fibers and lower number of type IIA fibers in the pectoralis major muscle than birds of the random bred control line (Choi et al., 2013). The pectoralis muscle of birds is one of major muscles responsible for flight, this muscle in volant birds, including quail, being composed almost exclusively of type IIA fibers (Rosser et al., 1998). The type IIB fibers are predominant in the muscle of animals selected for high growth rate, as reported by Choi et al. (2013), who showed that the line developed by selection for body weight had a higher proportion of type IIB fibers than the unselected line.

There must be a synchrony between the genetic progress of modern quails bred for meat production and the nutrition of these birds. Recent studies on AA requirements for quail (Hajkhodadadi et al., 2013; Mehri et al., 2013, 2015) showed a higher nutritional need than those recommended in older literature on bird nutrition, and updating of nutritional requirements is crucial to maximize the productivity of modern quail strains. This can be more accurately obtained by the use of factorial prediction models.

In conclusion, the efficiencies of Lys utilization shown in our study for deposition in the feather-free body (46.3%) and feathers (18.1%) can be considered the initial references for modeling purposes, serving as guidelines for further studies on estimation of efficiencies in meat quail.

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Table 6. Multiple linear regression equations adjusted with the Lys intake (LysI), feather-free body Lys deposition (FFBLysD), and feather Lys deposition (FLysD) for male and female meat quail.

Amino acid	Equation[1]	R^2	Efficiency (%)	
			FFBLysD	FLysD
Lysine	LysI = 2.242(±0.07) *FFBLysD + 5.515(±2.46)*FLysD	0.98	44.60	18.13

[1] $P < 0.0001$ for the regression coefficients of feather-free body; $P = 0.0303$ for the regression coefficients of feathers.

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DISCLOSURES

The authors declare that there is no conflict of interest.

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this article.

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