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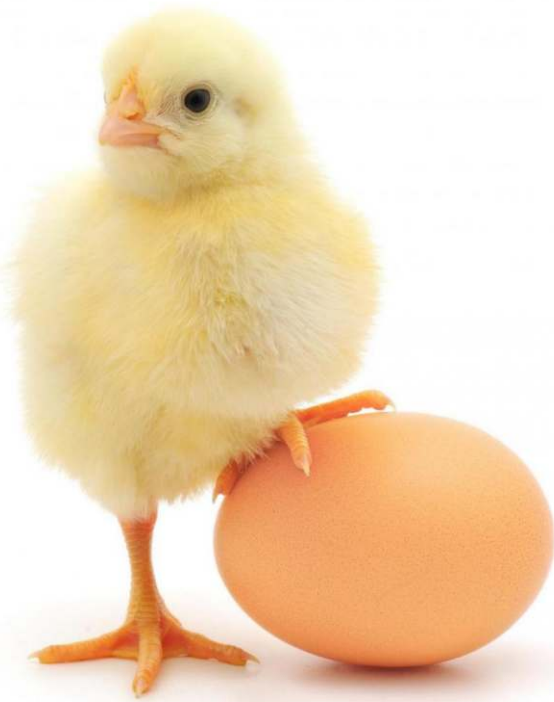

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Research Article
Lysine and Energy Trends in Feeding Modern Commercial Broilers

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Abstract

Background and Objective: It seems that current broiler chickens have modified the dietary nutrient needs and body composition over time. Further, the relationships between dietary nutrients and feed cost or biological nutrient requirements are unknown. The aim of this study was to understand and explain current energy and amino acid tendencies of dietary levels and requirements, to evaluate relationships between dietary energy and lysine among levels, feed cost and requirements and to compare energy and lysine efficiency from 2001-2017. **Methodology:** Data from literature were evaluated to predict the dietary ME and amino acids as well as the body fat content by multiple regression. Actual dietary ME and digestible lysine levels were linearly regressed with diet cost and ME and lysine requirements. Efficiencies of lysine and ME were calculated taking into account the broiler genetic improvement through body composition. **Results:** Dietary energy levels have been reduced at a rate of 5 kcal per year while digestible lysine has increased by 0.009% per year from 2001-2017. Nutritionists during the process of selecting dietary energy and lysine levels have been influenced by feed cost ($r^2 = 0.75$) and lysine requirements ($r^2 = 0.86$), respectively. During a period of 16 years, modern broiler chickens deposit less body fat (-6% of body weight) and more body protein (+4% of body weight) and convert energy and amino acids into meat more efficiently than older broiler genotypes. **Conclusion:** These data indicate that dietary energy and lysine are reduced and increased, respectively, influenced by feed cost and requirements, resulting in better energy and lysine efficiencies due to feed intake and body composition changes.

Key words: Amino acid, broiler chickens, energy, feed cost, lysine

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Globally, different energy and amino acid levels are used in different regions, although it is unknown the magnitude by which these dietary nutrients are influenced by feed cost or biological nutrient requirements. Furthermore, a study that explains nutrient trends, body composition and nutrient efficiency in one systemized approach over time as a way to gain insight into the future should shed light on biological mechanisms in modern broiler chickens.

As compared to slow growing birds, fast growing birds require more amino acids[1] or methionine[2] but less dietary energy[3]. However, these differences cannot be extrapolated to evaluate the magnitude of dietary nutrient changes in current broiler chickens. Many peer-reviewed papers studying nutrient needs from the last few years could be compiled and analyzed to calculate the genetic progress and future nutrient trends. Furthermore, a comparison between commercial nutrient levels and biological nutrient requirements could be analyzed which may suggest what is the main driving force that dictates nutrient levels used in the field. On the other hand, it seems that genetic progress has changed body composition significantly. The body protein can be accurately predicted by breast meat regardless of sex and broiler strains[4], whereas the body fat can be affected by sex, type of feed, age and strains[4-7]. Body fat was, for example, reduced in chickens with improved feed conversion or faster growth rates compared to birds of poorer feed conversion or slower growth rates[8,9]. In contrast, the carcass protein is enhanced by genetic progress[3]. However, when the breast yield is less than 15% of body weight (BW), the carcass protein is similar between chickens of fast and slow growth rate[3,9,10]. The objectives of the present study were to understand and explain current energy and amino acid tendencies of dietary levels and requirements, to evaluate relationships between dietary energy and lysine among levels, feed cost and requirements and to compare energy and lysine efficiency from 2001-2017.

MATERIALS AND METHODS

Metabolizable energy (ME) lysine and body fat: Data from literature were evaluated to quantify the ME and amino acids (AA) requirements for broiler starter, grower and finisher feed. The data were obtained from peer-reviewed journals and from performance results of 2 research studies at Aviagen Inc (unpublish data). The main criteria used for article selection were the following: a) commercial broiler chickens (Avian, Cobb, Hubbard and Ross), minimum of 3 nutrient levels and normal temperature or moderate heat stress. For each article, the year of publication, start and end period of each feeding phase, lysine or ME requirements, dietary ME, digestible lysine (dLys), dietary protein and body fat were included in the database. Further, other variables (genetic strains, feed form, sex, feed conversion, live body weight, body weight gain and method of estimated requirement) were registered to allow a more descriptive analysis. The nutrient requirements were recorded according to published journals using linear broken line, quadratic broken line, quadratic polynomial regression or difference of means based on feed conversion, body weight gain and breast muscle yield. The energy database included articles between 1996 and 2016, containing equal levels of amino acids[11-32]. The database for lysine requirements included journals considering constant amounts of amino acids between 2001 and 2017[18,33-67] and changing the amino acids proportionally to lysine between 2001 and 2014[41,68-77]. The body fat database included studies between 1991 and 2014, including the year of publication, broiler age, dietary ME, dLys and dietary crude protein (CP) as independent variables[4-6,65,73,78-88].

Comparisons among diet cost, dietary and requirements of lysine and energy: Average nutrient requirements were calculated to show trends over time using the following variables: year range (2001-2017), starter period between 0-10 days, grower period between 11-25 days and finisher period between 26-39 days and assuming feed intake proportions of 7.1, 30.2 and 62.8%, respectively. Thus, the actual ME or dLys values and diet costs were obtained from a US industry reporting service[89].

Body composition: Body fat was calculated from year, age and ME/dLys. Body protein was calculated from breast muscle yield using an allometric relationship between breast and body protein (lnBreast meat weight = -2.379 +1.409xlnbody protein weight) as described by Danisman and Gous[4] and breast meat yields reported by Agri Stats[89].

Lysine efficiency: Efficiencies of dlys from 2001 and 2017 were calculated considering the lysine used for maintenance and deposited for protein gain.

$$\text{Efficiency of dLys} = \frac{\text{Lysine for protein gain}}{\text{Actual dLys intake-dLys for maintenance}} \times 100$$

$$\text{Lysine for maintenance (g/period)} = \{35.73\times [(0.040+2.268)/2]^{0.75}/1000\}\times [\text{\#days to reach 2268 g}]$$

where 35.73 mg/kg$^{0.75}$/day was developed from data of Fatufe *et al.*[38] (dLys intake = 35.73+1.337×[Lysine accretion], r^2 = 0.97).

Lysine for protein gain (g/period) = [6.7/100×protein gain]×[# days to reach 2268 g], calculated using 6.7% of lysine for whole body protein from Fatufe *et al.*[38], protein gain as difference between gain at day 1 and market age of 2268 g (2268×body protein/100-40×16/100) and # days to reach 2268 g as division between target weight and body weight gain per day (2265 g/[body weight gain, g day^{-1}]).

Digestible lysine intake was calculated as follow:

$$\text{dLys intake} = \text{Actual dietary dLys (\%)}\times(\text{FCRadj}\times 2265)/100$$

where, the feed conversion adjusted by target body weight (2265 g) (FCRadj) was calculated as:

$$\text{FCR adj} = \text{FCRactual}+[(2265-\text{BWactual})/45\times 0.01]$$

where, 45 g difference in BW is equivalent to 1 point or one hundredth of FCR, as described by Lesuisse *et al.*[90]

$$\text{FCR actual} = \frac{\text{BW actual}}{\text{FIactual}}$$

where, actual BW and FI from 2001-2017 as reported by Agri Stats[89].

Energy efficiency: Efficiencies of energy from 2001 and 2017 were calculated as the energy used for gain and maintenance:

$$\text{Efficiency of ME for gain and maintenance} = [\text{net energy for body gain and maintenance}]/\text{MEintake}\times 100$$

where, net energy for body gain was calculated using the body protein (BP) and body fat (BF) gain and their corresponding caloric values of 5.66 and 9.35 kcal g^{-1} respectively, as described by Fraps and Carlyle[91].

$$\text{Net energy for body gain} = 5.66\times(2268\times\text{BP}) + 9.35\times(2268\times\text{BF})$$

$$\text{Net energy for maintenance} = 1.15\times 90\times[(2268+40)/2]^{0.75}\times[\#\text{ days to reach 2268 g}]$$

where, 90 kcal kg$^{-1\ 0.75}$ as reported by Sakomura *et al.*[92] and assuming 15% more of physical activity.

$$\text{ME intake} = \text{Actual dietary ME (kcal kg}^{-1})\times\text{FCRadj}\times 2265$$

Nutrient efficiencies: Nutrient efficiencies in relation to a year were calculated as follows:

$$\text{Nutrient efficiency} = \frac{\text{Nutrient 2001-2017}}{\text{Nutrients, 2001}}\times 100$$

where, nutrients were ME intake, dLys intake, energy requirement (NEm+NEgain) and lysine requirement (dLys for maintenance and protein gain).

Design of the analysis: Actual dietary ME and dLys levels were linearly regressed with diet cost and requirements of ME and dLys. To gain insight into possible future nutrient needs, efficiencies of dLys and ME were calculated taking into account the broiler genetic improvement through body composition for each year from 2001-2017. Body protein was estimated from breast meat yield, and body fat was calculated by multiple regressions in function of year, age, dLys, protein, ME/dLys or ME/CP. Further, ME intake, dLys intake, energy requirement (NEm+NEgain) and lysine requirement (dLys for maintenance and protein gain) were plotted against one specific year to observe the trends during the time. The actual dietary ME, digestible lysine, breast muscle yield, BW and FI were retrieved from a US industry reporting service[89] from 2001-2017. Because the genetic selection pressures on feed conversion and body composition had reduced the numbers of days to reach market weights, the nutrient intakes and efficiencies were adjusted to 2265 g of body weight, removing the age of market weight during the trends.

Statistical methods: Multiple linear regressions for estimating energy and digestible lysine requirements and linear regressions to evaluate the determination between dietary and requirement of ME and dLys were obtained using JMP Software[93]. Further, coefficients for year and market age, dietary ME, dLys, CP, or ME/dLys to estimate body fat were plotted by multiple linear regressions. Regression coefficients were compared among independent variables using confidence intervals derived from the SE of respective regression coefficients[94].

RESULTS AND DISCUSSION

Energy and lysine requirements: The energy and lysine requirements were statistically influenced by year and age (Table 1). Coefficients of lysine and amino acid (AA) requirements, though numerically higher, were statistically similar to those of lysine needs with constant levels of AA. Lana *et al.*[41,42] reported that lysine requirements based on equal lysine: AA ratios were higher than lysine needs based on constant levels of AA (+3% starter or +6% grower). Herein,

Table 1: The energy and lysine requirements predicted from year and age period

Variables	Intercepts	Year	Mean period (day)[1]	n	SEM	R^2	p-value
ME (kcal kg^{-1})	13599.00	-5.2900	6.5100	52	96	0.50	<0.0001
SE	5230.00	2.6000	1.0900				
p-value	0.01	0.0500	<0.0001				
dLys (%)	-17.52	0.0093	-0.0055	57	0.09	0.49	<0.0001
SE	5.43	0.0027	0.0009				
p-value	<0.01	<0.0100	<0.0001				
dLys:AA[2] (%)	-22.14	0.0117	-0.0067	21	0.07	0.64	<0.0001
SE	7.77	0.0039	0.0013				
p-value	0.01	<0.0100	<0.0001				

[1]Mean period for energy and lysine needs is middle age of feeding period and for body fat, the period age is the final broiler age, [2]dLys:AA: digestible lysine and amino acids were formulated proportionally

Table 2: Linear regression analysis comparing dietary energy and lysine with diet cost or lysine and energy requirement

Equations	SEM	p-value	r^2
ME (kcal kg^{-1}) = -0.24x[diet cost, $/t]+3197.3	10.100	<0.0001	0.75
dLys (%) = 0.0004×[diet cost, $/t]+0.95	0.025	0.0010	0.53
ME (kcal kg^{-1}) = 0.54×[ME requirements]+1335	14.700	0.0020	0.47
dLys (%) = 0.70×[dLys requirements]+0.30	0.014	<0.0001	0.86
dLys (%) = 0.56×[dLys:AA[1] requirements]+0.42	0.014	<0.0001	0.86

[1]dLys:AA: Digestible lysine and amino acids were formulated proportionally

similar increments of lysine requirements (+6% starter and +4% in grower) were found when lysine and AA were adjusted proportionally as compared to constant dietary AA. Nutrient requirement trends depict mainly the expression of genetic advancements for commercial broiler chickens used in the poultry industry. From the previously described, during each feeding phase, the ME needs are being lowered by 5 calories per year, while dLys levels have been increased by 0.009% per year. Further, trends in the US industry show that dietary ME and dLys levels in broiler diets are displaying opposite trends. From 2001-2017, dietary ME has shown a tendency of being reduced by 38 kcal kg^{-1} or 2.4 kcal $year^{-1}$, whereas dLys has shown to be increased by 0.12 or 0.008% per year (Fig. 1). Even though, the lysine requirement increment per year originated from different countries matches closely to the commercial dLys which represent values from the US poultry industry. In line with current reviewed tendencies, Wen *et al.*[2] demonstrated that fast growing broiler chickens need more dietary methionine compared to slow growing chickens. On the other hand, a more efficient digestion of energy in modern chickens with good FCR compared to those with poor FCR[95,96] suggest that modern chickens metabolize nutrients more efficiently and might need less dietary energy as suggested herein. Furthermore, a pair-fed study indicated that the dietary energy levels needed to improve feed conversion were lower in modern broiler chickens (3200 vs 3400 kcal kg^{-1}) than those in random bred chickens[3]. As broiler chickens age, the energy needs are increased by 6.5 kcal day^{-1}, whereas the digestible lysine is reduced by 0.006% per day. In agreement with these trends, lysine and energy requirements are reduced and increased, respectively, as broiler chickens aged[22,35,68].

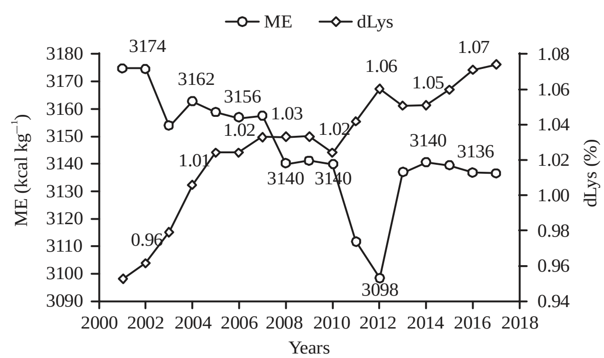

Fig. 1: Trends of ME and digestible lysine (dLys) in the poultry industry (adapted from a US industry reporting service[91]). The dLys was calculated from total lysine with an average digestibility of 0.89%, based on ingredients typically used in broiler chickens

Associations among diet cost, energy and lysine requirement: The relationship between dietary ME and diet cost, for example, indicates that when feed cost is higher, dietary ME is lower. The higher best fit to predict energy from feed cost (r^2 = 0.75) suggests that dietary ME over time is being driven by feed cost (Table 2). Other economic variables such as broiler meat price might also influence the dietary energy selection[97,98]. Conversely, a smaller coefficient of determination (r^2 = 0.53) is observed when predicting dLys from average feed cost as compared to dietary ME, inferring that other variables may be associated with the behavior of dLys values in recent years. When considering the relationship between average nutrient requirements and actual poultry industry nutrient levels, it seems that the actual dLys level is

Table 3: Prediction of body fat, (%BW) from year, age, dietary energy, lysine and protein

	a[1]	Year	Age days	ME (kcal kg^{-1})	dLys[2] (%)	CP (%)	ME/dLys (kcal kg^{-1}/%)	N	SEM	R^2	P
	571.0	-0.28	0.194					89	2.60	0.65	**
SE	98.6	0.05	0.020								
P	**	**	**								
	588.0	-0.30	0.173	0.0057				88	2.53	0.68	**
SE	96.6	0.05	0.021	0.0022							
p	**	**	**	0.0100							
	579.0	-0.28	0.144		-3.94			70	2.71	0.59	**
SE	110.0	0.05	0.031		2.36						
p	**	**	**		0.10						
	603.0	-0.29	0.167			-0.38		89	2.51	0.68	**
SE	96.0	0.05	0.022			0.14					
p	**	**	**			0.01					
	606.0	-0.30	0.131				0.00154	69	2.67	0.60	**
SE	113.1	0.06	0.03				0.00062				
p	**	**	**				0.02000				

[1]aintercept. Age: last day of experimental trial. P: p-value, **<0.001, *<0.01. [a,b]Values within columns having superscripts letters differ significantly (p<0.05) according to confidence interval. [2]Digestible lysine and amino acids were changed proportionally

primarily influenced by dLys requirements (r^2 = 0.86) but actual dietary ME is less related to actual ME requirements (r^2 = 0.47). According to these associations, it can be inferred that decisions made by commercial nutritionists for selecting ME values are mostly influenced by feed cost, whereas dLys values are mainly influenced by amino acid requirements. Both coefficients of dLys and dLys:AA requirements showed similar significance and r^2 for predicting dietary dLys.

Body composition and nutrient efficiency: Body fat was significantly predicted by year, age, ME, dLys, protein and ME/dLys (Table 3). The negative coefficient of dLys to predict body fat shows a tendency to be significant (p = 0.10). The body fat is reduced by 0.28% each year, by 0.39% for +0.10% of dLys and by 0.38% for +1.0% of CP. In contrast, the body fat is increased by 0.57% for +100 kcal of ME kg^{-1} and by 0.15% for +100 kcal of ME/kg/% of dLys. When plotting the predictive equations for body fat and protein, over the last 16 years, body protein has been increased by 4%, whereas body fat has been lowered by around 6% (Fig. 2). In general, these body compositions and feed conversion trends suggest that FCR is inversely related to body protein and positively related to body fat, especially from 2010-2012 where drastic changes for FCR, breast yield and body fat occurred. Corporal body fat at similar age or body weight was smaller by 2% in birds with good FCR compared to those with poor FCR[8,9]. In these old broiler lines, the body protein content was similar between high and low feed efficient birds[8-10]. However, both types of birds had small breast yield (≤15%) compared to modern broiler chickens and had not changed body composition with the exception of body fat. The breast muscle yield has been drastically increased during the last 10 years (Fig. 2) and these new differences in breast meat yield might

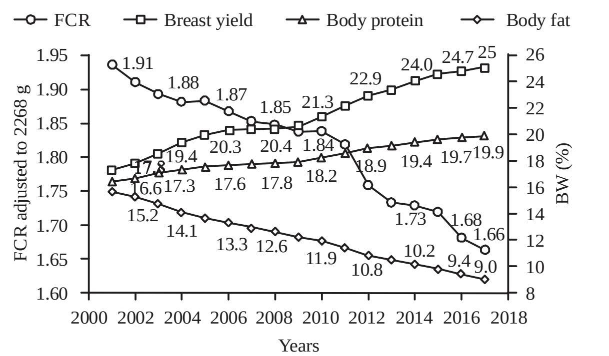

Fig. 2: Feed conversion (FCR), breast yield and body protein and fat changes over time. Breast yield and FCR adjusted to 2268 g of body weight

change the whole body protein in the modern broiler chickens. Thus, broiler chickens with higher growth performance and breast meat yield produced higher carcass protein than random broiler chickens[3]. In agreement with current results, the body fat is increased by 0.6% when dietary energy was augmented by 100 kcal 6,85. In contrast, as observed herein, body fat was lowered as the protein and lysine were proportionally increased[4,66,86]. The limited data evaluating only dietary dLys considering constant amounts of amino acids on carcass composition did not allow predicting the body fat in the current study. However, it is interesting to note that body fat was not affected when broilers were fed lysine above their requirements, although feeding lower lysine levels resulted in an increase in body fat[33,44,53.63,66].

Trends of dLys intake, dLys for maintenance, lysine for protein gain and efficiency of lysine are shown in Fig. 3. Since 2001, dLys efficiency has been positively improved from 61-76% due to body protein gain. Digestible lysine for

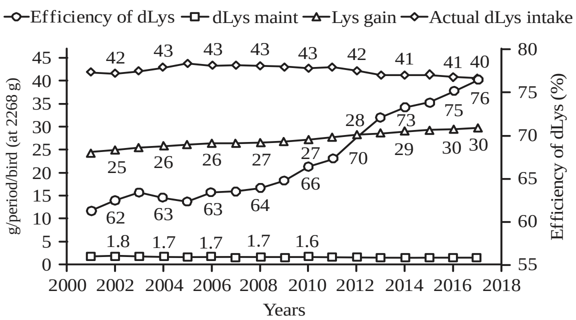

Fig. 3: Trends of digestible lysine (dLys) intake, dLys for maintenance (dLys maint), lysine for protein gain (Lys gain) and efficiency of lysine. Actual dLys intake is adapted from a US industry reporting service[91]

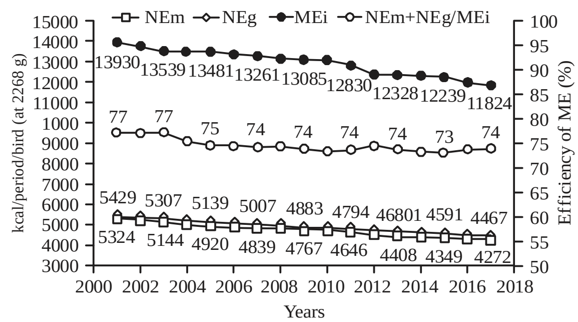

Fig. 4: Trends of ME intake (MEi), net energy for maintenance (NEm) and body gain (NEg) and ME efficiency [(NEm+NEg)/MEi]. Actual ME intake is adapted from a US industry reporting service[91]

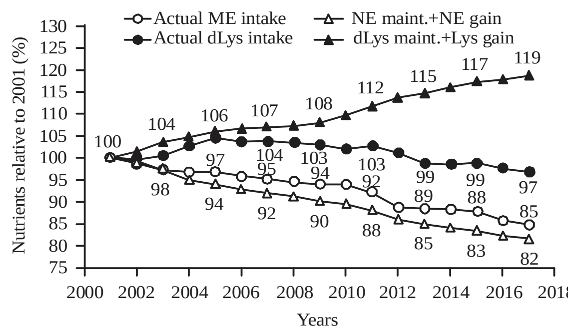

Fig. 5: Nutrients relative to 2001 [(Nutrients, 2001-2017)/(Nutrients, 2001)×3100]. Nutrient intakes were obtained from a US industry reporting service[91]. Net energy for maintenance (NE maint.), net energy for body gain (NE gain), digestible lysine for maintenance (dLys maint.) and lysine for protein gain (Lys gain). Digestible lysine (dLys)

maintenance has remained almost constant and relatively small, around 4% of actual dLys intake, and actual dLys intake remained almost constant due to reduced feed intake. Research studies also indicate that the modern broiler chickens or lines with best feed conversion had higher protein efficiency compared to random-bred chickens or lines with poor feed conversion. The improved protein efficiency can be attributed to a reduction in protein degradation and an increment in protein synthesis[10,99-102].

Trends of ME intake, net energy for maintenance and body weight gain and ME efficiency are shown in Fig. 4. The efficiency of ME for gain has remained almost constant (~74%) from 2001-2017. This efficiency has not increased because the energy gained from body fat has been decreased, whereas the energy gained from body protein has increased over the last years. Further, both the energy for body gain and the actual ME intake were also reduced in parallel, as a result of decreasing the feed intake and number of days to reach the target body weight. However, when energy efficiencies were compared to similar ages, birds with improved feed conversion or modern broilers had better energetic efficiency (energy gain/ME intake) compared to random-bred broiler chickens or lines with poorer feed conversion[103,104]. Therefore, the efficiency of nutrients by comparing the nutrient intake and requirements from a previous year shows another approach to measuring the energy efficiency (Fig. 5). When yearly nutrients were, for instance, compared to nutrients in 2001, the ME intake and NE for maintenance and body gain were observed to be more efficient by approximately 18% from 2001-2017. This type of ME efficiency by a specific year indicates that advancement from genetic progress is similar to that observed in dLys efficiency (Fig. 3). But when using the specific year approach for lysine, the dLys intake was found to be constant. As expected, the lysine for maintenance (dLys main.) and for body protein gain (Lys gain) was augmented from 100-119%. This 19% increase in lysine needs might be misunderstood as inefficiency; however, this higher lysine demand is accounted for by observed improvements in breast meat yield. From industry reports and research trials carried out over the last 16 years, it could be assumed that caloric values will continue to be influenced mostly by feed ingredient cost and less influenced by energy needs. However, future reduction trends of ME requirements might be evaluated by nutritionists when conducting field trial evaluation, which could result in this being the primary reason for selecting dietary ME values. Evidence from the scientific literature regarding the benefits of fiber-contributing ingredients in current broiler chickens[105-107] might suggest that birds in the future may eat diets lower in ME. In addition, primary breeder companies may also choose to select their birds based on diets with reduced caloric density. In the future, we can expect that amino acid trends will depend more on amino acid requirements mainly influenced by breast muscle yield rather than feed cost. However, if other traits such as robustness or health status were to take priority over breast muscle yield, this continuous tendency of increasing amino acid needs might plateau and become more impacted by feed cost.

CONCLUSION

Based on the research papers discussed and an industry report, the energy and lysine levels have been reduced and increased, respectively, over the last 16 years. The employment of commercial energy and amino acid levels in commercial feed formulation seem to be influenced by feed cost and lysine requirements, respectively. From genetic selection, the reduction of feed intake and body fat and the increment of weight gain and body protein have resulted in an improvement in the energy and lysine efficiencies based on available data.

SIGNIFICANCE STATEMENT

This study discovers the possible dietary energy and amino acid trends and body composition changes that can be beneficial for Nutritionist in the process of selecting the dietary energy and amino acids. This study will help the researcher to uncover the critical areas of energy and amino acid efficiencies over time that many researchers were not able to explore. Thus, a new theory on future nutrient levels and physiological mechanisms may be arrived at.

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