

Quantitative and qualitative feed restriction for broilers

Restrição alimentar quantitativa e qualitativa em frangos de corte

Restricción cuantitativa y cualitativa de alimento en pollos de engorde

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Abstract

The objective of this study is to evaluate the influence of five feed restriction programs (FRP) on broiler performance and carcass yield. 425 Cobb 500® broilers were distributed in a completely randomized design with five FRPs and five replicates with 17 broilers. The FRPs were: Program 1 (P₁): consumption *ad libitum* (AL) of control diet from 14 to 42 days; P₂: quantitative restriction (QTR) of 10% of AL consumption from 14 to 28 days and AL consumption from 29 to 42 days; P₃: AL consumption from 14 to 28 days and QTR from 29 to 42 days; P₄: qualitative restriction (QLR) of 10% of the level of crude protein and essential amino acids from 14 to 28 days and AL consumption from 29 to 42 days; and P₅: AL consumption from 14 to 28 days and QLR from 29 to 42 days. The broilers of the AL treatment gained more weight ($p \leq 0.01$), but had a similar FCR ($P > 0.05$) compared to broilers submitted to QTR from 29 to 42 days. In addition, broilers fed QTR from 14 to 28 days presented a lower FI and a better FCR ($p \leq 0.01$) in relation to broilers fed QLR of 14 to 28 (P₄) and 29 to 42 days (P₅). The broilers fed QTR of 14 to 28 days diet presented a similar FCR as broilers fed AL. The 10% reduction in AL consumption of 14 to 28 d is a viable economical alternative to feed broilers up to 42 days of age.

Keywords: Amino acids; Consumption; Economic analysis; Feedback.

Resumo

Avaliou-se a influência de cinco programas de restrição alimentar (PRA) sobre o desempenho e características de carcaça de frangos. 425 frangos de corte Cobb 500® foram distribuídos em delineamento inteiramente ao acaso, com 5 PRA e 5 repetições de 17 aves cada. Os PRA foram: Programa 1 (P₁): consumo *ad libitum* (AL) da dieta controle dos 14 aos 42 d de idade; P₂: restrição quantitativa (RQT) de 10% do consumo AL no período de 14 a 28 d e consumo AL de 29 a 42 d de idade; P₃: consumo AL no período de 14 a 28 d e RQT de 29 a 42 d; P₄: restrição qualitativa (RQL) em 10% no nível de proteína bruta e aminoácidos essenciais de 14 a 28 d e consumo AL de 29 a 42 d de idade e P₅: consumo AL no período de 14 a 28 d e RQL de 29 aos 42 d de idade. Os Frangos do tratamento AL ganharam mais peso ($p \leq 0,01$), mas tiveram conversão alimentar (CA) ($P > 0,05$) semelhante comparados aos frangos submetidos a RQT de 29 a 42 d. Além disso, frangos alimentados com RQT de 14 a 28 d apresentaram menor consumo e melhor CA ($p \leq 0,01$) em relação ao grupo de frangos alimentados com RQL de 14 a 28 (P₄) e de 29 a 42 dias de idade (P₅). Os frangos da dieta de RQT de 14 a 28 d apresentaram semelhante CA em relação as aves alimentadas com a oferta AL. A redução em 10% do consumo AL de 14 a 28 d é uma alternativa econômica viável para alimentar frangos de corte até 42 d de idade.

Palavras-chave: Aminoácidos; Análise econômica; Consumo; Realimentação.

Resumen

Se evaluó la influencia de cinco programas de restricción alimenticia (PRA) sobre el rendimiento y las características de la canal de pollos de engorde. Se distribuyeron 425 pollos de engorde (Cobb 500®) en un diseño completamente al azar, con 5 PRA y 5 réplicas con 17 aves cada una. Los PRA fueron: Programa 1 (P₁): consumo *ad libitum* (AL) de la dieta control, de los 14 a los 42 días de edad (d); P₂: restricción cuantitativa (RCT) del 10% del consumo AL, de los 14 a los 28 d y consumo AL de los 29 a los 42 d; P₃: consumo AL de los 14 a los 28 d y RCT de los 29 a los 42 d; P₄: restricción cualitativa (RCL) del 10% en el nivel de proteína cruda y aminoácidos esenciales, de los 14 a los 28 d y consumo AL de los 29 a los 42 d de edad y P₅: consumo AL de los 14 a los 28 d y RCL de los 29 a los 42 d. Los pollos del tratamiento AL ganaron más peso ($p \leq 0,01$), pero tuvieron una tasa de conversión alimenticia (CA) similar ($P > 0,05$) en comparación con los pollos de engorde sometidos a la RCT de los 29 a los 42 d. Además, los pollos de engorde alimentados con RCT de los 14 a los 28 d tuvieron menor consumo y mejor CA ($p \leq 0,01$) en comparación con el grupo de pollos de engorde alimentados con RCL de los 14 a los 28 d (P₄) y de los 29 a los 42 días de edad (P₅). Los pollos sometidos a la dieta de RCT de los 14 a los 28 d tuvieron una CA similar en comparación con las aves alimentadas AL. Una reducción del 10% en la ingesta AL de los 14 a los 28 d es una alternativa económica viable para alimentar a los pollos de engorde hasta los 42 días de edad.

Palabras clave: Aminoácidos; Análisis Económico; Consumo; Realimentación.

1. Introduction

The high growth rate of modern broilers is largely a result of genetic improvement programs and means a high potential for a healthy nutrient use in diets, with improvements in housing conditions with technological advances in handling. The fast growth of broilers increased greatly the yields of cuts for their later commercialization using different diets. According to Duarte et al. (2012), the yields of carcass, breast, thigh and leg quarters may be directly influenced by diets and feed programs.

Although a maximum weight of broilers at slaughter is desirable, yields of noble cuts may indicate a better efficiency of production systems in function of the evolution in weight gain and feed consumption (Ramos et al., 2011). However, problems such as accumulation of fat in the carcass and bone and metabolic dysfunctions (Zubair & Leesson, 1996) may cause high economic losses along the broiler production chain.

One of the proposals to address problems arising from a high growth rate has been feed programs based on feed restriction. There are two practical ways of applying nutritional restriction: the qualitative, characterized by a reduction in the nutrient density of the most expensive feeds, and the quantitative, characterized by a reduction in the intake of nutrient-balanced diets (Pelicano et al., 2005).

Consumption restriction is usually applied for a short period at an age that allows weight recovery until slaughter through a compensatory gain and an increased production of low-fat carcasses, free from bone or metabolic problems, and with broiler well-being and a good economic viability.

One advantage of feed restriction programs is the stimulus for compensatory gains (Rezaei & Hajati, 2010; Zhan et al., 2007), although it has not been proven in some studies (Khetani et al., 2009). The inconsistency of the response of birds to feed

restriction programs has been attributed to different lineages and the duration and severity of the adopted program, factors influencing the bird's ability to recover (Mazzuco et al., 2000).

This study was developed to evaluate the performance and carcass characteristics of broilers submitted to different feed restriction programs from 14 to 42 days of age.

2. Methodology

The experiment methodology was approved by the Ethics Committee on Animal Use (CEUA) of the UFPB, recorded under protocol 077/2015.

2.1 Location

The experiment was conducted at the aviary of the Poultry Laboratory of the Department of Animal Sciences of the Center for Human, Social and Agrarian Sciences, Federal University of Paraíba, *campus* III, in the municipality of Bananeiras, at 6°45'00" S and 35°38'00" W, altitude of 520 m above sea level.

2.2 Animals and feed programs

425 male Cobb 500[®] broilers with an average live weight of 501±2 g were distributed into two study periods: 14 to 28 (growth) and 29 to 42 (final) days of age. The birds were randomly assigned to five treatments with five replicates of 17 birds each.

The treatments consisted of the following feed programs (FP): *Program 1* - Consumption *Ad libitum* (AL) of 14 to 42 days of age of a control diet (CD); *Program 2* - Quantitative restriction of 10% of AL consumption of 14 to 28 days and consumption AL of 29 to 42 days (QTR - 14 to 28 days); *Program 3* - Consumption AL of 14 to 28 days with a QTR of 10% of the AL consumption of 29 to 42 days (QTR - 29 to 42 days); *Program 4* - qualitative restriction (QLR) of 10% of the broiler requirements in crude protein and essential amino acids of 14 to 28 days and AL consumption of CD of 29 to 42 days of age (QLR - 14 to 28 days); and *Program 5* - AL consumption of CD of 14 to 28 days with a QLR of 10% of the of crude protein and essential amino acids requirements of 29 to 42 days of age (QLR - 29 to 42 days).

The basal diet (Table 1) was formulated to meet the nutritional requirements of broilers aiming a normal growth, according to Rostagno et al. (2011). Prior to the feed restriction period, the birds received water and feed *ad libitum*.

Table 1. Feed, nutritional and energy composition of experimental diets.

Ingredients	14-28 days		29-42 days		
	Basal ¹	Qualitative restriction ²	Basal ¹	Qualitative restriction ²	
Corn	63.916	70.963	67.363	73.900	
Soybean meal	31.430	25.490	27.591	22.073	
Soybean oil	1.243	0.043	2.083	0.966	
Dicalcium phosphate	1.365	1.413	1.075	1.120	
Limestone	0.851	0.852	0.799	0.800	
DL-Methionine	0.245	0.209	0.207	0.178	
L-Lysine	0.209	0.245	0.198	0.235	
L-Threonine	0.038	0.039	0.022	0.025	
L-Valine	0.018	0.024	0.001	0.009	
L-Arginine	--	0.037	--	0.035	
Salt	0.456	0.455	0.431	0.430	
Choline chloride	0.050	0.050	0.050	0.050	
Vitamin premix ³	0.110	0.110	0.110	0.110	
Mineral premix ⁴	0.060	0.060	0.060	0.060	
Antioxidant ⁵	0.010	0.010	0.010	0.010	
Total	100.000	100.000	100.000	100.000	
Calculated chemistry composition					
Metabolizable energy	kcal/kg	3,000	3,000	3,100	3,100
Crude protein	%	20.000	18.000	18.500	16.650
Digestible lysine	%	1.100	0.990	1.000	0.900
Digestible methionine	%	0.516	0.464	0.463	0.417
Digestible methionine + cystine	%	0.800	0.720	0.730	0.657
Digestible arginine	%	1.226	1.103	1.117	1.005
Digestible threonine	%	0.715	0.643	0.650	0.585
Digestible tryptophan	%	0.220	0.198	0.200	0.180
Digestible valine	%	0.860	0.774	0.780	0.702
Calcium	%	0.760	0.760	0.660	0.660
Available phosphorus	%	0.360	0.360	0.300	0.300
Sodium	%	0.200	0.200	0.190	0.190
Potassium	%	0.761	0.672	0.700	0.618
Chloride	%	0.326	0.327	0.311	0.312
Electrolyte balance	mEq/kg	189.7	166.9	174.1	152.9

¹Recommendations by Rostagno et al. (2011);

²10% restriction in protein and amino acid levels;

³Warranty levels per kg product: 6,800,000 IU vitamin A; 1,500,000 IU vitamin D3; 12,000 IU vitamin E; 1,600 mg vitamin K3; 1,000 mg vitamin B1; 4,000 mg vitamin B2; 2,000 mg vitamin B6; 10,000 mg vitamin B12; 700 mg folic acid; 10 g pantothenic acid; 15 mg biotin; 30 g niacin; 1,000 mg BHT = beta hydroxy toluene.

⁴Warranty levels per kg product: 20 g copper; 96 g iron; 1,400 mg iodine; 156 g manganese; 500 mg selenium; 110 g zinc; ⁵Santoquim®.
Source: Authors.

At 14 days of age, the birds were transferred to 25 stalls measuring 2.00 x 1.70 m (3.4 m²) with screen partition walls and bird-proof mesh aperture and the floor covered with shavings. Each stall was equipped with a tubular feeder and a pendulum water feeder. The experimental area was installed in a masonry shed containing side curtains, fans and nebulizers to adjust temperature and relative air humidity in order to provide comfort for the birds. A continuous lighting program was adopted throughout the experimental period using 100-watt incandescent bulbs to provide 22 lumens/m². A digital thermohygrometer was used to gauge and record the temperature and the relative humidity, 28±1.8 °C and 70±2.2%, respectively.

2.3 Performance measurements

At the end of the experimental period, feed leftovers and the broilers were weighed to evaluate feed intake, weight gain and feed conversion ratio. The feed intake was calculated by the difference between the feed provided and the leftovers obtained.

The weight gain was determined by the difference between final and initial broiler weight, while feed conversion ratio was calculated by the ratio between feed consumption with weight gain.

2.4 Carcass characteristics

At 42 days of age, a total of 45 broilers, three per plot and 15 per treatment, were selected based on the mean weight, and submitted to eight hours of solids fasting. After fasting, the birds were weighed individually, desensitized by electrical stunning, and later sacrificed and eviscerated to obtain carcass weight, noble cuts weight (breast, thigh and leg quarters), edible organs weight and abdominal fat weight.

For the determination of carcass yield, we evaluated the clean and eviscerated carcass without head, legs and feet in comparison with live weight after fasting. The yields of cuts (breast, thigh and leg quarters) and edible organs (gizzard, liver and heart) were calculated by dividing the individual weight of each cut and/or organ by the carcass weight.

2.5 Economic viability analysis and productive efficiency index

The economic viability of the feed was evaluated considering the financial impact of feed restriction of breeding phases on the variables performance and carcass yield. The economic indexes were calculated according to the methodology described by Ramos et al. (2011) considering Feeding cost = feed consumed x price of feed; Gross Revenue = number of kilograms of broiler produced x price of live broiler; Gross Margin = average gross revenue - average feed cost; Average yield = (gross margin ÷ average feed cost) x 100; and Relative profitability = (average income of the tested program ÷ average income of the conventional program) x 100. In addition, the productive efficiency index (PEI) was calculated, expressed by the following equation: $PEI = (\text{average live weight (g)} \times \text{bird viability (\%)}) \div (\text{broiler age (days)} \times \text{feed conversion ratio (g g}^{-1}\text{)}) \times 100$.

The prices of the ingredients used to prepare the economic analysis were acquired from the local market, as well as the price of live broilers, while the amino acids were obtained from suppliers considering the daily dollar exchange rate (US\$ 3.1029).

2.6 Statistical analysis

The data were analyzed by the GLM procedure using the software *Statistical Analysis System* (version 9.3, 2012, SAS Institute Inc., Cary, NC). Then, the means of the treatments were interpreted by Student-Newman-Kuels test considering a probability of 5% and orthogonal contrasts.

3. Results

3.1 Performance

The performance of broilers from 14 to 42 days of age were influenced ($p \leq 0.05$) by feed programs (Table 2).

Table 2. Performance of broilers fed with different feed programs from 14 to 42 days of age.

Feed program ¹	Feed intake	Weight gain	Feed conversion ratio
	(g)	(g)	(g/g ⁻¹)
AL-14 a 42 d	4,070±82 ^A	2,290±34 ^A	1,777±0.02 ^{AB}
QTR-14-28 d	3,888±96 ^B	2,229±58 ^A	1,745±0.05 ^B
QTR -29-42 d	3,824±91 ^B	2,126±76 ^B	1,799±0.03 ^A
QLR-14-28 d	4,101±88 ^A	2,253±77 ^A	1,821±0.04 ^A
QLR -29-42 d	4,163±5 ^A	2,279±30 ^A	1,827±0.02 ^A
MSE	30.4	16.0	0.01
<i>P-value</i>	<0.001	0.002	0.003
Contrasts			
AL ² vs Others	ns	2,290 vs 2,222*	ns
AL vs QTR	4,070 vs 3,856**	2,290 vs 2,178*	ns
AL vs QLR	ns	ns	1,777 vs 1,840*
QTR vs QLR	3,856 vs 4,132**	2,178 vs 2,249*	1,772 vs 1,840*

^{AB}Means within columns differed by SNK test ($p < 0.05$); Probability ** ($p < 0.01$);

¹Program 1 (P₁): consumption *ad libitum* (AL) of a control diet of 14 to 42 days of age; P₂: quantitative restriction (QTR) of 10% of consumption AL of a control diet (CD) of 14 to 28 days and consumption AL of 29 to 42 days; P₃: consumption AL of 14 to 28 days with QTR of 10% of consumption AL of 29 to 42 days; P₄: qualitative restriction (QLR) of 10% of crude protein (CP) and essential amino acids (EAAs) levels of 14 to 28 days and consumption AL of CD of 29 to 42 days of age; and P₅: consumption AL of CD of 14 to 28 days with QLR in 10% of CP and EAAs levels of 29 to 42 days of age.

MSE = mean standard error.

Source: Authors.

3.1.1 Quantitative and qualitative feed restriction programs

Broilers submitted to a quantitative restriction of 10% of *Ad libitum* consumption of control diet of 14 to 28 days presented a lower ($p \leq 0.001$) feed intake, but a similar weight gain and feed conversion ratio ($P > 0.05$) compared with birds fed AL 14 to 42 days. While the groups of broilers submitted to qualitative food restriction programs of 10% of protein and essential amino acids of 14 to 28 days or of 29 to 42 days did not change the feed intake, weight gain and feed conversion ratio in comparison with birds fed AL of 14 to 42 days ($P > 0.05$).

The quantitative restriction program did not follow the suggestion of avoiding reductions in feed supply two weeks before slaughter, because it would have negative implications on the performance of broiler chickens. Despite this, a similar feed conversion ratio ($P < 0.05$) was observed for birds under feed restriction during the finishing phase (29 to 42 days) in comparison to AL supply, although with low weight gain and expected consumption.

3.1.2 Tests of contrasts between feeding programs

The analysis of orthogonal contrasts showed that broilers consuming the control diet supplied AL of 14 to 42 days presented a higher weight gain ($p \leq 0.01$) than broilers fed all feed program (2,290 vs 2,222 g), but feed intake and feed conversion ratio were similar ($P > 0.05$).

Broilers fed with 90% of *ad libitum* consumption expressed lower ($p \leq 0.01$) feed intake (3,856 vs 4,070 g) and weight gain (2,178 vs 2,290 g) in comparison with birds fed control diet *ad libitum*.

Broilers fed control diet *ad libitum* had a better feed conversion ratio ($p \leq 0.01$) than broilers fed qualitative feed restriction (1,777 vs 1,840 g g⁻¹). However, feed intake and weight gain were similar between birds receiving *ad libitum* feed and qualitative feed restriction ($P > 0.05$).

The qualitative feed restriction stimulated feed intake ($p \leq 0.001$) (4,132 vs 3,856 g), which led to a greater weight gain ($P \leq 0.01$) (2,249 vs 2,178 g) and a worse feed conversion ratio ($p \leq 0.01$) (1,840 vs 1,772 g g⁻¹) compared to broilers fed quantitative feed restriction, respectively.

3.2 Carcass and noble cuts yields

Carcass and noble cuts yields were not affected by feeding programs ($P>0.05$) up to 42 days of age (Table 3), although breast yields changed according with the orthogonal contrast among AL vs All program and AL vs QTR.

Broilers fed *ad libitum* presented a higher breast yield ($p\leq 0.05$) in comparison of average of all treatments (45.52 vs 38.94%) and broilers fed with feed restriction of 10% of *ad libitum* program (45.52 vs 38.56%).

Table 3. Values of carcass and noble cuts yields of broilers at 42 days of age fed with different feeding programs

Feed program ¹	Carcass	Breast	Thigh	Leg quartes
	---%---		-----%-----	
AL-14 a 42 d	77.48±0.8	40.52±0.7	12.16±0.4	14.83±0.6
QTR-14-28 d	76.83±1.2	38.89±1.5	11.90±0.6	14.60±0.7
QTR -29-42 d	77.05±1.0	38.24±1.9	12.01±0.8	14.55±0.6
QLR-14-28 d	76.67±0.7	40.15±0.8	11.96±0.4	14.09±0.6
QLR -29-42 d	78.67±2.9	38.47±1.6	12.08±0.2	13.84±0.6
MSE	0.32	0.31	0.09	0.14
<i>P-value</i>	0.281	0.054	0.937	0.119
Contrasts				
AL ² vs Others	ns	45.52 vs 38.94*	ns	ns
AL vs QTR	ns	45.52 vs 38.56*	ns	ns
AL vs QLR	ns	ns	ns	ns
QTR vs QLR	ns	ns	ns	ns

^{AB}Means within columns differed by SNK test ($p<0.05$); Probability ** ($p<0.01$);

¹Program 1 (P₁): consumption *ad libitum* (AL) of a control diet of 14 to 42 days of age; P₂: quantitative restriction (QTR) of 10% of consumption AL of a control diet (CD) of 14 to 28 days and consumption AL of 29 to 42 days; P₃: consumption AL of 14 to 28 days with QTR of 10% of consumption AL of 29 to 42 days; P₄: qualitative restriction (QLR) of 10% of crude protein (CP) and essential amino acids (EAAs) levels of 14 to 28 days and consumption AL of CD of 29 to 42 days of age; and P₅: consumption AL of CD of 14 to 28 days with QLR in 10% of CP and EAAs levels of 29 to 42 days of age.

MSE = mean standard error.

Source: Authors.

3.3 Weights and yields of edible organs and fat yield

The weights and yields of edible organs were not affected by feeding programs ($P>0.05$), as shown in Table 4.

Table 4. Weights and yields of edible organs of broilers at 42 days of age subjected to diets with different feeding programs.

Feed program ¹	Heart	Gizzard	Liver	Heart	Gizzard	Liver
	-----grams-----			-----%-----		
AL-14 a 42 d	11.0±1.0	30.8±2.7	41.3±4.1	0.52±0.04	1.44±0.09	1.98±0.20
QTR-14-28 d	10.7±1.3	29.8±2.2	40.7±1.7	0.53±0.06	1.47±0.17	1.95±0.08
QTR -29-42 d	9.9±1.3	30.1±0.4	42.2±3.2	0.48±0.05	1.51±0.10	2.02±0.15
QLR-14-28 d	10.3±1.0	30.1±3.0	38.5±3.4	0.51±0.05	1.48±0.12	1.85±0.16
QLR -29-42 d	10.7±1.1	28.7±1.0	45.3±5.9	0.52±0.06	1.39±0.03	2.06±0.10
MSE	0.20	0.40	0.60	0.01	0.02	0.03
<i>P-value</i>	0.3778	0.6832	0.6567	0.5181	0.2371	0.2367
Contrasts						
AL ² vs Too	ns	ns	ns	ns	ns	ns
AL vs QTR	ns	ns	ns	ns	ns	ns
AL vs QLR	ns	ns	ns	ns	ns	ns
QTR vs QLR	ns	ns	ns	ns	ns	ns

^{AB}Means within columns differed by SNK test ($p<0.05$); Probability ** ($p<0.01$);

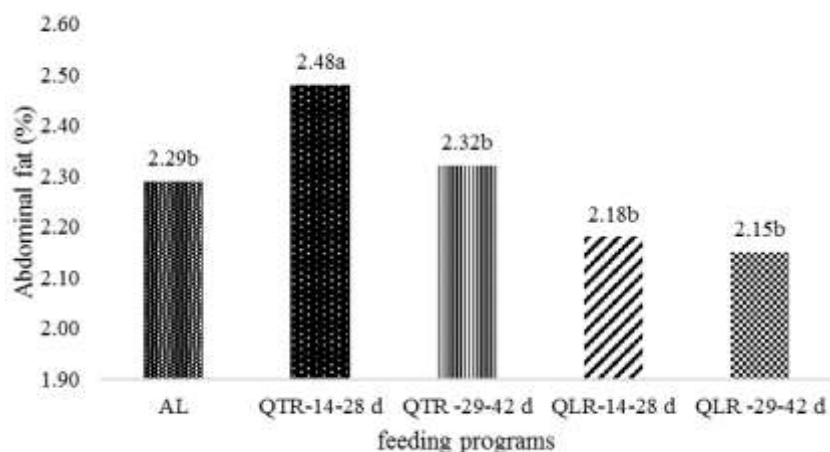
¹Program 1 (P₁): consumption *ad libitum* (AL) of a control diet of 14 to 42 days of age; P₂: quantitative restriction (QTR) of 10% of consumption AL of a control diet (CD) of 14 to 28 days and consumption AL of 29 to 42 days; P₃: consumption AL of 14 to 28 days with QTR of 10% of consumption AL of 29 to 42 days; P₄: qualitative restriction (QLR) of 10% of crude protein (CP) and essential amino acids (EAAs) levels of 14 to 28 days and consumption AL of CD of 29 to 42 days of age; and P₅: consumption AL of CD of 14 to 28 days with QLR in 10% of CP and EAAs levels of 29 to 42 days of age.

MSE = mean standard error.

Source: Authors.

Broilers that received the diet *ad libitum* and broilers subjected to quantitative restrictions of 29 to 42 days and qualitative restrictions, regardless of stage, presented a similar abdominal fat yield, while broilers treated with quantitative restriction of 14 to 28 days had a greater fat yield in the carcass (Figure 1).

Figure 1. Percentage of abdominal fat of broilers at 42 days submitted to diets with different feeding programs¹.



^{AB}Means within columns differed by SNK test ($p < 0.05$); Probability ** ($p < 0.01$);

¹Program 1 (P₁): consumption *ad libitum* (AL) of a control diet of 14 to 42 days of age; P₂: quantitative restriction (QTR) of 10% of consumption AL of a control diet (CD) of 14 to 28 days and consumption AL of 29 to 42 days; P₃: consumption AL of 14 to 28 days with QTR of 10% of consumption AL of 29 to 42 days; P₄: qualitative restriction (QLR) of 10% of crude protein (CP) and essential amino acids (EAAs) levels of 14 to 28 days and consumption AL of CD of 29 to 42 days of age; and P₅: consumption AL of CD of 14 to 28 days with QLR in 10% of CP and EAAs levels of 29 to 42 days of age.

MSE = mean standard error.

P-value= 0.0003; MSE = 0.03.

Source: Authors.

3.4 Economic evaluation of feed programs

The average cost of conventional diets and qualitative restrictions was higher ($p < 0.05$) than the quantitative restriction program (Table 5).

Table 5. Average economic viability indexes of broilers subjected to different feeding programs.

Feed program ¹	Feeding Cost	Gross Revenue	Gross Margin	Average yield	Relative profitability	productive efficiency index
	-----	(US\$/ave)	-----	---	% ---	
AL-14 a 42 d	11.955 ^A	23.362 ^A	11.407 ^{AB}	95.42 ^B	100.00 ^{AB}	369.21 ^A
QTR-14-28 d	11.413 ^B	22.892 ^A	11.479 ^A	100.58 ^A	105.41 ^A	364.20 ^A
QTR -29-42 d	11.239 ^B	22.036 ^B	10.797 ^B	96.07 ^B	100.68 ^{AB}	327.37 ^B
QLR-14-28 d	12.050 ^A	23.106 ^A	11.056 ^{AB}	91.75 ^B	96.16 ^B	339.40 ^B
QLR -29-42 d	12.227 ^A	23.307 ^A	11.080 ^{AB}	90.62 ^B	94.97 ^B	358.41 ^A
<i>P-value</i>	0.001	0.003	0.076	0.001	0.045	0.004

^{AB}Means within columns differed by SNK test ($p < 0.05$); Probability ** ($p < 0.01$);

¹Program 1 (P₁): consumption *ad libitum* (AL) of a control diet of 14 to 42 days of age; P₂: quantitative restriction (QTR) of 10% of consumption AL of a control diet (CD) of 14 to 28 days and consumption AL of 29 to 42 days; P₃: consumption AL of 14 to 28 days with QTR of 10% of consumption AL of 29 to 42 days; P₄: qualitative restriction (QLR) of 10% of crude protein (CP) and essential amino acids (EAAs) levels of 14 to 28 days and consumption AL of CD of 29 to 42 days of age; and P₅: consumption AL of CD of 14 to 28 days with QLR in 10% of CP and EAAs levels of 29 to 42 days of age.

Source: Authors.

The mean gross income of the control diet supplied *ad libitum* of 14 to 42 days was higher ($p \leq 0.05$) only for the treatment with a quantitative restriction of 10% of consumption *ad libitum* of 29 to 42 days (24,699 vs 23,297 US\$/bird).

The mean gross margin of the group of broilers subjected to quantitative restriction of 10% of consumption *ad libitum* of 14 to 28 days was higher ($p \leq 0.05$) than broilers subjected to 10% of *ad libitum* consumption of 29 to 42 days (11,479 vs 10,797 US\$/bird), with a similarity of results in comparison to other feed programs.

The average profitability of broilers subjected to a quantitative restriction of 10% of *ad libitum* consumption of 14 to 28 days was higher ($p \leq 0.05$) than the other feed programs, including the *ad libitum* consumption. The relative profitability of broilers fed 10% of *ad libitum* consumption of 14 to 28 days exceeded by 5%, numerically, the relative profitability of broilers that consumed feed *ad libitum*.

The European productive efficiency index (PEI), a reference standard for economic efficiency analysis of broiler breeding, showed similar results ($P > 0.05$) between the feed program *ad libitum* and the quantitative restriction of 10% of *ad libitum* consumption of 14 to 28 days, which performed better ($p \leq 0.05$) than broilers with a quantitative restriction diet of 29 to 42 days and a qualitative restriction diet of 14 to 28 days of age.

4. Discussion

Early feed restriction of broilers is usually used to induce growth and improve nutrient use efficiency (Susbilla et al., 2003). The restricted feeding programs are normally imposed by physical restriction of feed or the feeding of diets with a low nutrient density (Yagoub & Babiker, 2008). We choose the two methods of feed restriction to evaluate comparatively in this study.

The feed intake of birds fed nutrient restriction diet was highest when compared of birds fed quantitative feed restriction. The possibility of birds to increase feed intake in response of offer of *ad libitum* marginal low concentration essential nutrients diet was the pivotal factor of this result. Esmail (2018) commented that the birds tend to increase their feed intake to make up for deficiencies when fed with diets that are marginally deficient in crude protein. According to Guyton and Hall (2011), the increase in consumption may be explained by the fact that the animal's appetite is controlled by its nutritional status, that is, when the availability of nutrients decreases, the organism automatically increases food intake in response to stimuli from the hunger center in the lateral hypothalamus.

The highest weight gain of broilers subjected to qualitative feed restriction *versus* broilers subjected to a quantitative feed restriction in this study corroborate with Butzen et al. (2013), who also observed a greater weight gain in broilers treated with a qualitative feed restriction from 8 to 16 days of age.

The restriction in the amount of feed have a negative impact on weight gain, but the restriction of essential nutrient affects more the feed conversion ratio. The broilers fed quantitative restriction diet of 14 to 28 days presented a similar feed conversion ratio to birds fed *ad libitum*, and better compared to the broilers fed diet with qualitative restriction (Table 2). The better feed conversion ratio in birds fed diet with quantitative restriction may be associated with a reduced need for maintenance energy related to a low body weight and metabolic adaptation (Yu & Robinson, 1992). Jordão Filho et al. (2011) met same relationship among low feed intake and better feed conversion ratio, and showed that birds with low feed intake had smaller maintenance requirements than birds fed diet in voluntary feed intake. Also Butzen et al. (2013) observed better feed conversion ratio for broilers receiving feed with quantitative restriction in comparison with the supply *ad libitum*.

In our study, with quantitative food restriction of 10% of consumption *ad libitum*, a feed conversion ratio value similar to the control (*ad libitum*). On the other hand, several studies demonstrate the improvement of feed conversion ratio and reduction of feed costs with the use of food restriction programs (Abdel-Hafeez et al., 2016; Bordin et al., 2021). In this case, it is suggested that the lack of significant difference for feed conversion ratio between the control diet and the quantitative feed restriction, may be due to a low severity of feed restriction (10% reduction in *ad libitum* consumption).

In a study with different levels of feed restriction in broilers, Rahimi et al. (2015), obtained better feed conversion ratio according to the increase in the percentage of feed restriction in relation to the control treatment, possibly due to the reduced time available for digestion (Bordin et al., 2021). At the same time, birds with feed restriction may have adequate time to use feed nutrients more efficiently, leading to better feed conversion than birds fed *ad libitum* (Abdel-Hafeez et al., 2016). Adeyemi et al. (2015) and Trocino et al. (2020) observed that birds submitted to the stress of food restriction stay longer near the feeder, have a potential to use their feed more efficiently in relation to those with *ad libitum* feed.

There are effects of feed restriction on carcass and noble cuts yields compared to results of broilers fed *ad libitum*. These data corroborate those reported by Hassanien (2011), Tesfaye et al. (2011) and Jalal and Zakaria (2012). However, both forms of feed restriction provided a low breast yield compared to broilers fed *ad libitum*. It is probable that the reduction in breast yield of birds with restricted feed may be due to a decreased amino acid intake. The results suggest that the growth rate of broilers is related to nutrient intake, which supports the statement of O'sullivan, Dunnington and Siegel (1992), for whom the improvement in the body weight of birds is correlated to feed consumption.

Weights and yields of edible organs are similar among broilers with and without feed restriction, regardless of the restriction methodology applied. The results of this study are in agreement with Hassanien (2011), Tesfaye et al. (2011), Jalal and Zakaria (2012) and Van der Klein et al. (2017). It appears that the organs of the gastrointestinal tract are spared from the effects of food restriction depending on animal age and duration of the restriction period (Ferraris et al., 2001).

The results for abdominal fat yield (Figure 1) of the group of birds that received a quantitative restriction of 10% of consumption *ad libitum* of 14 to 28 days was highest than of the groups of birds fed others treatments of restrictions or fed *ad libitum*. The no agreement with those results reported by Boostani et al. (2010) and Shabani et al. (2015), who did not observe differences in abdominal fat yield among broilers fed with restriction or *ad libitum*. Disagreeing with the results of present study, Jalal and Zakaria (2012) and Mirshamsollahi (2013) determined that diet restriction reduced abdominal fat yield, the activity of lipogenic enzymes are depressed during the feed restriction period, peaking during the first week of re-feeding, and gradually reducing in the subsequent weeks.

The average cost of broiler feed with a quantitative restriction of 10% of consumption *ad libitum* was lower than that of other feeding programs. This is justified by a low feed intake. The similarity in the gross income of broilers subjected to quantitative feed restriction of 14 to 28 days with that of broilers subjected to consumption *ad libitum* was due to weight gain. It resulted in an at least similar gross margin between feed programs. The broilers that provided the highest profitability were subjected to a quantitative restriction of 10% of consumption *ad libitum* of 14 to 28 days of age ($p < 0.05$). Because of a lower cost of feed, they yielded 5% more than birds subjected to consumption *ad libitum*.

The relative profitability index and the productive efficiency index presented results similar to those of broilers fed with a quantitative restriction of 10% of consumption *ad libitum* of 14 to 28 days and broilers fed at will. Novel et al. (2009) and Hassanien (2011) reported that the level of food restriction provided an economic advantage over broilers fed *ad libitum*, mainly by an efficient nutrient use. This denotes the possibility of applying a restriction plan in the intermediate phase of production, reducing costs and avoiding bone and metabolic problems.

5. Conclusion

In conclusion, a 10% reduction in *ad libitum* consumption over the period from 14 to 28 days is an economically viable alternative to feed broilers up to 42 days of age.

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